AR TARGET SHEET

The following document was too large to scan as one unit, therefore, it has been divided into sections.

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DOCUMENT #:	Letter: 07-AMRC-0224 Document: DOE/RL-2007-21 Draft A
TITLE:	Risk Assessment Report for 100 Area and 300 Area Component of River Corridor Baseline Risk Assessment (RCBRA)

Department of Energy
Richland Operations Office
P.O. Box 550
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0073124

07-AMRC-0224

JUN 25 2007

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Addressees:

RISK ASSESSMENT REPORT FOR THE 100 AREA AND 300 AREA COMPONENT OF THE RIVER CORRIDOR BASELINE RISK ASSESSMENT (RCBRA), DOE/RL-2007-21, DRAFT A

Attached for your review is the Risk Assessment Report for the 100 Area and 300 Area component of the RCBRA, DOE/RL-2007-21, Draft A. This transmittal constitutes the completion of the June 30, 2007, Tri-Party milestone, M-016-72, "Submit Draft 100 Area and 300 Area Component Baseline Risk Assessment Report." Comments are requested in 45 days of receipt of this letter.

This document is the result of several years' effort in working through a very open process with the Tribes, Regulators, Hanford Natural Resource Trustee Council representatives, Hanford Advisory Board members and interested public. Due to the size and complexity of this baseline risk assessment, a total of 32 meetings/workshops were held to gather technical input for the sampling plan and the baseline risk assessment methodology in support of this report. The U.S. Department of Energy, Richland Operations Office (RL), appreciates the time and energy of all who participated in these workshops to provide input. One specific issue which requires additional Tri-Party attention is how to handle non-detects.

RL plans to host a mid-review workshop on July 25, 2007, with the Tribes, Regulators, Hanford Natural Resource Trustee Council representatives, Hanford Advisory Board members, and interested public to answer any questions and facilitate the review. If you have any questions or comments, please contact John Sands, of my staff, on (509) 372-2282.

Sincerely,

Joe R Franco

Joe R. Franco, Assistant Manager
for the River Corridor

AMRC:JPS

Attachment

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DOE/RL-2007-21
Draft A

Risk Assessment Report for the 100 Area and 300 Area Component of the River Corridor Baseline Risk Assessment

United States
Department of Energy

DOE/RL-2007-21
Draft A

Risk Assessment Report for the 100 Area and 300 Area Component of the River Corridor Baseline Risk Assessment

United States
Department of Energy

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DOE/RL-2007-21
Draft A

Risk Assessment for the 100 Area and 300 Area Component of the River Corridor Baseline Risk Assessment

June 2007

United States Department of Energy

P.O. Box 550, Richland, Washington 99352

EXECUTIVE SUMMARY

The 100 Area and 300 Area Component of the River Corridor Baseline Risk Assessment (RCBRA) addresses post-remediation residual contaminant concentrations in the 100 Area and 300 Area, as well as the Hanford Townsite and White Bluffs Townsite. This assessment also investigates risks related to the potential transport of Hanford Site contaminants into Columbia River riparian and near-shore environments adjacent to the operational areas. Media-based exposure concentrations and resulting risk values are presented for a range of future exposure scenarios that were not initially considered in the interim action records of decision (RODs). These exposure and risk values will be considered in risk management decision making, including development of final RODs.

Per the U.S. Environmental Protection Agency (EPA) (EPA/540/1-89/002), a baseline risk assessment is an "*analysis of the potential adverse health effects (current or future) caused by hazardous substance releases from a site in the absence of any actions to control or mitigate these releases (i.e., under an assumption of no action).*" The RCBRA is designed to characterize the current and potential threats to human health and the environment that may be posed by residual, post-remediation contaminants under current and a range of hypothetical future site uses. This risk assessment evaluates sites as they are now, after cleanup has been completed and approved through Waste Information Data System reclassification process, in which the cleanup verification packages (CVP) are generated.

Because the RCBRA is a post-remediation risk assessment, the most current data, predominantly from within the last 5 years, are being used. Included are data from remediated waste site verification samples, groundwater sampling, special studies from the Columbia River, and samples collected specifically for the RCBRA. The report is inclusive in the assessment of all detected constituents and, in the case of some radionuclides and polychlorinated biphenyls (PCBs), the assessment evaluated detected and nondetected results.

The *Hanford Site Comprehensive Land-Use Plan Environmental Impact Statement* (CLUP) (DOE/EIS-0222-F), its subsequent ROD (64 FR 61615), and Presidential Proclamation 7319 (65 FR 37253), which established the Hanford Reach National Monument, all established future land uses for the Hanford Site. The identification of land uses is important for investigating potential receptors and exposure pathways to be used in the risk assessment. Completed under the *National Environmental Policy Act*, the CLUP provides detailed descriptions of anticipated activities under each land-use designation selected in the preferred alternative (DOE/EIS-0222-F). To support continued protection of natural and cultural resources, the proclamation stated that the Monument would not be developed for residential or commercial use in the future (65 FR 37253). The land-use designations identified in the CLUP and the National Monument are the basis for some of the human exposure scenarios evaluated in the report. Other human-use scenarios, such as industrial (in the 100 Areas), rural-residential, and the Confederated Tribes of the Umatilla Indian Reservation (CTUIR) scenario, are not allowed by current Hanford Site operations, the CLUP, or the National Monument, but have been evaluated as a sensitivity analysis and to meet agreements with the CTUIR and the Tri-Parties (i.e., EPA, Washington State Department of Ecology, and U.S. Department of Energy [DOE]). Alternative land uses and human health exposure scenarios that were developed based on stakeholder input are hypothetical and were evaluated in the risk assessment for comparative purposes. The assumptions underlying these hypothetical uses and exposure scenarios may be inconsistent with intended current and future land uses as stated in the CLUP (DOE/EIS-0222-F) and have not been endorsed by DOE; therefore, DOE neither agrees with nor endorses the premises or conclusions of the risk analyses for these hypothetical site uses.

The purpose of the 100 Area and 300 Area Component of the RCBRA is two-fold:

- Evaluate human health and ecological risks resulting from conditions subsequent to the implementation of the remedial actions in the 100 Area and 300 Area of the Hanford Site
- Support risk management decision making and support development of final RODs.

This report provides the methods, data analysis, and results of the human health and ecological risk assessments for the 100 Area and 300 Area Component of the RCBRA. The risk assessment process includes the identification of a range of human health and ecological exposure scenarios for comparison purposes, compilation and collection of data, ecological toxicity testing, data analysis, comparison of contaminant concentrations to applicable ecological benchmarks and human health cleanup levels, and quantification of risk associated with post-remediation contaminant concentrations. The risk assessment, which evaluates the effectiveness of current cleanup measures for protecting human health and the environment, will inform the development of final remedy RODs.

Field sampling of soil, sediment, surface water, pore water, groundwater (well water), and biota was conducted for the 100 Area and 300 Area Component of the RCBRA between October 2005 and December 2006. Forty-five terrestrial sites were sampled; these sites included remediated upland waste sites (native soil and backfilled), riparian, and reference sites. Thirty-seven aquatic sites were selected based on the known uranium, chromium, and strontium-90 groundwater plumes. A total of 163 remediated waste sites were evaluated in the human health risk assessment: 45 waste sites in the 100-B/C Area, 28 waste sites in the 100-D Area, 38 waste sites in the 100-F Area, 8 waste sites in the 100-H Area, 14 waste sites in the 100-K Area, 2 waste sites in the 100-N Area, 6 waste sites in the 100-IU-2 Operable Unit (OU), 5 waste sites in the 100-IU-6 OU, and 17 waste sites in the 300 Area. Additionally, risks related to groundwater exposures were computed for 64 groundwater monitoring wells sampled for the 100 Area and 300 Area Component of the RCBRA.

To appreciate how the 100 Area and 300 Area Component of RCBRA fits into the overall strategy for closure of the River Corridor, it is important to place it in the context of past and present risk assessments, characterization efforts and remedial actions at the Hanford Site. Projects relevant to this effort include the acquisition of cleanup verification data and data collected or compiled for special investigations such as the river effluent pipeline evaluations, the Inter-Areas shoreline risk assessment, the 100-NR-2 shoreline assessment, the 100-B/C Pilot Project risk assessment, the Central Plateau ecological risk assessment, and the Columbia River

Component of the RCBRA. There are also numerous additional projects that were used to supplement data collected for the 100 Area and 300 Area Component of the RCBRA, including the Surface Environmental Surveillance Program, the Near-Facility Environmental Monitoring Program, Columbia Generating Station annual reports, and other special studies such as Pacific Northwest National Laboratory reports. These projects will allow for a broader understanding of the nature, trends, and sources of contamination along the River Corridor.

Human Health Risks

A series of hypothetical exposure scenarios were evaluated in the human health risk assessment reflecting a range of high-intensity to low-intensity exposure conditions to provide risk managers with information on how potential risks may vary as a function of exposure intensity under a variety of exposure assumptions. There a five basic scenarios, with one scenario (Recreational) having three variations, for a total of seven exposure scenarios. These scenarios include the following:

- Hypothetical Rural-Residential Scenario
- Hypothetical Native American User Scenario[1]
- Hypothetical Industrial/Commercial Worker Scenario
- Hypothetical Resident Monument Worker Scenario
- Hypothetical Recreational Use Scenarios
  - Avid Wild Game Hunter
  - Avid Angler
  - Casual User.

[1] Additional hypothetical Native American scenarios may be provided in the future by the Yakama tribe, the Wanapum, or other groups.

Local and regional Tribes having ancestral ties to the Hanford Reach of the Columbia River and surrounding lands have been requested by DOE to provide an exposure scenario(s) reflecting their traditional activities. At this time, only the CTUIR have submitted an exposure scenario report to DOE. As noted previously in this summary, the use of these hypothetical scenarios in this risk assessment does not imply any endorsement of either the scenarios or the underlying assumptions by DOE or other stakeholders with respect to future land use.

Each of the exposure scenarios included the following exposure pathways: incidental soil ingestion, inhalation of dust in ambient air, dermal absorption of chemicals on soil, and external irradiation from soil exposure. The Rural-Residential and CTUIR scenarios also incorporate exposure via a variety of foodstuffs such as garden produce, domestic livestock, and fish from the Columbia River. Evaluation of potential exposures via domestic uses of groundwater was performed for these two scenarios and the Resident Monument Worker scenario. Additionally, the CTUIR scenario addresses potential exposures via gathered plants and game meat as well as exposure to contaminants in water used in a sweat lodge. The Avid Angler and Avid Wild Game Hunter scenarios included exposures via fish and game meat, respectively.

The exposure models and parameter values applied in these scenarios were based on peer reviewed scenarios, similar to those employed in the 100-B/C Pilot Project risk assessment, but they have been modified and expanded to be faithful to comments received during the risk assessment workshops conducted with the Hanford Natural Resource Trustees, the Tri-Parties, the Hanford Advisory Board, Tribes, and others. In particular, all but the CTUIR scenario were evaluated to capture the range of potential exposure intensity from a central tendency to a reasonable maximum exposure. The CTUIR scenario was developed in a manner consistent with information provided by the Confederated Tribes of the Umatilla Indian Reservation, which generally included only a single set of exposure parameter values. A second important differentiation from previous assessments related to the remediated waste sites (either in the 100-B/C Pilot Project or in the application of the interim action cleanup criteria) is the development of a physically practical excavation and mixing model to estimate chronic surface soil exposure concentrations related to residual subsurface soil contamination.

Potential human health effects evaluated in the risk assessment include chemical and radionuclide cancer risks, radiation dose, and chemical hazards (i.e., chronic health effects other than cancer). These effects are all collectively referred to simply as "risks." The results of the human health risk assessment therefore encompass three human health effects endpoints and seven hypothetical exposure scenarios. Four of the exposure scenarios (Industrial/Commercial Worker, Resident Monument Worker, Rural-Residential, and CTUIR) are applied to each of the 163 remediated waste sites encompassed in this risk assessment. Of these four, all but the Industrial/Commercial Worker scenario are also applied in calculating potential groundwater-related risks at each of the 64 groundwater monitoring wells sampled to support this risk assessment. Considering that there are also one or more types of background risk calculations for each scenario, and calculations related to both central tendency and reasonable maximum exposure assumptions, it is obvious that the scope of the risk assessment is very large. It is therefore important to understand how the risk results have been summarized and presented.

The results of the human health risk assessment may be organized into four groups. These groups include the following:

1. Operational area risks deriving from residual contamination in soil, sediment, or groundwater

2. Background risks, primarily related to analyte concentrations measured in reference area samples (soil and sediment) or Hanford Site background (groundwater)

3. Operational Area risks related to ingestion of fish from the Columbia River

4. Risks related to naturally occurring levels of potassium-40 and certain isotopes of the elements radium and thorium.

Of these four groups of results, the last two have been purposefully separated in order to facilitate the identification of operational and reference area risks in soil and sediment that pertain to Hanford Site-related contaminants.

A summary of the results of the reasonable maximum exposure (RME) human health risk calculations across all exposure scenarios is presented in Table ES-1. The first four scenarios listed in Table ES-1 are scenarios for which risks are calculated on a relatively small spatial scale, such that an individual risk calculation is conducted for each of the 163 remediated waste sites. As indicated in the first column of results in this table, the range of soil-related RME risk results across the 163 remediated waste sites was often as great as a factor of 100 and occasionally even larger. To a great extent, the range of these risk results is skewed by a relatively few remediated waste sites where RME risk calculations are inordinately affected by very high upper confidence level values for certain analytes. By contrast, the range of central tendency exposure results across the remediated waste sites is more often about a factor of 10.

The specific remediated waste sites associated with some of the highest calculated RME cancer risks and/or radiation dose are relatively consistent across all four of the scenarios for which risks are calculated on a relatively small spatial scale (Rural-Residential, CTUIR [local exposures], Resident Monument Worker, and Industrial/Commercial Worker). A selection of these sites, with the analytes that are predominantly associated with the calculated risks across one or more of the four scenarios and either cancer risk and/or radiation dose, include the following:

- 316-5 (arsenic, isotopic uranium, cesium-137, cobalt-60)
- 316-2 (isotopic uranium , arsenic, cobalt-60)
- 300-10 (arsenic)
- 116-F-14 (isotopic europium, cesium-137, cobalt-60)
- 316-1 (arsenic, isotopic uranium)
- 100-F-35 (strontium-90, arsenic, cesium-137)
- 100-F-37 (arsenic)
- 118-B-3 (isotopic europium, arsenic, cesium-137)
- 116-B-11 (isotopic europium, cesium-137)
- 118-F8-1 (isotopic europium, cesium-137).

Table ES-1. Summary of Reasonable Maximum and CTUIR Exposure Results for the Human Health Risk Assessment. (2 Pages)

RME Cancer Risk						
Scenario	**Range of Remediated Waste Site Soil-Related Risks**	**Operational Area (No Excavation) Soil-Related Risks**	**Reference Area Soil-Related Background Risks**	**Range of Operational Area Fish Ingestion Pathway Risks**	**Range of Groundwater Exposure Risks**	**Soil-Related Risks for Thorium, Radium, and Potassium Isotopes**
Rural-Residential	2E-04 to 7E-03	3E-04	2E-04	3E-06 to >1E-02 (b	4E-06 to 6E-03	2E-03
CTUIR (local area only)	1E-03 to >1E-02	>1E-02	8E-03	7E-05 to >1E-02 (b)	1E-04 to >1E-02 (c)	6E-03
Resident Monument Worker	3E-05 to 3E-03	4E-05	3E-05	NA	4E-06 to 4E-03	3E-04
Industrial/Commercial	3E-06 to 2E-03	2E-05	1E-05	NA	NA	1E-04
Avid Angler	NA	2E-06 to 3E-05	4E-06	1E-05 to >1E-02 (b)	NA	4E-05
Avid Hunter	NA	1E-04	3E-05	NA	NA	4E-04
Casual User	NA	3E-06	3E-06	NA	NA	2E-05
RME Radiation Dose (mrem /yr)						
Scenario	**Range of Remediated Waste Site Soil-Related Doses**	**Operational Area (No Excavation) Soil-Related Doses**	**Reference Area Soil-Related Background Doses**	**Range of Fish Ingestion Pathway Doses**	**Range of Groundwater Exposure Doses**	**Soil-Related Doses for Thorium, Radium, and Potassium Isotopes**
Rural-Residential (e)	1.0 to 370	2.7	1.8	0.14 to 13	0.20 to 150	46
CTUIR (local area only)	2.4 to 620	5.4	4.8	1.4 to 130	0.70 to 840 (c)	75
Resident Monument Worker	1.3 to 150	2.3	1.5	NA	0.20 to 150	14
Industrial/Commercial	0.19 to 120	1.0	0.66	NA	NA	6.1
Avid Angler	NA	0.04 to 1.1	0.15	0.52 to 49	NA	1.7
Avid Hunter	NA	0.27	0.17	NA	NA	8.4
Casual User	NA	0.095	0.090	NA	NA	0.68

Table ES-1. Summary of Reasonable Maximum and CTUIR Exposure Results for the Human Health Risk Assessment. (2 Pages)

RME Hazard Index (higher of child or adult)					
Scenario	**Range of Remediated Waste Site Soil-Related HI**	**Operational Area (No Excavation) Soil-Related HI**	**Reference Area Soil-Related Background HI**	**Range of Fish Ingestion Pathway HI**	**Range of Groundwater Exposure HI**
Rural-Residential	5 to 200 (a)	8	20 (d)	3000 to 11000 (b	0.06 to 500
CTUIR (local area only)	30 to 700 (a)	90	500 (d)	300 to 1100 (b)	0.5 to 600 (c)
Resident Monument Worker	0.09 to 0.7	0.2	0.2	NA	0.02 to 300
Industrial / Commercial	0.01 to 0.2	0.07	0.04	NA	NA
Avid Angler	NA	0.03 to 0.08	0.04	1200 to 4000 (b)	NA
Avid Hunter	NA	3	4	NA	NA
Casual User	NA	0.03	0.03	NA	NA

(a) Upper end of range is commonly skewed by 3 to 10 sites with elevated results; most waste sites have values at least a factor of 10 below the upper-end value.

(b) Lower and/or higher end of range related to elevated detection limits for organic chemicals.

(c) Includes exposure via groundwater use in the sweat lodge.

(d) Related to an elevated UCL for thallium in reference area soil.

(e) The high calculated risk results for a few of the remediated waste sites, relative to the cleanup verification package results, appears to reside in the protocol for calculating UCLs, which occasionally returns UCL values that are a factor of 10 or more above the mean.

CTUIR = Confederated Tribes of the Umatilla Indian Reservation
HI = hazard index
NA = not applicable
RME = reasonable maximum exposure
UCL = upper confidence level

A different set of waste sites is predominantly associated with the highest calculated hazard index (HI) values, but again the sites are relatively consistent across all four of scenarios for which risks are calculated on a relatively small spatial scale. A selection of these sites for the Rural-Residential and CTUIR scenarios (RME HI values did not exceed 1.0 for any remediated waste sites under the Resident Monument Worker and Industrial/Commercial Worker exposure scenarios) include the following:

- 100-K-33 (mercury)
- 100-K-30 (mercury)
- 128-C-1 (copper)
- 110-K-32 (mercury)
- 300-10 (arsenic).

For the Rural-Residential, CTUIR, Resident Monument Worker, and Industrial/Commercial Worker exposure scenarios, "background" risks are calculated and presented in two ways. The fourth column of Table ES-1 shows "background" risks for soil-related exposures that are calculated using soil data from samples collected in the reference area. The reference area risk calculations are intended to represent background levels of risk for the soil contaminants of potential concern (COPCs) evaluated in the risk assessment independent of the impacts of the Hanford Site. These are the background risk values that are used, by subtraction from the total risk values for these scenarios shown in the first column of Table ES-1, to calculate incremental cancer risk and dose. The results shown in the "Operational Area (No Excavation)" for the Rural-Residential, CTUIR, Resident Monument Worker, and Industrial/Commercial Worker exposure scenarios present the results for these scenarios calculated using present-day surface soil COPC concentrations across the upland portions of the 100 and 300 Areas. Conceptually, these results portray a situation where a hypothetical residence or commercial structure is located within the operational area but the construction of which does not intrude into the subsurface soils represented by the CVP/remaining sites verification package soil verification data.

For the Rural-Residential and CTUIR (with only local exposures) exposure scenarios, arsenic via produce ingestion was the primary contributor to background cancer risks. In the variation of the CTUIR scenario where native plants and wild game were evaluated, exposure to arsenic, PCBs, and pesticides via wild plants were of most significance to background cancer risks. Produce and native plant exposures were also the primary exposure pathways for cancer risks related to the remediated waste sites for these scenarios. Exposure to isotopic europium and cobalt-60 via external irradiation was the main contributor to radiation dose for the Rural-Residential, Resident Monument Worker, and Industrial/Commercial Worker scenarios.

The operational area risk results for the recreational scenarios (Casual User, Avid Hunter, and the sediment-based exposure pathways of the Avid Angler scenario) shown in Table ES-1 reflect exposures that occur over a larger area than that associated with any particular waste site. The relatively higher RME cancer risk and HI values for the Avid Hunter reflect modeled exposures to PCBs and certain metals in soil via ingestion of wild game. The range of results shown for the Avid Angler exposure scenario pertains to the four exposure areas where COPC sediment concentrations were differentiated: 100-B/C Area, 100-N Area, the 300 Area, and the entire 100 Area assessed in aggregate.

The risk assessment results for exposures related to fish ingestion are calculated and presented independently of the risk related to other exposure pathways. Risks related to a subset of six naturally occurring radionuclides (potassium-40, radium-226, radium-228, thorium-228, thorium-230, and thorium-232) that are not associated with Hanford Site operations are also calculated and presented independently. These risk calculations are not integrated with the other risk assessment results because the relative risks shown in these calculations are very high, such that the potential impacts of residual levels of Hanford Site-related contamination in the remediated waste sites and in operational area surface soils are indiscernible when these results are included in the risk calculation sums. For the fish ingestion pathway, the high risk results are an artifact of the calculated exposure point concentrations for certain organic chemicals in fish tissue (particularly carcinogenic polyaromatic hydrocarbons and, to a lesser extent, PCBs) being inordinately affected by elevated detection limits and also to widespread levels of these and other organic compounds being present in fish of the Columbia River basin.

Potential risks related to groundwater were calculated for 64 monitoring wells sampled under the *100 Area and 300 Area Component of the RCBRA Sampling and Analysis Plan* (DOE/RL-2005-42). The purpose of evaluating possible groundwater-related risks is primarily to provide an approximate measure of the relative significance of soil and groundwater as exposure media in the 100 and 300 Areas. Cancer risk and radiation dose values across the Rural-Residential, CTUIR, and Resident Monument Worker scenarios were approximately equivalent for the soil-related exposure pathways (not including the thorium, radium, and potassium isotopes) and the groundwater exposure pathways. With the inclusion of these radionuclides, soil-related risks at the various remediated waste sites generally exceeded those calculated for groundwater exposures. The calculated HI values were generally somewhat higher for the soil-related exposure pathways. There is a small subset of monitoring wells with high concentrations of Aroclor-1254 (well A4614 in the 100-H Area) and strontium-90 (wells A9910 and A4679) in groundwater where calculated cancer risk and dose were higher than at most of the remediated waste sites. Also, very high cancer risk estimates for certain wells with elevated concentrations of hexavalent chromium (B8778, B8753, A4570, B8750, 199-N-80, A4647, C4670, 199-K-22, and A4600) were calculated for the CTUIR exposure scenario via the sweat lodge inhalation exposure pathway. There are, however, significant protective biases inherent in the exposure estimates for this pathway. An important distinction between the risk calculations for groundwater wells and remediated waste sites is that the contribution of background to the total calculated risks was generally quite small for the monitoring wells in comparison to the remediated waste sites.

Although a range of behavioral variability was investigated in this assessment by evaluating both central tendency and reasonable maximum exposures, the human health risk assessment incorporates several inherently protective assumptions. The toxicological models used to estimate both cancer and noncancer effects employ known protective biases so as not to underestimate potential effects for a hypothetical receptor who may be particularly sensitive to a given toxicant. The waste site excavation model assumes that CVP data represent concentrations both below and adjacent to the excavation, and that a basement will be situated in such a manner as to maximize removal of such soil. Models for predicting contaminant concentrations in foodstuffs from measured concentrations in soil may overestimate such concentrations, particularly when residual soil concentrations are elevated. In general, as the number of exposure pathways and individual chemicals in a risk calculation increases, the degree of protective bias will also increase due to the summation across pathways and analytes.

Ecological Risks

The ecological risk assessment methods for the 100 Area and 300 Area Component of the RCBRA were developed in accordance with the approved planning and decision documentation for the 100 Area and 300 Area Component of the RCBRA and reflect input received during numerous workshops conducted with the Tri-Parties, the Hanford Natural Resource Trustees, the Hanford Advisory Board, contractors, and others. The assessment endpoints and associated measures, data inputs, analyses, and exposure calculations for the terrestrial/upland, riparian, and near-shore aquatic data from the 100 Area and 300 Area are described in this report. In addition, as indicated in the letter from EPA and the Washington State Department of Ecology approving the sampling and analysis plan (DOE/RL-2005-42, *100 Area and 300 Area Component of the RCBRA Sampling and Analysis Plan*), a number of elements of the assessment methodology required further development including uncertainty analyses, reference sites, and risk integration. These and other topics were covered in regulator/trustee workshops conducted from July 2006 to May 2007, and the notes from these workshops are provided in Appendix D (presentation materials can be found on the project web site, http://www.washingtonclosure.com/Projects/EndState/100-300_comp.html). This risk assessment report reflects the input and recommendations from these workshops.

The primary ecological risk assessment goal for *Comprehensive Environmental Response, Compensation, and Liability Act of 1980* (CERCLA) sites is to support remedial action decisions that reduce ecological risks to levels that will result in the recovery and maintenance of healthy local populations and communities of biota. The specific purpose of this ecological risk assessment is to characterize potentially adverse effects on plants and animals that may be posed by residual, post-remediation contamination in the Hanford Site River Corridor operational areas. In addition, management goals for the River Corridor include considering impacts to state or federally listed threatened or endangered species, protecting rare habitats, and minimizing contaminant loading (or bioaccumulation) into biota.

The characterization of ecological risks is structured around exposure zones in accord with the assessment endpoints in upland, riparian, and near-shore environments. Assessment endpoints were developed from the ecological management goals, the conceptual exposure model, and trophic relationships among ecological receptors. Assessment endpoints are representative of biota potentially at risk from contaminants within and between exposure zones. For the upland and riparian terrestrial environments, this includes producers, invertebrates, and middle and upper trophic-level birds and mammals. Receptors in the near-shore aquatic environment include plants; herbivorous invertebrates and vertebrates; omnivorous invertebrates, fish, birds, and mammals; invertivorous (invertebrate-eating) amphibians, fish, birds, and mammals; and carnivorous fish, birds, and mammals. Sculpin are considered to be protective representatives of threatened and endangered salmonids due to their year-round exposure duration and limited home range relative to salmonids. While some receptors are unique to one type of environment, such as fish in the near-shore aquatic area, others can traverse multiple environments in the course of daily foraging activities; e.g., broad-ranging red-tailed hawk capturing mammalian prey at upland remediated waste sites and using the river as a source of drinking water.

Ecological risk assessment guidance indicates that a variety of measures are to be evaluated for each assessment endpoint. These constitute the lines of evidence in this risk assessment and include measures of exposure, measures of effect, and measures of ecosystem/receptor characteristics (EPA/630/R-95/002F). Lines of evidence are evaluated based on literature information, historical information, and data collected as described in the *100 Area and 300 Area Component of the RCBRA Sampling and Analysis Plan* (DOE/RL-2005-42).

- **Measures of Exposure:**
  - Exposure concentrations in abiotic media
  - Bioaccumulation into plants and animals
  - Calculation of exposure to wildlife

- **Measures of Effect**:
  - Literature toxicity information
  - Literature tissue effect levels
  - Laboratory toxicity tests
  - In situ riverbed survival
  - Biological condition
    - Gross field measurements
    - Histopathology measurements

- **Measures of Ecosystem/Receptor Characteristics**:
  - Field measures
    - Abundance
    - Diversity
    - Community structure
    - Reproduction observed in field
      - Gender ratios
  - Abiotic data (pH, soil texture, etc.).

Each measure has an associated weight, and the actual weights were achieved through agreements developed in workshops with the regulators, Hanford Natural Resource Trustees, and other interested parties. Lines of evidence are weighted based on whether the measurement is an integrated versus single COPC analysis, site-specificity, standardization, temporal representation of exposure, replication/repeatability of the measurement, variability, and relevance to management goals. Higher weighted measures can be used to assess adverse effects and causality with less uncertainty (e.g., measures incorporating site-specificity such as toxicity bioassays). Lower weights were assigned to measures where greater uncertainty exists in assessing effects (e.g., comparisons to literature values) or causality (e.g., attributing natural variability in relative population estimates to COPCs). Risk conclusions based on multiple lines of evidence for ecological receptors in each exposure zone are described below.

Upland Environment. The terrestrial upland zone consists of remediated backfill sites and remediated native soil sites. The assessment endpoints evaluated for the upland environment include terrestrial plants, terrestrial invertebrates, middle trophic-level birds (mourning dove, meadowlark, and killdeer), mammals (pocket mouse, deer mouse, and grasshopper mouse), and upper trophic-level birds and mammals (red-tailed hawk and badger).

Upland Terrestrial Plants. No lines of evidence suggest that COPCs are adversely affecting terrestrial plants in upland soils. The general lack of plant contaminant uptake indicates minimal COPC exposure. Some COPCs are detected in plants, but tissue concentrations do not differ between upland remediated waste sites and reference sites and generally do not correlate with abiotic media concentrations. Another measure of risks to upland plants is based on comparisons of soil concentrations to screening benchmarks. Hazard indices for plants based on these benchmarks are greater than 1 (most fall between 25 and 35) for all sites but are not different between remediated waste and reference sites, indicating that potential risks to plants are based largely on concentrations of naturally occurring elements in soil and not due to COPCs. The weight attributed to this line of evidence is low. A medium-weighted line of evidence, field measures, shows no difference in plant diversity, richness, and cover at remediated waste sites compared to reference sites. Plant toxicity testing was performed, but the results are compromised by issues with laboratory test methodology and are not being used as a basis for conclusions on plant effects. The other lines of evidence for plants are used to draw inferences regarding the potential for ecological risks to plants from COPCs at upland sites.
Terrestrial Invertebrates. The overall weight of evidence indicates that COPCs do not adversely impact terrestrial invertebrates. The highest weighted line of evidence, toxicity bioassays of nematode survival, is not significantly different between remediated waste sites and reference

site soils. Some COPCs are detected in invertebrates, but concentrations of COPCs in invertebrates near operational areas do not differ from concentrations at reference sites and generally do not correlate with abiotic media concentrations. Hand-picking invertebrates was necessary to gain sufficient mass for analytical COPC measurements. While this practice facilitated laboratory analyses, this collection approach disabled estimates of relative abundance as a line of evidence. Lastly, while hazard indices for terrestrial invertebrates are significantly higher at remediated waste sites mainly due to detection of polycyclic aromatic hydrocarbons, the weight attributed to this conclusion is low.

Middle Trophic-Level Birds. There is no indication of risk to birds from COPC concentrations. Exposure modeling for herbivorous, omnivorous, and invertivorous birds was performed, and exposure to invertebrates in the diet was of greatest concern considering the propensity for heavy metals and radionuclides to be taken up into terrestrial invertebrates. As with risks to avian herbivores and omnivores, risks to birds consuming terrestrial invertebrates were comparable between reference areas and remediated waste sites.

Middle Trophic-Level Mammals. Overall, risks to small mammals from COPCs, a focal taxon of this investigation, are not indicated. Small mammal relative abundance, total numbers, and species richness were comparable in remediated backfill waste sites and borrow pit reference site soils and higher at native soil reference sites than at native soil operational sites. In general, small mammal population metrics can be explained by difference in plant cover and composition (e.g., grasses versus shrubs). Gross morphological anomalies were not evident in field-collected animals, and there was limited evidence of contaminant uptake. Indications of reproductive differences were not apparent for small mammals inhabiting remediated waste sites relative to reference locations. Hazard indices for small mammals occupying all trophic levels were above one at all sites and similar between remediated waste site and reference site locations.

Carnivorous Birds. Risks to upper trophic-level birds are negligible on the basis of modeled dietary exposure. Through modeling, red-tailed hawks were exposed to multiple media, obtaining soil in their diet, ingesting small mammals and kingbirds, and drinking water from the river. Hazard indices were low and not significantly different among all locations, and risks would be further reduced when considering a realistic home range and area use factor for these receptors.

Carnivorous Mammals. Risks to upper trophic-level mammals are negligible on the basis of modeled dietary exposure. Badgers were exposed to multiple media through ecological exposure models, obtaining soil in their diet, ingesting small mammals, and drinking water from the river. Risks to upper trophic-level mammals are indicated by elevated (HI of about 10) hazard indices on the basis of modeled dietary exposure from individual sites. However, HIs are similar between remediated waste sites and reference sites, and risks would be further reduced when considering a realistic home range and area use factor for these receptors.

Riparian Environment. These sites are located along the Columbia River shoreline where affected media (springs, groundwater, or soil) have the potential for exposing receptors to contaminants. The assessment endpoints evaluated for the riparian environment include terrestrial plants and invertebrates, middle trophic-level birds (mourning dove, meadowlark, killdeer, and kingbird) and mammals (pocket mouse, deer mouse, and grasshopper mouse), and upper trophic-level birds and mammals (red-tailed hawk and badger, respectively).

Riparian Plants. The observation of highest diversity and richness in riparian sites with the highest metal levels in soil suggests that there are no adverse impacts on plants from COPCs. Some COPCs are detected in plants, but concentrations of COPCs in plants do not differ from operational sites relative to reference sites and do not correlate with abiotic media concentrations. Another measure of risks to riparian plants is based on comparisons of soil concentrations to screening benchmarks. Hazard indices for plants based on these benchmarks are greater than one for all sites but are not different between operational and reference sites, indicating that risks to plants are largely based on concentrations of naturally occurring elements in soil and not due to other COPCs. The weight attributed to this line of evidence is low. A medium-weighted line of evidence involves field measures of plant diversity, richness, and cover at operational areas compared to reference sites; no difference in these field measures are noted between riparian operational sites and reference sites. Although the highest weighted line of evidence, toxicity testing, showed no differences in plant growth between operational sites and reference sites, these results are compromised by issues with laboratory test methodology and are not being used as a basis for conclusions on plant effects.

Riparian Invertebrates. The weight of evidence indicates that COPCs do not adversely impact riparian invertebrates. The highest weighted line of evidence, toxicity bioassays of nematode survival, while significantly lower in riparian soils compared to upland soils, is not significantly different between riparian operational sites and reference site soils. Some COPCs are detected in invertebrates, but concentrations of COPCs in invertebrates at remediated waste sites do not differ from concentrations at reference sites, and, furthermore, do not correlate with abiotic media concentrations. As with upland site invertebrate field-measures, the sample collection method did not permit estimates of invertebrate abundance. Although HIs for riparian invertebrates are greater than one at all sites, they are not different between operational sites and reference sites and are primarily related to naturally occurring constituents in soil.

Riparian Middle Trophic-Level Birds. Based on the lines of evidence, while there are data gaps for avian field measures of nest success, there is no indication of risk to birds from COPCs. Given the importance of invertivorous birds as representative and potentially sensitive biota, exposure of aerial insectivores to emergent insects from the river was also modeled. The data from the rock baskets were used as a measure of the emergent insects, which is appropriate because larval stages of some emergent insects were sampled from the baskets. Risks to birds consuming either invertebrates on the ground or benthic macroinvertebrates were comparable between reference areas and riparian operational sites. An evaluation of kingbird abundance and reproductive success was confounded by heavy nest predation from crows and ravens.

Middle Trophic-Level Mammals. Overall, risks to small mammals from COPCs, a focal taxon of this investigation, are not indicated. Small mammal relative abundance was slightly higher in riparian operational sites versus reference sites. In general, small mammal population metrics can be explained by characteristics of the plant community. Gross morphological anomalies were not evident in field-collected animals, and there was limited evidence of contaminant uptake. Indications of reproductive differences were not apparent for small mammals inhabiting operational sites relative to reference locations. Hazard indices for small mammals occupying all trophic levels were uniformly above one but are similar between riparian operational and reference locations.

Carnivorous Birds. Risks to upper trophic-level birds are negligible on the basis of modeled dietary exposure. Red-tailed hawks were exposed to multiple media, obtaining soil in their diet, ingesting small mammals and kingbirds, and drinking water from the river. Hazard indices were low and not significantly different among locations and would be further reduced considering an appropriate area use factor.

Carnivorous Mammals. Risks to upper trophic-level mammals are negligible on the basis of modeled dietary exposure. Badgers were exposed to multiple media through exposure modeling, obtaining soil in their diet, ingesting small mammals, and drinking water from the river. Risks to upper trophic-level mammals are indicated by elevated HIs (HI about 10) on the basis of modeled dietary exposure from individual sites. However, HIs are similar between operational and reference sites, and risks would be further reduced when considering the appropriate home range and area use factor for these receptors.

Near-Shore Aquatic Environment. These sites are in the near-shore aquatic zone in locations where there were elevated levels of contaminants in biota or the presence of seeps or springs as determined by groundwater plume maps, previous sampling, and conductivity surveys in the river. The aquatic reference sites are located upstream of the Hanford Site or upstream of the 300 Area. The study boundary for the near-shore river zone extends to a water depth of 1.8 m (6 ft) below the low-water mark. The low-water mark is identified by a "green line" where periphyton remains green all year long. Ecological receptors in the near-shore environment include aquatic plants, benthic macroinvertebrates (aquatic insects, snails, clams), amphibians, invertivorous fish (sculpin), birds (kingbird, bufflehead duck), mammals (bat), and piscivorous birds (Great Blue heron), as well as broad-ranging terrestrial carnivores (red-tailed hawk and badger) using the river for drinking water.

Near-Shore Aquatic Plants. Uncertainties exist with regard to possible impacts on near-shore plants from sediment COPCs; these uncertainties can be addressed with the expanded sediment bioassay data being compiled for the Inter-Area shoreline assessment. For sediment, phytotoxicity bioassay (with pak choi) results suggest that growth was reduced in sediments collected in the strontium plume associated with the 100-N Area. However, there are no relationships between the bioassay results and strontium levels from the 10 sediment sampling locations. In addition there are very few macrophytes along most of the operational areas, most likely due to the strong and variable river flows.

Benthic Macroinvertebrates – Sediment-Dwelling Organisms. For aquatic macroinvertebrates associated with sediments, a high-weighted line of evidence (Hyalella bioassay) suggests that the chromium plume shoreline locations are associated with significantly reduced survival and growth. However, statistical analyses indicate that decreased growth and survival of sediment-dwelling macroinvertebrates is associated with sediment grain size across aquatic stations. Hazard indices for sediment-dwelling aquatic macroinvertebrates at reference and operational sites are similar and are lowest in the chromium plume shoreline locations.

Benthic macroinvertebrates – Associations with Pore Water. A high-weighted line of evidence (Ceriodaphnia bioassays) suggests that pore water in the chromium and strontium plume areas is not associated with effects. Ceriodaphnia survival and reproduction in operational and reference site pore water were not significantly different. Clam survival was significantly reduced in the chromium plume shoreline locations, but reduced clam survival was significantly correlated with the confounding factor of sediment grain size. The concentrations of all COPCs in benthic macroinvertebrate tissue are less than tissue effect levels (tissue concentrations that have been reported to be associated with adverse effects on aquatic organisms) with the exception of selenium. Selenium concentrations at upstream and downstream locations are greater than tissue effect concentrations published in the literature. Results of histopathology, the study of changes in biotic tissues caused by disease or other stresses, show no strong trends between clams collected at aquatic operational and reference site locations; of 21 measures, 1 (epithelial cell shedding) was significantly higher at operational areas, and another, reproductive follicle cysts, was higher at reference areas. Aquatic macroinvertebrate community metrics do not indicate that groups of organisms tolerant of poor water quality are more abundant in operational locations relative to reference areas. And while total macroinvertebrate diversity is significantly lower in the chromium plume, this trend may be explained by significantly higher abundance of species (e.g., net-spinning caddisflies) that competitively exclude other taxa from establishing there. Overall abundance and diversity of metals-sensitive taxa are not significantly different among aquatic stations. Molluska taxa (snails) were studied in detail considering the presence of several special status species occurring in the Hanford Reach. Molluska diversity and total taxa were not significantly different among sites, but the number of rare taxa was significantly greater in stations from the uranium area.

Benthic Macroinvertebrates - Summary. Community metrics do not suggest that contaminant-related impacts are evident to benthic macroinvertebrates in operational sites. However, risks to aquatic macroinvertebrates based on the highest weighted lines of evidences, toxicity testing, and histopathology show some relationships with confounding factors (mainly particle size). Additional data from the Inter-Areas shoreline assessment would help to better understand the influence of confounding factors and better understand the potential for adverse ecological effects of COPC concentrations on benthic macroinvertebrates.

Amphibians. The results of Frog Embryo Teratogenesis Assay – *Xenopus* (FETAX) bioassays show that differences between operational and reference areas (98% versus 99.7% survival, respectively), while significant, are slight and likely not ecologically relevant. In addition, difference in FETAX measures was not associated with differences in COPC concentrations. Although the initial pore water samples may have represented mostly river water during the initial sampling events at many sampling stations, subsequent pore water sampling obtained more representative pore water samples. Tissue samples of amphibians were not collected due to a lack of available organisms, which makes field measures of exposure to amphibians a data gap.

The Inter-Areas shoreline assessment is planning to fill this data gap. However, the available data do not suggest that COPC concentrations are adversely affecting amphibian survival and growth.

Fish. There is no clear indication of an impact of COPCs on fish populations in the Hanford Reach. Fish with higher reproductive maturity were more frequent in operational areas relative to reference locations. There are no strong trends in fish histopathological observations between organisms collected at operational and reference site locations; of 18 endpoints, slight adverse effects are associated with 3 in operational areas and with 3 endpoints in reference areas. In general, tissue effect levels were elevated for some metals (or in the case of selenium, all locations) at a few operational and reference site locations. In addition, evidence of greater contaminant uptake in fish from operational areas was not apparent.

Birds. Exposure to birds modeled to consume emergent insects (kingbirds), a combination of emergent insects and sessile invertebrates (buffleheads), or primarily fish (Great Blue heron) was not higher at operational sites versus reference site locations.

Bats. There is an indication of potential risk to bats based on modeling bat consumption of benthic macroinvertebrates. Hazard indices were significantly higher in operational areas relative to reference sites, indicating greater contaminant uptake into macroinvertebrate prey in operational areas. The COPCs that contributed to the bat HI were antimony and selenium, which are not key groundwater plume contaminants. A broader scale assessment of bats including the Inter-Areas shoreline assessment is warranted to address conservatism in the home range used in this assessment. It is also important to better understand the sources of the COPCs contributing to risk to bats.

Ecological Risk Summary. In conclusion, this ecological risk assessment evaluated a comprehensive array of assessment endpoints using multiple measures of exposure, effect, and ecosystem/receptor characteristics. Some inherently protective assumptions have been made for the ecological exposure assessment based on agreements made at the regulator/trustee workshops. For example, this report includes all detected constituents in the analytical suites as COPCs in the assessment and evaluates all receptors on a site-specific basis.

The assessment provides information on some near-shore environment operational areas that are worth further investigation in terms of uncertainties associated with the potential for ecological risks associated with COPC concentrations:

- Medium: Sediments and pore water; assessment endpoints: near-shore aquatic plants and macroinvertebrates
  - Uncertainties to address
    - Verify the lack of COPC associations with effects by incorporating additional information from the Inter-Areas shoreline assessment
- Medium: Macroinvertebrates; assessment endpoint: bats
  - Uncertainties to address
    - Improve the ecological relevance of the assessment by evaluating exposure for an appropriate home range in the Inter-Areas shoreline assessment
    - Additional information on nature and sources of antimony and selenium in macroinvertebrates may be useful.

No major uncertainties associated with the potential for ecological risks were identified for upland remediated waste sites or riparian operational sites investigated for this report.

100 Area River Effluent Pipelines

Between 1943 and 1988 at the Hanford Site, pipelines extending from reactor outfall structures in the 100 Areas into the Columbia River were used to carry reactor cooling water for discharge to the river. Today, the effluent pipelines at the 100-B/C, 100-D, 100-H, 100-F, 100-K, and 100-N Areas remain in place on or beneath the river channel bottom. The river effluent pipelines are known or suspected to contain small amounts of residual contamination from past reactor operations.

Samples of scale from the interior surfaces and enclosed sediment of the effluent pipelines from the 105-C, 105-DR, and 105-F Reactors in 1984 were analyzed for radionuclides and revealed primarily cobalt-60, cesium-137, europium-152, europium-154, and europium-155. In 1995, pipe scale and sediment from the interior of the effluent pipelines from the 105-B and 105-D Reactors were sampled and analyzed for metals as well as a larger suite of radionuclides than the 1984 sampling.

Using the 1984 and 1995 data, risk evaluations using the RESidual RADioactivity (RESRAD) and RESRAD-BUILD computer codes have been performed for an exposure scenario in which a pipeline section breaks away from the main pipeline and is washed onto the shore of the river. An evaluation of potential risks related to the river effluent pipelines as they are today, located on or beneath the river channel bottom, was conducted in 1998. Although the 1998 study indicated no potential for significant effects, the more recent analysis determined that a child receptor in the Avid Recreational scenario could receive an estimated annual dose greater than 15 mrem/yr above background for 15 years beyond 2007.

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ACRONYMS

ALARA	as low as reasonably achievable
ASTM	American Society for Testing and Materials
BCG	biota concentration guide
BDAC	Biota Dose Assessment Committee
bgs	below ground surface
CAS	Chemical Abstracts Service
CDC	Centers for Disease Control
CEM	Conceptual Exposure Model
CERCLA	*Comprehensive Environmental Response, Compensation and Liability Act of 1980*
CLUP	*Hanford Site Comprehensive Land-Use Plan Environmental Impact Statement*
COPC	contaminant of potential concern
COPEC	contaminant of potential ecological concern
CRC	Columbia River Component
CSF	cancer slope factor
CSM	conceptual site model
CTE	central tendency exposure
CTUIR	Confederated Tribes of the Umatilla Indian Reservation
CVP	cleanup verification package
DCF	dose conversion factor
DDE	dichlorodiphenyldichloroethylene
DDT	dichlorodiphenyltrichloroethane
DOE	U.S. Department of Energy
DQO	data quality objective
Ecology	Washington State Department of Ecology
ENRE	Environmental Restoration database
EPA	U.S. Environmental Protection Agency
ERAGS	*Ecological Risk Assessment Guidance for Superfund*
ERDF	Environmental Restoration Disposal Facility
ESD	explanation of significant differences
FS	feasibility study
GEA	gamma energy analysis
GiSdT	Guided Interactive Statistical Decision Tools
HEAST	*Health Effects Assessment Summary Table*
HEIS	Hanford Environmental Information System
HGP	Hanford Generating Plant
HHCEM	human health conceptual exposure model
HI	hazard index
HPPS	Hanford Past Practice Strategy
HQ	hazard quotient
HRM	Hanford river mile
HSRAM	*Hanford Site Risk Assessment Methodology*
ILCR	incremental lifetime cancer risk
IRIS	Integrated Risk Information System

Acronyms

ISS	interim safe storage
LOAEL	lowest-observable-adverse-effects-level
LOE	line of evidence
MIS	multi-increment sampling
MVUE	minimum variance unbiased estimate
NCEA	National Center for Environmental Assessment
NCP	National Contingency Plan
NEPA	*National Environmental Policy Act of 1969*
NOAEL	no-observable-adverse-effects-level
NPL	National Priority List
NRDA	natural resource damage assessment
OU	operable unit
PAH	polycyclic aromatic hydrocarbons
PCB	polychlorinated biphenyl
PEF	particulate emission factor
PNNL	Pacific Northwest National Laboratory
PP	proposed plan
PPRTV	provisional peer-reviewed toxicity criteria
PQL	practical quantitation limits
QA	quality assurance
QAPP	Quality Assurance Project Plan
QC	quality control
QRA	qualitative risk assessment
RAG	remedial action goal
RAO	remedial action objective
RCBRA	River Corridor Baseline Risk Assessment
RCRA	*Resource Conservation and Recovery Act of 1976*
RESRAD	RESidual RADioactivity (model)
RfD	reference dose
RI	remedial investigation
RL	DOE Richland Operations Office
RME	reasonable maximum exposure
ROD	record of decision
RSVP	remaining sites verification package
SAP	sampling and analysis plan
SESP	Surface Environmental Surveillance Program
SLERA	screening-level ecological risk assessment
SOF	sum of fraction
SVOC	semivolatile organic compound
T&E	threatened and endangered
Tri-Parties	U.S. Environmental Protection Agency, Washington State Department of Ecology, and U.S. Department of Energy
Tri-Party Agreement	*Hanford Federal Facility Agreement and Consent Order*
TRV	toxicity reference value

Acronyms

UCL	upper confidence level of the mean
UF	uncertainty factor
VOC	volatile organic compound
WAC	*Washington Administrative Code*
WCH	Washington Closure Hanford
WDOH	Washington State Department of Health

1.0 INTRODUCTION

1.1 BACKGROUND ON RISK ASSESSMENT AT THE HANFORD SITE

As a part of its efforts to address hazardous contamination releases at the Hanford Site facility, the U.S. Department of Energy (DOE) has undertaken assessment of risk from past releases. There are several assessments being conducted at the Hanford Site, and they are part of an integrated strategy, consistent with the "National Oil and Hazardous Substances Pollution Contingency Plan" (NCP) and U.S. Environmental Protection Agency (EPA) guidance, to ensure that any unacceptable threats to human health and the environment from releases on the Hanford Site are identified and appropriately addressed through cleanup and/or risk management strategies. DOE's approach to risk assessment across the site was addressed in the document *Status of Hanford Site Risk Assessment Integration, FY2005* (DOE/RL-2005-37). In brief, as explained in that document, DOE is required to assess human and ecological risk, under the *Comprehensive Environmental Response, Compensation and Liability Act of 1980* (CERCLA); *Resource Conservation and Recovery Act of 1976* (RCRA); *National Environmental Policy Act of 1969* (NEPA), and DOE orders. These assessments of risk focus on particular locations at the Hanford Site facility. Within these locations, assessments are sometimes divided into types of media and potential exposures to people and the environment associated with these media. Looking at the many assessments and studies that have been conducted at the Hanford Site to assess risk, one can think of the assessments in terms of conceptual building blocks that are organized according to locations and pathways of exposure. Two key CERCLA ecological risk assessments are ongoing:

- Central Plateau – surficial source areas
- River Corridor – surficial source areas, the area where groundwater enters the Columbia River, and the riparian zone along the shoreline of the Columbia River.

Figure 1-1 depicts the River Corridor scope. It includes the operational areas (100-B/C, 100-K, 100-N, 100-D, 100-H, 100-IU-2, 100-F, 100-IU-6, and the 300 Area), as well as the "Interim Areas," which is primarily outside the main industrial and reactor areas. The River Corridor Baseline Risk Assessment (RCBRA) has three components. The 100 Area and 300 Area Component of the RCBRA focuses on the River Corridor operational areas and is a part of the overall effort to assess risk associated with releases on the Hanford Site. This component of the RCBRA, along with the other two components in progress (the shoreline between operational areas [Inter-Areas Component] and potentially impacted areas of the Columbia River [Columbia River Component]) and other site characterization activities, will be used in the remedial investigation (RI) report to describe nature and extent of contamination of all the River Corridor scope in Figure 1-1 and supports the final CERCLA decision-making process for the 100 Area and 300 Area.

In addition, Figure 1-1 also identifies the 200 West and 200 East Areas located in the "Central Plateau" of the Hanford Site. Remedial investigations will also be completed for these areas and will include baseline risk assessments. Figure 1-2 depicts the groundwater operable unit (OU) boundaries associated with 200 Areas shown in Figure 1-1. Similar to the source areas, a risk assessment will be conducted for the groundwater contamination as part of the RI process. Collectively, the source and groundwater OU RIs will provide decision makers with the information needed for development of final cleanup decisions across the Hanford Site.

Under EPA guidance there are different approaches to performing risk assessments. Guidance allows parties like DOE to tailor approaches that are most effective in consideration of the unique characteristics of the site. The NCP requires a baseline risk assessment. Historically, one performed these risk assessments prior to cleanup. However, as the Superfund Program matured, EPA recognized that such an approach often resulted in delays to cleanup protective to health and the environment. Thus, EPA developed guidance to comply with the NCP and accommodate the need for faster cleanup (see discussion of EPA guidance in Section 1.2.1).

EPA-adopted guidance instructs some sites that it is appropriate to (1) move ahead to cleanup with interim actions (after reaching Interim Action Records of Decision [RODs]), (2) assess the risk that is residual to such cleanup actions, and then (3) conduct a final remedial action/risk management actions if needed. This strategy has often been used nationally to achieve cleanup and eliminate risk sooner than would be possible if one conducted a complete baseline risk assessment before taking any cleanup action. Thus, EPA was able to serve important policy goals associated with the protection of health and the environment while also achieving compliance with the NCP. EPA's expedited approach is memorialized in EPA guidances. See *Superfund Accelerated Cleanup Model* (EPA/540/R-98/025) and the *RCRA Facility Stabilization Initiative* (DOE/EH-231-076/0295r). EPA Region 10 in furtherance of these objectives has developed its own guidance for parties in Region 10 called *Supplemental Guidance for Superfund Risk Assessments in Region 10* (EPA 1991f), which provides guidance on how to achieve cleanup in a streamlined fashion (Section 1.2.1).

1.2 STREAMLINED ASSESSMENT AND RESPONSE AT THE HANFORD SITE

At the Hanford Site, as a result of consultation with the public, tribes, DOE's sister response agencies, and natural resource trustees, DOE adopted an approach, consistent with EPA guidance and the NCP, to eliminate risk through interim cleanup action to achieve results protective of the environment and people sooner rather than later. Shortly after the original *Hanford Federal Facility Agreement and Consent Order* (Tri-Party Agreement) (Ecology et al. 1989) was signed in mid-1989, it became apparent that a larger-than-anticipated amount of time and money would be required to characterize and clean up the thousands of waste sites. In 1991, the Tri-Parties, which include the EPA, Washington State Department of Ecology (Ecology), and DOE, agreed to a "bias-for-action" approach to the CERCLA process for the Hanford Site's *National Priority List* (NPL) sites. The agreement, known as the Hanford Past-Practice Strategy (HPPS) (DOE/RL-91-40), streamlined the RI/feasibility study (FS) process to begin remediation of contaminated waste sites earlier than typically performed under the traditional CERCLA process in place at that time. The bias-for-action strategy allowed site characterization and remediation to proceed in tandem, focusing on clean up of the contaminated soil and waste sites with the highest potential to contribute to contamination of groundwater and the Columbia River.

To achieve the "bias for action," the Tri-Parties developed interim action RODs (e.g., EPA 1995c). These RODs were based on a substantial amount of existing knowledge and similarities in types of waste sites and contaminants of potential concern (COPCs) among the operational areas. Remedial actions use the "observational approach," which relies on the existing knowledge combined with a "characterize and remediate in one step" methodology. Remediation proceeds until field screening and confirmation sampling demonstrate that the cleanup goals have been met. The interim action RODs used qualitative human health and ecological risk assessments (Section 1.2.1) to demonstrate that risks existed and actions were warranted. However, as noted in the *Hanford Risk Assessment Methodology* (HSRAM) (DOE/RL-91-45) and HPPS, the qualitative risk assessments do not meet the stringent requirements of a CERCLA baseline risk assessment. Consequently, the HPPS path forward identified the baseline risk assessments as a task that would be required after waste site remediation, to document protectiveness to human health and the environment before the final RODs could be issued.

Now that many remedial actions performed under the Interim Action RODs have been completed, efforts are being made to arrive at final RODs, and a critical step in developing the final RODs is a baseline risk assessment. The RCBRA, which is composed of several components, is that post-remedial action baseline risk assessment.

Also, no decisions on final land uses had been made when the Interim Action RODs for the 100 Area were written. To permit development of cleanup goals, a conservative assumption of 'unrestricted use' was assumed in the RODs. The unrestricted use was evaluated via a hypothetical rural resident, a reasonably maximally exposed individual who would spend his life on the site and consume irrigated crops grown on the remediated waste site. While the Comprehensive Land Use Plan (CLUP) later identified future uses of the Hanford Site, the Interim Action RODs have not been changed to deviate from a goal of unrestricted use.

Once a remedial action at a waste site is complete and the field screening and confirmation sampling indicate that the cleanup goals have been met, a cleanup verification package (CVP) for a site, or small group of adjacent sites, is prepared (e.g., CVP-98-00006) for regulator approval. The CVP evaluates the concentrations of residual contaminants in both the shallow zone (ground surface to a depth of 4.6 m [15 ft]) and the deep zone (greater than 4.6 m [15 ft] below ground surface [bgs]) to demonstrate protectiveness to the hypothetical future rural resident. The residual concentrations are also evaluated to demonstrate that the remediated site is protective of groundwater and the river, as specified in the Interim Action RODs.

1.3 THE 100 AND 300 COMPONENT RISK ASSESSMENT AND HOW IT FITS IN

As noted above, there are two key CERCLA ecological risk assessments at the Hanford Site. The RCBRA is designed to use the levels residual to cleanup as the baseline for "risk assessment" that is conducted post-interim cleanup action and conforms with the NCP and EPA guidance. Through this approach, DOE has been able to expeditiously achieve reduction in unacceptable risks to health and natural resources.

The 100 Area and 300 Area Component of the RCBRA focuses on the risk from current conditions (post-remediation) in the following:

- The operational areas
- Old townsites (which were used as support areas during early construction activities)
- Riparian areas adjacent to operational areas
- Related groundwater plumes emerging in the near-shore river environment (DOE/RL-2005-37, DOE/RL-2004-37).

1.4 PURPOSE AND SCOPE

The purpose of the 100 Area and 300 Area Component is two-fold:

- Evaluate human health and ecological risks resulting from conditions subsequent to the implementation of the remedial actions in the 100 Area and 300 Area of the Hanford Site
- Use results to support risk management decision making and to support development of final RODs.

The EPA (EPA/540/1-89/002) defines a baseline risk assessment as "*the analysis of the potential adverse health effects (current or future) caused by hazardous substance releases from a site in the absence of any actions to control or mitigate these releases (i.e., under an assumption of no action).*" Although a baseline risk assessment typically implies that no remediation has occurred, the risk evaluation performed for this effort analyzes residual risks, i.e., risks remaining at a site following remediation.

This report provides the methods, data analysis, and results of the human health and ecological risk assessments for the 100 Area and 300 Area Component of the RCBRA. The risk assessment process includes the identification of human health and ecological exposure scenarios for comparison purposes, compilation and collection of data, ecological toxicity testing, data analysis, comparison of contaminant concentrations to applicable ecological benchmarks and human health cleanup levels, and quantification of risk associated with post-remediation contaminant concentrations. Risk management decisions resulting from the risk assessment will be incorporated into the final remedy RODs and used in the decision-making process to remove the 100 Area and 300 Area from the NPL.

Three general exposure areas were identified for investigation: the upland, riparian, and near-shore areas. Soil, sediment, water, and biota were sampled and analyzed to conduct human health and ecological risk assessments for areas that have undergone remedial actions. Contaminant concentrations in abiotic and biotic media were compared to endpoint criteria specified by Washington State regulations, EPA technical guidance, DOE technical guidance, or as supported by the scientific literature.

The geographical boundary of the study area encompasses the remediated 100 Area and 300 Area CERCLA waste sites as well as the interfaces between the upland zone, riparian zone, and near-shore river zone of the Columbia River aligned with the known groundwater plumes in the 100 and 300 Areas. The scope of the 100 Area and 300 Area Component of the RCBRA included riparian and near-shore river zones near the 100-K, 100-D, 100-H, and 100-F Reactor areas; the Hanford Townsite (100-IU-6 OU); the White Bluffs Townsite (100-IU-2 OU); and the 300 Area. Upland areas at the 100-B/C, 100-K, 100-N, 100-D, 100-H, and 100-F Reactor areas; the White Bluffs and Hanford Townsites; and the 300 Area were also included. The upland, riparian, and aquatic zones encompass terrestrial and aquatic investigation areas and are described in more detail below.

- **Upland Sites**: The terrestrial upland zone consists of remediated/backfill sites and remediated/native soil sites. *Remediated/backfill sites* are generally large remediated waste sites in operational areas; their excavations have been backfilled with coarse, cobble soils from the borrow pits. They are comparable to inactive borrow pits in terms of their soil structure and ecology. *Remediated/native soil sites* generally include locations in the former White Bluffs and Hanford Townsites. The ecosystem is more similar to the native shrub steppe. Generally the remedial actions have been small in extent, and most excavations do not require importing backfill from borrow pits. The soils at these waste sites are mostly the original soils from pre-Hanford days, but the vegetation is in varying stages of recovery. These sites, as well as the inland 100 Area and 300 Area groundwater plumes between the reactors (or inland from the 300 Area), were included in this study (Figures 1-1 and 1-3).

- **Riparian Sites**: These sites are generally located along the Columbia River shoreline where affected media (springs, groundwater, or soil) have the potential for exposing receptors to contaminants. Riparian sites were determined from previous radiation surveys, groundwater plume maps, and previous sampling in the riparian and aquatic zones. These locations are ecologically comparable to the riparian corridor upstream of Vernita Bridge.

- **Aquatic Sites**: These sites are in the near-shore aquatic zone in locations where there are seeps or springs (these sites have been subgrouped by substrate class); they have been determined by groundwater plume maps, previous sampling, and conductivity surveys in the river. The aquatic reference sites are located upstream of, or near to, Vernita Bridge.

The study boundary for the near-shore river zone extends to a water depth of 1.8 m (6 ft) below the low-water mark. The low-water mark is identified by a "green line" where periphyton remains green all year long.

Part of the scope of the 100 Area and 300 Area Component of the RCBRA is to integrate data from other Hanford Site risk assessments and environmental data collection efforts. In addition to examining existing cleanup verification data, monitoring data, and data collected specifically for the risk assessment, the 100 Area and 300 Area Component integrated data from the 100-B/C Pilot Project, 100-NR-2 shoreline study, reactor area effluent pipelines, and the Columbia River Component of the RCBRA for a more complete analysis of risks within the River Corridor. The 100-B/C Pilot Project risk assessment (100-B/C Pilot Project), which was initiated in 2001 to evaluate the protectiveness of interim remedial actions in the 100-B/C Area, evaluated the riparian and near-shore river zones, as well as a number of remediated large liquid waste sites in the upland 100-B/C Area. Resultant data were incorporated into the 100 Area and 300 Area Component dataset and reevaluated in the context of new data gathered since the completion of that project. The Columbia River shoreline of the 100-N Area (including riparian zone and near-shore river zone) was evaluated in a separate effort as required by the 100-NR-2 OU ROD (EPA 1999d). Data collected from the 100-N Area shoreline have been integrated into the risk evaluation for the 100 Area and 300 Area Component of the RCBRA. An evaluation of residual risk from the river effluent pipelines that extend from the edge of the reactor areas to the main channel of the Columbia River is also included in this report.

The goal of the RI is to determine the nature and extent of contaminants. This typically involves developing data quality objectives (DQOs), work plans, and field sampling. These steps have been completed for the 100/300 Areas over the past several years. Once the nature and extent of contamination has been determined, the next question is, "do these contaminants create a risk?" To address this question, a risk assessment is conducted to evaluate potential risk to humans and environmental receptors.

The primary use of the risk assessment results, within the RI/FS process, is to determine risk and compare it with relevant standards to determine if a remedial action is warranted. It informs management decisions regarding for which media and to what level a remedy is to be completed.

1. RI Reports – Risk assessments results are used in the RI to determine risk. To determine risk, this risk assessment identifies COPCs, likely exposure scenarios, receptors, exposure pathways, and finally quantifies risk to human health and ecological receptors.

2. FS –The risk assessment results are used to inform the development of remedial action objectives (RAOs) for each affected media (e.g., soil, surface water, or groundwater). The risk assessment results also allow for the technology screening process of the FS to evaluate the effectiveness of remedial technologies to meet cleanup standards.

3. Proposed Plans (PPs) – The risk assessment is summarized in the PP to communicate the basis for the proposed remedy to interested stakeholders.

4. Final RODs – The risk assessment is used within the ROD to support the remedy decision-making process, as developed by the RI, FS, and PP. The basic question addressed in the risk assessment is "will a remedial action be required to address an unacceptable risk posed by site-related COCs?" If the answer to this question is yes, then cleanup levels are determined for each of the COPCs in each environmental media where these chemicals triggered a risk. These cleanup goals are specific numerical concentrations that, once met, the site is determined to be "clean." The ROD documents the appropriate cleanup goals and the final remedy.

1.5 PROJECT BACKGROUND

This section discusses the history of the 100 Area and 300 Area Component and describes the activities performed to plan and support completion of the risk assessment. The groundwork for the 100 Area and 300 Area Component of the RCBRA risk assessment was initiated in the spring of 2003. Work conducted to support the risk assessment effort included defining the basis and assumptions of work scope (DOE/RL-2003-61); development of a work plan (DOE/RL-2004-37); public and stakeholder participation, including the development of several communication plans (e.g., DOE/RL-2003-65, DOE/RL-2003-67); identification of issues through a series of agency and stakeholder interviews, identification of DQOs (BHI-01757); and development and implementation of a sampling and analysis plan (SAP) (DOE/RL-2005-42). These activities have culminated in an extensive set of data and resources used to identify and calculate potential risks to human health and the environment resulting from post-remediation concentrations of Hanford Site contaminants.

1.5.1 EPA Guidance

This section describes how the 100 Area and 300 Area Component of the RCBRA is performed in the context of EPA guidance.

1.5.1.1 Guidance on Baseline Risk Assessment in the CERCLA Process. EPA's *Role of the Baseline Risk Assessment in Superfund Remedy Selection Decisions* (EPA 1991e) acknowledges that early and interim actions may be taken without a complete baseline risk assessment, but that an interim action ROD must be followed by a subsequent ROD on the complete RI/FS, that includes the baseline risk assessment. The preamble to the NCP also acknowledges that "a completed baseline risk assessment generally will not be available or necessary to justify an interim action" (55 *Federal Register* [FR] 8704). EPA's *A Guide to Preparing Superfund Proposed Plans, Records of Decision, and Other Remedy Selection Decision Documents* (EPA 1999a) states that in considering site risks for an interim action: "Qualitative risk information may be presented if quantitative risk information is not yet available. The more specific findings of the baseline risk assessment, and the ultimate clean-up objectives (i.e., acceptable exposure levels) for the site or unit, should be included in the subsequent final action ROD for the operable unit." This concept of performing a baseline risk assessment after completion of some interim actions is reflected in the *100 Area and 300 Area Component of the River Corridor Baseline Risk Assessment: Basis and Assumptions on Project Scope* (DOE/RL-2003-61). This document, which was developed by the Tri-Parties and approved by the DOE Richland Operations Office (RL), also states that the baseline risk assessment will be based on the *current* risk (e.g., post-interim action risk for many waste sites.) The *Basis and Assumptions* document is included in Section C of the Washington Closure Hanford (WCH) prime contract with DOE-RL.

From a regulatory perspective, 40 *Code of Federal Regulations* (CFR) 300.430(d)(4) *requires* development of a baseline risk assessment "to characterize the *current* and potential threats to human health and the environment." (Emphasis added.) A baseline risk assessment is completed after interim actions to demonstrate compliance with 40 CFR 300.430(d)(4) and the guidance.
EPA Region 10's *Supplemental Guidance for Superfund Risk Assessments in Region 10* (EPA 1991, pages 3 and 4) states:

> "Some NPL sites will be managed as multiple operable units, or as projects of several phases, including early or interim actions, rather than a single RI/FS. Appropriate modifications of the risk assessment process to meet the needs of decision-makers will be important to these sites. Instead of a single 'baseline' risk assessment, the risk assessment deliverables might include one or more focused risk assessments addressing a single source area or medium. The focused risk assessment would be used to justify a specific action. This is consistent with RAGS HHEM [Risk Assessment Guidance for Superfund human health exposure model], Section 3.3. This type of approach is also discussed in the guidance for CERCLA Municipal Landfills (EPA 1991a), on pages 3-39 and 3-40:
>
> 'It may be possible to streamline or limit the scope of the baseline risk assessment in order to initiate remedial action on the most obvious landfill problems . . . Ultimately, it will be necessary to demonstrate that the final remedy, once implemented, will address all pathways and contaminants of concern, not just those that triggered the need for remedial action.'
>
> Sites where early action or OU actions had been taken based on focused risk assessment or other criteria would later require a comprehensive risk assessment, considering all sources, pathways, and contaminants, to justify final actions or 'no further action' decisions. At a partially remediated site, the risk assessment would evaluate the site in its present physical condition. The RPM [remedial project manager] and risks assessor would decide how to factor ongoing actions into the risk assessment."

In summary:

- EPA guidance is clear that interim action can occur without a complete baseline risk assessment and that, in such cases, a completed baseline risk assessment will be needed post-interim action to support development of a final ROD.
- A baseline risk assessment is required by regulation at 40 CFR 300.430. This assessment is to characterize the *current* and potential threats.

- Region 10 guidance acknowledges that focused risk assessments may be used in lieu of a single baseline risk assessment to support interim or early actions, to be followed by a comprehensive risk assessment to justify final action decisions. For partially remediated sites, this latter risk assessment evaluates the site in its present physical condition.

1.5.1.2 EPA Guidance on Identifying Reference Sites. EPA's *ECO Update*, "Selecting and Using Reference Information in Superfund Ecological Risk Assessments" (EPA/540-F-94-050), states that, ideally, on-site reference samples are collected from unaffected portions of contaminated habitats. More commonly, on-site samples are taken along a gradient from lowest to highest contaminant concentration. The area of lowest impact or lowest measured concentration is the "reference" target for the site. This approach can be necessitated when a suitable reference location cannot be found. The guidance also discusses the guideline to select sites that match the Superfund site in all aspects except contamination. Characteristics to be considered include physical characteristics, climatic characteristics, and biological characteristics (see pages 3 through 5 of EPA/540-F-94-050).

Similar language appears in EPA's *ECO Update*, "Field Studies for Ecological Risk Assessment" (EPA/540-F-94-014), which again states that the reference site should be as close as possible to the Superfund site so it will accurately reflect conditions at the site. It also acknowledges that in some cases no single reference site adequately approximates the Superfund site (in which case multiple reference sites may be needed), and that in some instances there may be no suitable reference sites. See additional "Reference Site" discussion in Section 4.0.

1.5.2 Land Use

Section 3153 of the *National Defense Authorization Act for Fiscal Year 1997* required DOE to develop a future land use plan for the Hanford Site. This plan was formally developed using NEPA and is documented in the *Final Hanford Comprehensive Land-Use Plan Environmental Impact Statement* (DOE/EIS-0222-F) and associated NEPA ROD published in the Federal Register on November 12, 1999 (64 FR 61615). As required by NEPA, development of the Hanford CLUP included an extensive public participation effort involving the general public as well as nine cooperating agencies (including local city and county planning entities) and consulting Tribal governments. The 1992 report *The Future for Hanford: Uses and Cleanup – The Final Report of the Hanford Future Site Uses Working Group* (Drummond 1992) was submitted to DOE as a formal scoping document for the land-use planning effort; additional input was supplied from (among other stakeholder groups) the Hanford Tank Waste Task Force and the Hanford Advisory Board. Over 400 comment documents were received by DOE on the revised draft of the land-use planning document, along with over 200 pages of transcripts resulting from four public hearings.

In developing the land-use plan, DOE took into account its role as the long-term caretaker for the Hanford Site for at least the next 50 years rather than a 20-year development plans frequently used by local community planning authorities (e.g., land-use planning under Washington's "Growth Management Act" [*Revised Code of Washington* 36.70A]).

The CLUP designations within the Columbia River Corridor (the area adjacent to the Columbia River that includes the reactor areas) includes high-intensity recreation, low-intensity recreation, conservation (mining), and preservation land-use designations. The "100 Area" addressed by this risk assessment is generally within the Columbia River Corridor. The river islands and a 0.4-km (0.25-mi) buffer zone adjacent to the Columbia River is designated as preservation land use to protect cultural and ecological resources.

Four sites away from existing contamination are designated high-intensity recreation to support visitor-serving activities and facilities development. These include B Reactor (considered for a museum with the surrounding area available for museum-support facilities), a high-intensity recreation area near Vernita Bridge (where the current Washington State rest stop is located) to be expanded across State Highway 240 and to the south to include a boat ramp and other visitor facilities, and two areas on the Wahluke Slope designated as high-intensity recreation for potential exclusive tribal fishing.

The CLUP indicates that six areas will be designated for low-intensity recreation. The area west of the B Reactor would be used as a corridor between the high-intensity recreation areas associated with the B Reactor and the Vernita Bridge rest stop and boat ramp. A second area near the D/DR Reactors site would be used for visitor services along a proposed recreational trail. The third and fourth areas, the White Bluffs boat launch and its counterpart on the Wahluke Slope, are located between the H and F Reactors and would be used for primitive boat launch facilities. A fifth area, near the old Hanford High School, would accommodate visitor facilities and access to the former town site and provide visitor services for hiking and biking trails that could be developed along the Hanford Reach. A sixth site, just north of Energy Northwest, would also provide visitor services for recreational trails (e.g., hiking and biking) along the Hanford Reach. On the Wahluke Slope side of the Columbia River, the White Bluffs boat launch would remain managed as is, with a low-intensity recreation designation. A low-intensity recreation designation for the water surface of the Columbia River would be consistent with current management practices and the wishes of many stakeholders in the region.

The remainder of land within the Columbia River Corridor outside the 0.4-km (0.25-mi) buffer zone is designated for conservation (mining). Mining would be permitted only in support of governmental missions or to further the biological function of wetlands (i.e., conversion of a gravel pit to a wetland by excavating to groundwater). A conservation (mining) designation allows DOE to provide protection to sensitive cultural and biological resource areas, while allowing access to geologic resources. Activities that use or affect groundwater are restricted.

The CLUP designates an area north of the City of Richland (including most of the 300 Area evaluated in this risk assessment) for industrial use to support new DOE missions or economic development.

In addition, on June 9, 2000, Presidential Proclamation 7319 was signed, creating the Hanford Reach National Monument (65 FR 37253). The Hanford Reach National Monument consists of an 82.1 km (51-mi)-long unimpounded stretch of the Columbia River and federally owned land on either side of the river with an average width of 402 m (1,320 ft). The Monument encompasses approximately 793 km^2 (306 mi^2) of lands already owned by the federal government that had previously been designated for preservation or conservation under the CLUP (DOE/EIS-0222-F). To support continued protection of natural and cultural resources, the proclamation stated that the Monument would not be developed for residential or commercial use in the future (65 FR 37253). As of May 2007, no changes have occurred with respect to land uses since the monument designation.

1.5.3 Development of Risk Assessment and Related Activities in the Hanford CERCLA Process

While risk assessments have been conducted for many years at the Hanford Site for a variety of projects, the HSRAM (DOE/RL-91-45) was developed to prepare human health and ecological evaluations of risk to support the CERLCA and RCRA process at the Hanford Site. Technical representatives from DOE, Ecology, EPA, and their respective contractors participated in an Inter-Agency Working Group for Risk Assessment to provide input into the development of the HSRAM. The methodologies presented in the HSRAM addressed both baseline and qualitative risk assessments, and served as the basis for the development of the specific requirements of the RCBRA.

While the NCP calls for a site-specific baseline risk assessment (40 CFR 300.430(d)(4)) to serve as a basis for determining whether or not a remedial action is necessary at a site (55 FR 46, p. 8709), the Tri-Party's HPPS (DOE/RL-91-40) called for qualitative risk assessments (QRA) to provide the characterization of site risk that Tri-Parties will evaluate to determine whether an interim action is appropriate. A QRA is defined in the HPPS as "a judgment not based solely on quantification, agreed to by the parties, based on available site data regarding the threat posed by site contamination." Per the HSRAM, "Qualitative risk assessments were not intended to replace the need for a baseline risk assessment…" The HSRAM also states that "These applications are consistent with recent guidance on the *Role of the Baseline Risk Assessment in Superfund Remedy Selection Decisions* (EPA OWSER Directive 9355.0-30, 1991)."

Now that many remedial actions performed under the Interim Action RODs have been completed, efforts are being made to arrive at final RODs, and a critical step in developing the final RODs is a baseline risk assessment. The RCBRA, along with its three components, is that baseline risk assessment. The components of the RCBRA are as follows:

- *The 100 Area and 300 Area Component Baseline Risk Assessment*, which focuses on the risk from current conditions (post-remediation) in the operational areas and old townsites (which were used as support areas during early construction activities), along with the adjacent riparian areas and related groundwater plumes emerging in the near-shore river environment (see DOE/RL-2005-37 and DOE/RL-2004-37)

- *The Inter-Areas Component Baseline Risk Assessment*, which evaluates risk from current concentrations of contaminants between the operational areas, especially in the sediment depositional areas (see Appendix E of DOE/RL-2005-42)

- *The Columbia River Component Evaluation*, which addresses any additional contaminants that may reside elsewhere in the Hanford Reach and downstream. The geographic scope of the Columbia River Component is currently in development.

Other CERCLA risk assessments, such as for the Central Plateau and groundwater OUs, are in various stages of preparation. As data and methodologies are developed for each assessment, they are being shared and used by other assessments as appropriate. The geographic scope, media, and methodologies for each of these assessments are included in the appendices of DOE/RL-2005-37.

Another site-wide evaluation is being performed by the DOE and Natural Resource Trustees under the natural resource damage assessment (NRDA) process per 43 CFR 11.23(f)(4). The parties will develop a phased assessment process that is being informed by ongoing CERCLA activities and the data collected by the RCBRA work.

Finally, other projects such the Sitewide Monitoring Program and the Orphan Sites program are filling in the gaps between the risk assessment study boundaries. A decades-long monitoring program has been managed by the Pacific Northwest National Laboratory (PNNL) to evaluate areas that are not addressed by focused, specific projects and can be used to locate unknown waste sites (e.g., PNNL-15892). The Orphan Sites program is designed to discover any previously unsuspected waste sites through an extensive historical document review and field walkdowns and flyovers of the lands between known waste sites and between operational areas.

1.5.4 Summary of Planning Documentation for the 100 Area and 300 Area Component

1.5.4.1 Risk Assessment Work Plan. The *Risk Assessment Work Plan for the 100 Area and 300 Area Component of the RCBRA* (DOE/RL-2004-37) was the first significant planning document in the development of this risk assessment. The risk assessment work plan described the site background and setting, defined the strategy and approach for conducting the risk assessment in accordance with human health and ecological risk assessment guidance, identified the environmental standards of protectiveness to be followed or considered during the assessment process, discussed the relevant requirements for data quality, and established a preliminary schedule for the performance of work. Preliminary human and ecological exposure scenarios were also presented in the risk assessment work plan as a basis for discussion for the DQO process.

1.5.4.2 Data Quality Objectives. The DQO process is a strategic planning approach for defining the criteria that a data collection design should satisfy, including when to collect samples, the tolerable level of decision errors for the study, and how many samples to collect. The DQO process for the 100 Area and 300 Area Component was performed during 2003 and 2004 to establish consensus on endpoints and data collection protocols. The DQOs developed for the 100 Area and 300 Area Component are documented in *DQO Summary Report for the 100 Area and 300 Area Component of the RCBRA* (hereafter referred to as the DQO Summary Report) (BHI-01757). The DQO approach used for the ecological component of the risk assessment followed Steps 1 through 4 of *Ecological Risk Assessment Guidance for Superfund:*

Process for Designing and Conducting Ecological Risk Assessments (Interim Final) (ERAGS) (EPA/540/R-97/006) (Figure 1-4). These components of the ERAGS approach satisfy equivalent needs of EPA's traditional DQO approach with respect to ecological risk.

The DQO process for the 100 Area and 300 Area Component was initiated by conducting interviews to identify specific issues and concerns related to potential human and ecological risks associated with contaminant releases from the Hanford Site. The project team conducted interviews with the Tri-Parties (i.e., EPA, Ecology, and DOE), Natural Resource Trustee Council representatives, Hanford Advisory Board members, and Tribal representatives. The interview issues and Tri-Party decision-maker responses and positions were tabulated in an issues matrix table that was used to focus the scope of the DQOs for the risk assessment. The issues matrix table is presented in Appendix B, Table B-1, of the DQO Summary Report (BHI-01757).

In addition to interviews, a series of workshops were held to present and receive feedback for proposed data collection.[1] Risk questions were presented and assessment approaches were strategized to satisfy these questions. The DQO Summary Report (BHI-01757) identified the data needed to characterize potential ecological risks from residual contamination at remediated waste sites in the 100 Area and 300 Area. Sampling and other field activities planned as part of the baseline risk assessment to fill analytical data needs for specific abiotic or biotic media (i.e., soil, sediment, surface water, groundwater, and biota) or constituents (e.g., chemicals, radionuclides, polychlorinated biphenyls [PCBs]) were addressed in the DQO process. Several data needs were defined as a result of the DQO process, including collection of supplemental data to characterize exposure pathways, support site-specific exposure and risk calculations, or serve as post-remediation baseline monitoring data.

The DQO process included problem formulation, which described the environmental setting and fate and transport mechanisms, identified exposure pathways, and identified screening levels for media of concern. A screening-level assessment was also performed by comparing available data from cleanup verification and environmental monitoring to conservative ecological screening benchmarks and human health cleanup levels. Media evaluated in the screening-level assessment included soil, sediment, groundwater, surface water, and aquifer tube water. The data were assessed with regard to detection frequency, relation to Hanford Site background concentrations (for available analytes), and exceedance of applicable media-based thresholds or screening values.

In the initial screening-level evaluation (Appendix C of BHI-01757), abiotic data were evaluated from 10 locations: 100-B/C, 100-K, 100-N, 100-D, 100-H, 100-F, 300 Area, 600 Area, Hanford Townsite, and White Bluffs Townsite. Environmental media included shallow zone soil (collected for cleanup verification at remediated waste sites, generally from a depth ranging from 0 to 4.6 m [0 to 15 ft] bgs), sediment, surface water, groundwater, seep, and aquifer tube water. Existing data from soil collected from depths greater than 4.6 m (15 ft) bgs (i.e., deep zone soil)

[1] Notes from the DQO workshops and presentation materials are available in the End States and Final Closure Project Library at URL: http://www.washingtonclosure.com/Projects/EndState/http://www.washingtonclosure.com/Projects/EndState/100-300_comp.html

also were obtained and compared to soil cleanup levels established for protection of groundwater.

Groundwater, seep, and aquifer tube data (also known as pore water) were evaluated because these waters have the potential to discharge to surface waters (i.e., the Columbia River), resulting in potential exposure to aquatic and human receptors. Entities in the 100 Area and 300 Area that were considered in the screening-level evaluation included soil biota communities, soil invertebrates, and soil microbial function (for nonradionuclides); plant and terrestrial wildlife communities (for radiological and nonradiological analytes); and aquatic and sediment biota communities (for radionuclides and nonradiological analytes). Potential ecological risks were evaluated based on conservative assumptions, utilizing the maximum media concentration. Human health risk estimates were based on 95% upper confidence level (95% UCL) of the mean concentrations.

The results of the screening-level evaluation identified analytical data gaps and helped prioritize resources for further assessment on those media and entities that may be adversely affected by Hanford Site contamination. Risk hypotheses were developed as part of the DQO process (BHI-01757) to address screening data gaps and form the basis for identifying contaminant suites and the selection of assessment endpoints and associated measures. Analytical suites identified for follow-up investigation and sample collection as a result of the screening evaluation included metals, radionuclides, PCBs, pesticides, and semivolatile organic compounds (SVOCs).

The result of the DQO process was a consensus path forward for data collection which was documented in the DQO Summary Report (BHI-01757), and formalized in a Tri-Party-approved SAP (DOE/RL-2005-42). Appendix E in Revision 1 of the SAP (DOE/RL-2005-42) describes the DQOs for the Inter-Areas shoreline assessment. The purpose of the Inter-Areas shoreline assessment is to collect data not obtained in previous sampling efforts (e.g., amphibian tissue) and to target locations where exposure information was not previously available (e.g., shorelines between operational areas, sloughs). Data collected for the Inter-Areas shoreline assessment are considered supplemental to the 100 Area and 300 Area Component of the RCBRA.

1.5.4.3 Sampling and Analysis Plan. The *Sampling and Analysis Plan for the 100 Area and 300 Area Component of the RCBRA* (DOE/RL-2005-42) presented the rationale and strategy for sampling and analysis activities for the 100 Area and 300 Area Component of the RCBRA. The SAP provided background information about the project, discussed previous sampling within the River Corridor, listed the contaminant suites to be analyzed, and summarized the DQOs and risk questions. The SAP also presented the Quality Assurance Project Plan (QAPP), which described the field work and data management quality assurance (QA) requirements. The field sampling plan provided the field sampling details and supporting logic. Health and safety considerations were also discussed.

The study design was intended to satisfy data needs required to test risk hypotheses posed during the DQO process. The data collection strategy presented in the SAP included the sampling of abiotic (soil, sediment, water) and biotic (plant and animal) media representative of Hanford Site exposure media and receptors. Toxicity testing of soil, water, and sediment was also proposed in the study design.

Chemical analyses of the various media types were based on the analytical suites identified during the DQO process. Contaminant suites were developed from an assessment of historic data collected over 10 locations: 100-B/C Area, 100-K Area, 100-N Area, 100-D Area, 100-H Area, 100-F Area, 300 Area, 600 Area, Hanford Townsite, and White Bluffs Townsite. Suites of analytes were identified for additional investigation based on the screening-level risk characterization presented in Appendix C of the DQO Summary Report (BHI-01757) and input received during the DQO process. Analytical suites include metals; alpha-, beta-, and gamma-emitting radionuclides; PCBs and pesticides; and SVOCs.

Sample collection rationale and techniques varied by area and media. Investigation areas characterized by data collected under the SAP included the upland, riparian, and near-shore river zones. Sites selected for sampling were identified based on existing data demonstrating a range of contaminant concentrations. Reference sites were identified using evidence/knowledge of areas not affected by contaminant release and selected based on physical/ecological similarity to on-site investigation areas.

Media collected in the upland and riparian zones included soil, vegetation, invertebrates, small mammals, and kingbirds (kingbirds in riparian zone only). Near-shore media included sediment, interstitial pore water, surface water, benthic macroinvertebrates, clams, and sculpin. Toxicity testing was performed on soil, sediment, and water to provide Hanford Site-specific information on the ecological effects of contaminant mixtures and contaminant bioavailability. The results of these tests are used to make informed inferences on the toxicity of contaminants to Hanford Site biota.

The terrestrial investigation areas were approximately 1 hectare (ha) in area because this is an ecologically relevant area for estimating the average exposure to wildlife organisms and populations (DOE/RL-2005-42). The goal of sampling was to estimate the average concentrations of contaminants, thus exposure, across the investigation area. The geometry of each investigation area varied to accommodate site-specific conditions, although upland investigation areas were roughly square or rectangular, and riparian investigations were long and narrow to accommodate the geometry of the shoreline embankment and the Columbia River shoreline.

A brief summary of the field sampling carried out in accordance with the SAP, including the media collected, sample collection techniques, and specific investigations for the upland, riparian, and near-shore investigation areas, is provided in Section 1.2.4, "Field Sampling."

1.5.4.4 Agency, Stakeholder, and Public Participation in the Risk Assessment. Throughout the risk assessment planning and implementation stages, a number of workshops were held to encourage participation of interested parties, including state and Federal agencies, natural resource trustees, site contractors, and the public. These workshops served as important forums for soliciting input and feedback for project objectives, study design, and resource protection. Meeting notes from the DQO and SAP workshops are provided on the WCH End States and Final Closure project library web site:
http://www.washingtonclosure.com/Projects/EndState/100-300_comp.html.

During the implementation of the risk assessment, several workshops were held to discuss the progress of the risk assessment, including discussion of sampling results and preliminary analyses, improvement of study design, and to solicit feedback on risk approaches.

1.5.5 Field Sampling for the 100 Area and 300 Area Component

Field sampling of soil, sediment, surface water, pore water, groundwater (well water), and biota was conducted for the 100 Area and 300 Area Component between October 2005 and December 2006. Forty-five upland and riparian sites were staked with metal fence posts; the upland sites were staked at each corner and center, and the riparian sites were staked at each end and center point. Maps showing the locations of these areas are provided in Appendix A. Analytical results for the sampling effort are provided in an online data repository (see Appendix B for the on-line database interface user's manual) and summarized in two data summary reports that are available on the project website (WCH-85, WCH-139). Environmental dosimeters were placed at each stake and remained in place for 6 months. The upland sites were placed with the intent to maximize both relative homogeneity of habitat and regularity of shape (as square or rectangular as possible) to ease the planning, collection, and reporting of multi-increment sampling (MIS) results and subsequent biota sampling (the MIS study design is described in Section 1.2.5.1). For those riparian sites where MIS was to be performed in the fall, pin flags were placed at the upper and lower edges of the riparian zone to help delineate the borders. Soil texture at each site was described using ASTM D2488–00, *Standard Practice for Description and Identification of Soils (Visual – Manual Procedure).*

Sample grids were laid out for both the upland and riparian investigation areas. The approximately 1-ha upland study areas were designed to evaluate waste sites that were remediated and verified as clean through the CVP process. The 200-m (656-ft)-long riparian study areas were designed to evaluate the locations where the known 100 Area and 300 Area plumes emerged into the riverine environment.

For the upland study sites, two types of remediated waste sites were evaluated: (1) those that had a significant amount of material removed, and then the site backfilled with off-site material ("backfill sites"), and (2) sites with minimal excavation and material removal, little vegetation disturbance, and little or no backfill material brought in and used ("native soil sites").

Most of the original backfilled waste sites were larger than 1 ha and had backfill that was at least 4.6 m (15 ft) deep. For the RCBRA assessment, the desire was to evaluate residual contamination so the actual backfill, trucked in from clean, off-site sources, was deemed to not be suitable for sampling. The edge of the former excavation hole is where any residual contamination was expected to reside, so the study sites were designed to:

- Maximize the exposure to the edges of the excavation (be longer than wide, to follow along the edge of the waste site)
- Be as evenly rectangular as possible to simplify and standardize the soil, plant, and animal collection

- Lay slightly over the backfill, to capture any plant roots or animal burrows that reach down several feet to the upper edge of the now-buried former excavation side-slope
- Be wide enough to minimize the influence of outside mice and insects migrating in from outside the study plot
- Have enough years since remediation so that vegetation would have had time to establish over the entire study site, grow deeper roots, and support mouse and insect populations.

This study design is sometimes referred to as a "bathtub ring," even if most of these designs are rectangular and not circles.

For the native soil sites there was rarely any outside backfill material used and the vegetation was minimally disturbed during remediation, so the study plots were shaped and placed to maximize exposure to the original waste site. In most of the native soil locations, the original waste was more diffuse over a large area, with a consistent habitat all over the site, so the 1-ha size was maintained. In some cases (e.g., the J.A. Jones site) the waste was more discrete, and the habitat and remaining soils at the former location of the waste were significantly different from the surrounding area. So, to minimize "dilution" and mixing different species of plants and animals, the study plot was reduced from the 1 ha to match the size of the study site.

The riparian sites are not regular in shape because they follow the riparian zone, as defined by the types of vegetation along the edge of the river that influenced by the shallow groundwater. Typical riparian vegetation species are reed canary grass and mulberry trees. To make these sites as consistent as possible, all riparian study sites are 200 m (219 yd) long and parallel with the river. The width varies at each site, and follows the zone of riparian vegetation – narrow at steeper sites, wider at low, flatter sites.

Soil and biota were collected at the 20 on-site upland and 10 on-site riparian locations. Ten upland reference site locations and five riparian reference locations were also evaluated. Surface soil samples were collected in on-site and reference upland and riparian locations using the MIS technique. Soil samples were analyzed for metals, PCBs, organochlorine pesticides, SVOCs, polycyclic aromatic hydrocarbons (PAHs), and radionuclides. Supporting measurements (e.g., soil nutrients, pH, total organic carbon, and particle size) were also collected to aid in interpretation of bioassays and bioaccumulation. Vegetation surveys were performed in the upland and riparian areas to evaluate relative abundance, diversity, and measures of habitat quality.

Biota collected in the upland and riparian zones included vegetation, ground-dwelling invertebrates, and small mammals. Each biotic receptor was analyzed for tissue concentrations of contaminants. Small mammals were examined for histopathological abnormalities. Nesting surveys were also performed in riparian investigation areas to evaluate the relative abundance and reproductive success of kingbirds. In addition to the avian surveys, fledgling kingbirds were sacrificed for contaminant analysis of crop contents and body burdens.

Thirty-seven aquatic sites were selected based on the known uranium, chromium, and strontium-90 groundwater plumes; results of the 2005 conductivity survey; and past biota sampling locations and results. The sampling sites were located throughout the 300 Area (for uranium plume), 100-D and 100-K Areas (for chromium plumes), and 100-N Area (for strontium plume) to capture a range of conditions. Federal and state threatened, endangered, and rare riparian and near-shore aquatic plant species were surveyed during October 2005 while the river flows were low (WCH-85). At each of the near-shore sites (including ten 100-NR-2 sampling locations), horizontal pore water sampling tubes were placed 10 to 15 cm (4 to 6 in.) below the riverbed and allowed to equilibrate with ambient conditions at least a week before sampling began. Sediment and biota were also collected at each location.

In addition to abiotic media, biota were collected for histopathological and/or contaminant analysis at multiple investigation areas. Aquatic site setup spanned from November through December 2005 with the placement of Asiatic clam tubes and artificial substrate (macroinvertebrate) baskets. The Asiatic clams were collected from 3 locations below Priest Rapids dam and inserted in 6 mesh tubes (25 per tube) that were placed at each of 27 aquatic sites. Clam tubes were not placed at the 100-N Area because the 100-NR-2 risk evaluation collected the river biota during 2005. Each clam was examined and measured; only live clams from 15 mm to 22 mm were used in the tubes. The tubes remained in place for at least 6 months. Six artificial substrate baskets were also placed at each of 27 aquatic sites and left for at least 6 months to allow colonization by macroinvertebrates. Gravel in the 45 mm to 60 mm size range was placed in each basket. As with the clam tubes, the macroinvertebrate baskets were not placed at the 100-N Area because the 100-NR-2 risk evaluation collected the river biota during 2005.

Other biota targeted in the field sampling effort included sculpin and amphibians. Sculpin were collected and their tissues analyzed to model contaminant exposure to piscivores and to estimate exposure to humans through consumption. The use of fish from near-shore areas provides an upper bound exposure scenario for deeper water fish, which are more typically consumed by humans and have less exposure to Hanford Site contaminants, due to their limited residence time in the Hanford Reach. Whole-body sculpin were analyzed for inorganic, organic, radionuclide, PCB, and pesticide contaminant suites. Sculpin liver/kidney were analyzed for metals only. Sculpin whole-body and tissues were also assessed for biological condition and histopathology to identify any abnormalities from suspected toxicity. Tissues of interest in the histopathological investigation included kidney, liver, gills, bone, and muscle. Histopathological interpretation of the tissues of interest was performed by a professional histologist. Results were reported numerically, from a rating of 1 to 4 as follows: (1) indicating essentially normal tissue; (2) indicating a condition that was slightly less healthy than normal tissue; (3) high, indicating a pathological condition indicating disease or poor water quality conditions, but likely a recoverable condition; and (4) very high, indicating a distinctly pathological condition indicating that tissues is not likely to be unable to recover. Sculpin collection was focused in areas of known emergent chromium-, strontium-, and uranium-containing groundwater plumes in the near-shore.

Juvenile amphibians (tadpoles) were also targeted for metals analysis. Near-shore sampling locations were assessed for the presence of amphibians, including the bullfrog, Great Basin spadefoot, and Woodhouse's toad. Tadpoles were not encountered at the proper time for sampling and thus were not collected for analysis.

1.5.5.1 Fall 2005 Sample Collection. Sample collection for the 100 Area and 300 Area Component of the RCBRA investigation during the fall of 2005 consisted of the collection of soil and groundwater. Soil sampling began on October 26, 2005, and was completed on November 29, 2005. Groundwater sampling was conducted between October 13, 2005 and December 29, 2005. Further details describing the sampling effort are provided below. Raw analytical results from the fall 2005 sampling event are provided in the project-specific database.

Multi-Increment Sampling. MIS is a sampling methodology used to estimate the true average concentrations of constituents in an investigation area. The technique employed involves collection of approximately 50 equally sized increments (aliquots) that are combined and analyzed as a single sample. The study design for MIS sampling is documented in the SAP (DOE/RL-2005-42). The 100 Area and 300 Area Component of the RCBRA used MIS to evaluate contaminant concentrations in the soil fraction less than 2 mm in size, consistent with the "Model Toxics Control Act Cleanup Regulation" (*Washington Administrative Code* [WAC] 173-340). Each representative investigation area was evaluated by collecting five multi-increment samples. During the fall sampling event, a total of 55 MIS soil samples were collected, including 18 riparian soil samples and 37 upland samples. An additional 18 discrete soil samples were collected from the riparian zone to characterize COPCs in potential threatened and endangered plant species habitat. The results of the analyses were evaluated through a performance assessment to determine the number samples collected using the MIS method that are required to obtain accurate results among samples within a site. The MIS performance assessment is discussed in Section 1.2.6, and the complete report is provided in Appendix C of this report.

Laboratory subsampling of each MIS sample was performed to obtain the analytical soil sample. Samples were sent to the CH2M HILL Analytical Services Laboratory in Corvallis, Oregon for preparation to be sent to Lionville Laboratory, Inc. in Exton, Pennsylvania (chemical constituents) or Eberline Services in Richmond, California (radiological constituents). Samples had an approximate 45-day turnaround time. Samples for toxicity bioassays were sent to CH2M HILL Analytical Services Laboratory in Corvallis, Oregon using bioassays for Sandberg bluegrass (*Poa secunda*), nematode (*Poa secunda*), nematode (*Caenorhabditis elegans*), pak choi (*Brassica chinensis*), amphipod (*Hyalella azteca*), and water flea (*Ceriodaphnia dubia*). Additional toxicity bioassays were sent to Fort Environmental, Oklahoma, for Frog Embryo Teratogenesis Assay – *Xenopus* (FETAX) testing. A more detailed summary describing the MIS field collection and laboratory sampling is found in Appendix B of the field sampling summary report (WCH-85).

Groundwater. Groundwater monitoring is currently being managed by Fluor Hanford, Inc. and performed by Energy Solutions, Inc. (eSolutions). Samples were collected per eSolutions Technical Services Procedure Number SP3-1, "Groundwater Sampling" (DTS-SSPM-001).

WCH has been able to join this work and collect additional samples for the risk assessment at the same time the monitoring samples are being collected. The appropriate sampling method and type of pump depended on whether the borehole to be sampled was a well or a piezometer. Depth to water was measured in accordance with SP3-1, "Groundwater Sampling," to the nearest 1 mm for metric tapes, on the groundwater sample report, in the field logbook, and on the groundwater measurement form. Drawdown was determined and, after removing the water level tape from the well, a sheen or oil product was checked for while cleaning the tape. After calculating purge time and allowing the readings to stabilize, pH, conductivity, and temperature were recorded at least three times (start, middle, and end of designated purge time).

Sample containers were filled in the following order unless otherwise specified: total organic halogens, total organic carbon, SVOCs, other unfiltered samples, and filtered samples. The sample bottles were slowly filled by placing the inner side of the sample bottle near the sampling manifold drop leg to prevent trapping any air bubbles. Splashing or agitating the water while the bottle is being filled was avoided. The outside of the container was wiped clean of any dirt, grime, or liquid after sample was placed in the sample container. If required, the samples were placed into a cooler with ice. Once the samples were collected, they were brought back to the shipping facility (3728 Building) where they were stored in a refrigerator at 4 °C and prepared for shipment.

Groundwater samples were sent to Lionville Laboratory, Inc. in Exton, Pennsylvania (chemical constituents), Eberline Services in Richmond, California (radiological constituents), and Severn Trent Laboratories, Inc. in Richland, Washington (Cr-VI). A total of 92 groundwater well samples were collected between October 2005 and February 2006.

1.5.5.2 Spring/Summer 2006 Sample Collection. The remaining 36 MIS sites were sampled between January and August 2006. Spring MIS sampling continued with five samples collected at each investigation area. A total of 228 soil samples were collected during spring 2006, including 84 riparian soil samples and 144 upland soil samples. The remaining 32 groundwater monitoring wells were also sampled in summer 2006, by the same methods as described above. A total of 60 individual groundwater well samples were collected between March and June 2006. The spring/summer 2006 sample results are provided in the project on-line database and further details describing the sampling effort are provided below.

Sampling was completed for pore water, surface water, sediment, and biota. Specific sample matrices included fish and small mammal (mice) tissue, upland invertebrates, discrete soil samples associated with endangered or threatened plant species locations, plant tissue, aquatic macroinvertebrates, bivalves (clams), and kingbird crops. The schedule of sample collection is provided in Table 1-1. Samples were sent to Lionville Laboratory, Inc. in Exton, Pennsylvania (chemical constituents), or Eberline Services in Richmond, California (radiological constituents).

1.5.6 Multi-increment Sampling Performance Assessment

MIS was employed to determine the average concentration of contaminants across areas investigated in the 100 Area and 300 Area Component of the RCBRA. A performance assessment was completed for the fall sampling event to provide information on the variability of soil results and to address regulator concerns on the procedure. The fall sampling event, which assessed soil at 20% of the investigation areas, representing all nine environment and site type combinations (DOE/RL-2005-42), was conducted as a performance assessment. The purpose of the performance assessment was to provide information on the "between-sample" and "between investigation-area" variability in contaminant concentrations. The MIS methodology uses approximately 50 increments of soil, one from each section of the grid established over the study area, to comprise one sample per investigation area. Five total MIS were collected from each upland (approximately 1 ha) and riparian investigation area (200 m long of variable width). Each soil increment was collected from the 0- to 15-cm (0- to 6-in.) depth. The soil was sieved to remove any particles and organic materials larger than 2 mm. Root and biological masses were separated during the sieving process after capturing the attached soil. To facilitate the sieving process, a stiff nylon bristle brush was used. The results of the performance assessment were used to evaluate the adequacy of the number of samples and increments per investigation area.

Data analysis followed Figure 2-2 of DOE/RL-2005-42. The first step in the assessment was to determine if the indicator contaminants in Tables 1-1 and 1-2 of DOE/RL-2005-42 were detected. Detected indicator contaminants were then evaluated to determine if they were present at levels greater than practical quantitation limits (PQLs) or Hanford Site background. Contaminants that were not detected, and contaminants with concentrations less than quantitation limits or Hanford Site background, did not warrant further consideration in the statistical design. Contaminants that exceeded these criteria were retained for evaluation against cleanup levels. As a result of the performance assessment, five indicator contaminants were retained for further evaluation. These included arsenic, hexavalent chromium, lead, benzo(a)pyrene, and uranium-233/234.

The statistical performance of sampling design options for these contaminants was assessed using Visual Sampling Plan Version 4.0a. For arsenic, benzo(a)pyrene, and uranium-233/234, the minimum recommended number of MIS samples was two. For hexavalent chromium and lead, the minimum record number of samples was greater than three. As a result of site heterogeneity and comments from the regulatory agencies, however, it was agreed that the spring 2006 sampling campaign would continue with of the collection of five multi-increment samples from each location.

The summary and results of the performance assessment is presented in Appendix C of this document.

1.6 SUMMARY OF HUMAN HEALTH AND ECOLOGICAL RISK ASSESSMENT APPROACH

1.6.1 Human Health Risk Assessment Approach

This section provides an overview of the approach for the 100 Area and 300 Area Component of the RCBRA human health risk assessment, which was refined during a series of workshops (see Appendix D for the meeting notes and the project web site for presentation materials).

Human health risk assessment guidance documents applicable to the human health risk assessment are identified below. A general description of the criteria for the identification of COPCs is also provided.

1.6.1.1 Human Health Risk Assessment Guidance and Compliance. The technical approach used for the human health risk assessment and sources of values for exposure and toxicity parameters were consistent with those described in EPA sources, including the following:

- *Risk Assessment Guidance for Superfund (RAGS) – Volume I: Human Health Evaluation Manual, Part A (Interim Final)* (EPA/540/1-89/001 [EPA 1989])
- *Risk Assessment Guidance for Superfund (RAGS) – Volume I: Human Health Evaluation Manual, Part A* (EPA/540/1-89/002)
- *Risk Assessment Guidance for Superfund Volume I: Human Health Evaluation Manual, Supplemental Guidance Standard Default Exposure Factors* (EPA 1991d)
- Science Policy Council *Guidance for Risk Characterization* (EPA 1995b)
- *Soil Screening Guidance: User's Guide* (EPA/540/R-96/018)
- *Soil Screening Guidance: Technical Background Document* (EPA/540/R-95/128)
- *Soil Screening Guidance for Radionuclides: Technical Background Document* (EPA/540-00-006)
- *Soil Screening Guidance for Radionuclides: User's Guide* (EPA/540/R-00/007)
- *Exposure Factors Handbook, Volume I: General Factors* (EPA/600/P-95/002Fa)
- *Exposure Factors Handbook, Volume II – Food Ingestion Factors* (EPA/600/P-95/002Fb)
- *Exposure Factors Handbook, Volume III – Activity Factors* (EPA/600/P-95/002Fc)
- *Risk Assessment Guidance for Superfund Volume I: Human Health Evaluation Manual (Part E, Supplemental Guidance for Dermal Risk Assessment) Final* (EPA/540/R/99/005).
- *Guidelines for Carcinogen Risk Assessment* (EPA/630/P-03/001F).

Additional information used in the risk assessment included the following:

- *User's Manual for RESRAD, Version 6* (ANL/EAD-4)
- *Exposure Scenario for CTUIR Traditional Subsistence Lifeways* (Harris and Harper 2004).

- *Cleanup Levels and Risk Calculations Under the Model Toxics Control Act Cleanup Regulation (CLARC), Version 3.1* (Ecology 2001)
- *Hanford Guidance for Radiological Cleanup,* Revision 1 (WDOH/320-015)
- "Model Toxics Control Act -- Cleanup" (WAC 173-340).

1.6.1.2 Criteria for Human Health COPC Identification/COPC Elimination. All analytes initially reported in the analytical suites identified in the SAP are considered COPCs. Radiological and nonradiological analytes are then screened on the basis of detection status to identify COPCs. Additionally, nonradiological analytes that are considered essential human nutrients that are toxic only at very high doses and are present at concentrations only slightly higher than naturally occurring levels were not evaluated in a human health risk assessment (EPA/540/1-89/002).

1.6.1.3 General Methodology for the Human Health Risk Assessment. The human health risk assessment employs a four-step process to estimate the potential health effects and radiation dose associated with exposure to residual contaminants in environmental media. These steps are (1) data collection and evaluation, (2) contaminant exposure assessment, (3) toxicity assessment, and, (4) risk characterization. The components of each of the four steps are described briefly below.

Data Collection and Evaluation. The first step of the process is Data Collection and Evaluation. The Data Collection and Evaluation section provides a summary of the relevant historical processes and a discussion of the sampling and analysis of environmental media and associated DQOs. This step describes past practices at and around a site and how the site was characterized to support evaluation of potential human and ecological impacts. Data processing protocols related to treatment of qualified data, representation of concentrations in samples where a chemical was not present above detection limits, and similar issues are defined.

Exposure Assessment. The Exposure Assessment focuses on identifying how much of a chemical is present in an environmental medium, determining who might be exposed and in what manner, and quantifying the rate of exposure. In the first part of the Exposure Assessment, chemicals and radionuclides that are associated with site releases and could potentially pose an unacceptable health risk are identified. The average concentration of these COPCs within areas where human exposure may occur is then quantified. Then, the rate of chemical and radionuclide intake into the body via each potentially complete exposure pathway is calculated for each combination of COPC and land-use scenario. Many of the attributes of the conceptual site model (CSM), including land use and receptors, exposure media, and exposure routes, are essential components of the Exposure Assessment.

Toxicity Assessment. The Toxicity Assessment uses chemical-specific animal and human toxicity data to identify what health effects might be caused by exposure to the COPCs. Particular emphasis is placed on those chemicals and radionuclides making significant contributions to potential health effects and radiation dose, respectively. For most chemicals, the higher the level of exposure, the more likely the chemical will cause a toxic effect. Since every chemical can cause a toxic effect at *some* level, the toxicity assessment is used together with the exposure assessment in order to assess potential human health risks.

Risk Characterization. The Risk Characterization is the final step of the risk assessment process. It provides estimates of potential health effects and radiation dose for each exposure scenario and clarifies which COPCs and exposure pathways are associated with these risks. Uncertainty related to the various assumptions and inputs used in the human health risk assessment is also assessed to qualify the risk assessment results. Potential human health risks for nonradiological COPCs are characterized for two health endpoints: (1) the risk of potential carcinogenic (cancer-related) health effects, and (2) the potential for noncancer health effects (systemic hazards). For radiological COPCs, radiation dose is calculated as the annual committed effective dose equivalent (internal dose) or annual effective dose equivalent (external dose).

1.6.2 Ecological Risk Assessment Approach

This section gives an overview of the approach taken for the 100 Area and 300 Area Component ecological risk assessment, which was refined during a series of workshops (see Appendix D for the meeting notes and the project web site for presentation materials). Ecological risk assessment guidance used to perform the ecological risk assessment for the 100 Area and 300 Area Component are identified below. A general description of the criteria for the identification of contaminants of potential ecological concern (COPECs) is also provided. Section 1.3.2.3 provides an overview of the weight-of-evidence (WOE) approach and how various lines of evidence are used to substantiate or refute risk conclusions.

1.6.2.1 Ecological Risk Assessment Guidance and Compliance. Primary guidance used in completing this ecological risk assessment included *Ecological Risk Assessment Guidance for Superfund: Process for Designing and Conducting Ecological Risk Assessment, Interim Final* (EPA/540/R-97/006), *Final Guidelines for Ecological Risk Assessment* (EPA/630/R-95/002F), and the terrestrial ecological evaluation procedures in WAC 173-340-7490. Additional guidance provided by other sources was integrated into this ecological risk assessment, as appropriate, such as the following:

- *ECO Update*, Vol. 1, No. 1 through 5 (EPA 1991g, 1991b, 1992a, 1992b, 1992d)
- *ECO Update*, Vol. 2, No. 1 through 4 (EPA/540/F-94-012, EPA/540/F-94-013, EPA/540/F-94-014, EPA/540/F-94-050)
- *ECO Update*, Vol. 3, No. 1 and 2 (EPA/540/F-95/037, EPA/540/F-95/038)
- *ECO Update*, "The Role of Screening-Level Risk Assessments and Refining Contaminants of Concern in Baseline Ecological Risk Assessments" (EPA 540/F-01/014)
- *Issuance of Final Guidance: Ecological Risk Assessment and Risk Management Principles for Superfund Sites (Memorandum)* (EPA 1999b).

The ecological risk assessment process for the 100 Area and 300 Area Component of the RCBRA is consistent with and begins with the first two steps outlined in EPA's Superfund guidance to provide the most conservative evaluation (EPA/540/R-97/006). These first steps include pathway identification/problem formulation, toxicity evaluation, exposure estimation, and screening-level risk characterization. The screening-level risk characterization represents the first tier of a phased approach in which chemicals and radionuclides that clearly present no risk are differentiated from those with the potential for ecological risks. Contaminants identified in the screening-level risk characterization as potentially causing adverse effects were retained for more detailed evaluation in the second-tier risk characterization, which begins in step 3 of the ecological risk assessment guidance. The screening-level ecological risk assessment (SLERA) was performed as part of the DQO effort and is documented in Appendix C of the DQO Summary Report (BHI-01757). The SLERA was used to identify potential sampling locations and to identify contaminants in abiotic and biotic media based on existing data. While contaminants were identified for further evaluation in the SLERA, it was agreed that analytical suite analyses would be performed for completeness during future sampling. In this risk assessment, this second tier is referred to as the "focused risk characterization," with the purpose of determining if (and to what degree) the retained ecological COPCs may present risks to the selected assessment endpoints.

1.6.2.2 Criteria for Ecological COPC Identification and Elimination. Laboratory results for all analytical suites were evaluated to identify individual COPCs for further assessment. Analytical results were initially evaluated against detection status (detect, nondetect) and essential nutrients. The detection limits of nondetected analytes were evaluated against media-based toxicity no-effect thresholds to determine the adequacy of detection limits. Analytes for which detection limits were greater than applicable benchmarks are discussed in the uncertainty analysis. Analytes that were not detected or were essential nutrients were not evaluated further.

1.6.2.3 General Methodology for Ecological Risk Assessment. The general approach to ecological risk assessment includes three phases: problem formulation, analysis (characterization of exposure and effects), and risk characterization (EPA/540/R-97/006, EPA/630/R-95/002F). Uncertainty analysis is also performed as part of the ecological risk assessment process to help interpret risk results. The following text summarizes the components of each phase to fulfill each of the aspects of the ecological risk assessment process.

Problem Formulation. Problem formulation is a process for generating preliminary hypotheses about why effects have occurred or may occur as a result of human activities. Key aspects of problem formulation include compiling and evaluating information related to the following:

- Site history and environmental setting
- Extent and distribution of COPCs at the site
- Contaminant fate and transport
- Potential receptors
- Exposure pathways
- Ecotoxicity of COPCs present
- Anticipated effects of site COPCs on receptors

- Assessment endpoints and measures of exposure and effects.

These components comprise the CSM that is later used to determine or predict a receptor's response to COPCs under site exposure conditions in the Analysis phase.

Analysis. Analysis consists of two components: characterization of exposure and characterization of ecological effects. Exposure characterization describes potential or actual contact or co-occurrence of COPCs with receptors (EPA/630/R-95/002F). Once exposure has been verified/quantified, concentrations of COPCs can be linked to adverse effects in the selected receptors. Literature reviews, field studies, and laboratory studies can provide information for establishing or refuting a relationship between a contaminant concentration and an ecological effect. Each type of information is then considered as a line of evidence for evaluation in the risk characterization.

Risk Characterization. Risk characterization is the process that links the presence of site contaminants with evidence of adverse ecological effects, and then determines the magnitude or ecological significance of the resulting risk. All chemical and biological data related to the site, including results of chemical analyses, toxicity testing, and field studies, are used to characterize risk. Risks are characterized relative to reference sites and contaminant gradients; additional information on reference sites is provided in Section 4.0 and Appendix E. Several other parameters are evaluated to characterize the ecological significance of the risk, such as relative population size and habitat suitability.

Weight-of-Evidence Approach to Ecological Risk Assessment. The WOE approach relates measures of effects to an assessment endpoint using a balance of literature, field, and laboratory data to assess the potential for risk to the environment. The WOE evaluation provides an explicit link between risk characterization and the assessment endpoints. Potential risks to receptors exposed to contaminants in upland and riparian soils, near-shore sediments, and water were initially evaluated by comparing media-based and dietary exposures to conservative benchmark values from the literature (see Section 6.0).

The risk characterization is conducted by evaluating multiple lines of evidence in a WOE approach (as described by Suter et al. 2000 and WAC 173-340-7493[3][f]). In a WOE approach, each available line of evidence for each assessment endpoint is evaluated individually to provide a conclusion concerning the presence or absence of risk, based on that line of evidence. Once all available lines of evidence have been evaluated, they are considered jointly to determine whether the combined WOE supports a conclusion of risk. The quality of conclusions increases and uncertainty (generally) decreases as the number of lines of evidence increases. All lines of evidence for each receptor group are then integrated to present a WOE conclusion.

The lines of evidence for this assessment included both site-specific and literature-based measures. In most cases, greater weight is given to conclusions based on site-specific data, consistent with WAC 173-340-7493(3)(f). The overall WOE conclusion is determined using best professional judgment based on the preponderance of evidence. Confidence in the overall risk conclusion determined from the WOE evaluation is based on scientific and professional judgment considering all available lines of evidence, supporting data, agreement, and relative weighting. Low confidence was typically given to conclusions based on a single line of evidence or on multiple lines of evidence that did not agree. Moderate confidence in risk conclusions resulted when most lines of evidence were consistent but where these lines of evidence had low weight. High confidence in risk conclusions was warranted when multiple lines of evidence corroborated one-another and with some of the lines of evidence having moderate or high weight.

General lines of evidence evaluated in the risk characterization included the following:

- Media-based comparison to background values
- Media-based comparison to literature-derived single chemical toxicity threshold
- Tissue-based comparison to literature-derived single chemical toxicity threshold
- Statistical comparisons of concentration distributions across areas and habitats
- Refined dietary exposure modeling and comparison to literature-derived single chemical toxicity thresholds
- Site-specific histopathology
- Site-specific ecological data such as community indices.

Uncertainty Analysis. Risk assessment as a science is subject to uncertainty, both generally and with respect to understanding of location-specific conditions. Sources of uncertainties in ecological risk assessment include the following:

- Sampling and analysis
- Fate and transport estimation
- Exposure estimation
- Toxicological data.

A qualitative uncertainty analysis identifies specific causes of uncertainties and evaluates their potential impact on risk estimates. Specific sources and effects of the uncertainty factor on the resulting risk estimates for the site (whether the factors tend to over- or underestimate calculated risks) are discussed in the ecological uncertainty analysis (Section 6.5).

1.7 ORGANIZATION OF THE RISK ASSESSMENT REPORT

This risk assessment report is organized into several sections. The first three sections of the report contain general information, such as introductory text (Section 1.0), CSM (Section 2.0), other Hanford Site investigations and risk assessments (Section 3.0), and preliminary data analyses (Section 4.0). Sections 5.0 and 6.0 of the report are the human health and ecological risk assessments. Each assessment is organized as follows:

A. Human Health Risk Assessment

- Introduction
- Exposure scenarios and receptors
- Exposure assessment: calculation of exposure point concentrations
- Exposure assessment: calculation of intake
- Toxicity assessment
- Risk characterization
- Human health risk assessment results
- Human health risk assessment conclusions

B. Ecological Risk Assessment

- Overview
- Problem formulation
- Analysis
- Risk characterization
  - Weight-of-evidence
- Uncertainties
- Ecological risk assessment conclusions.

Figure 1-1. Geographical Boundaries of the 100 Area and 300 Area Component of the RCBRA Risk Assessment.

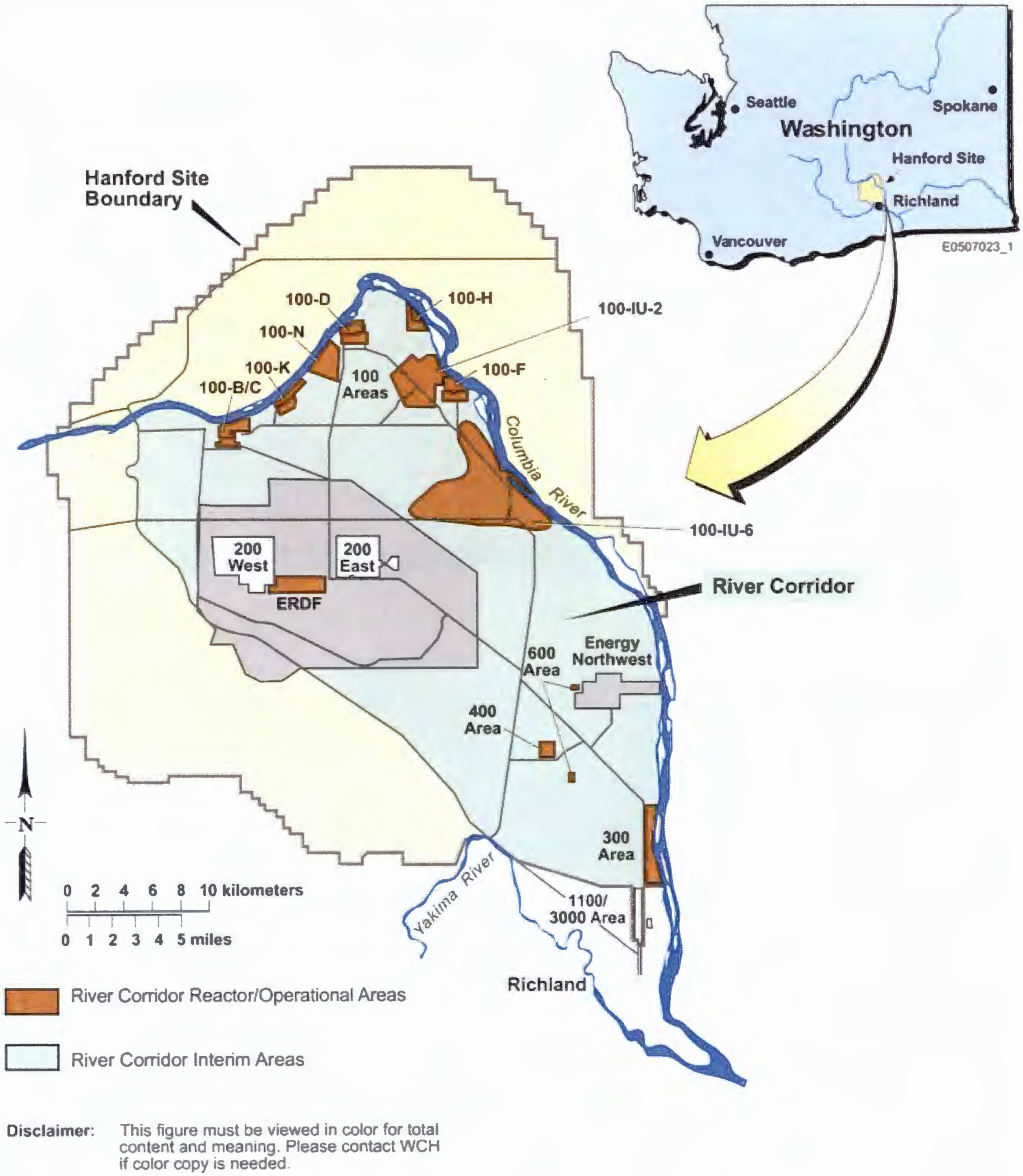


Figure 1-2. Hanford Site Groundwater Operable Unit Areas.

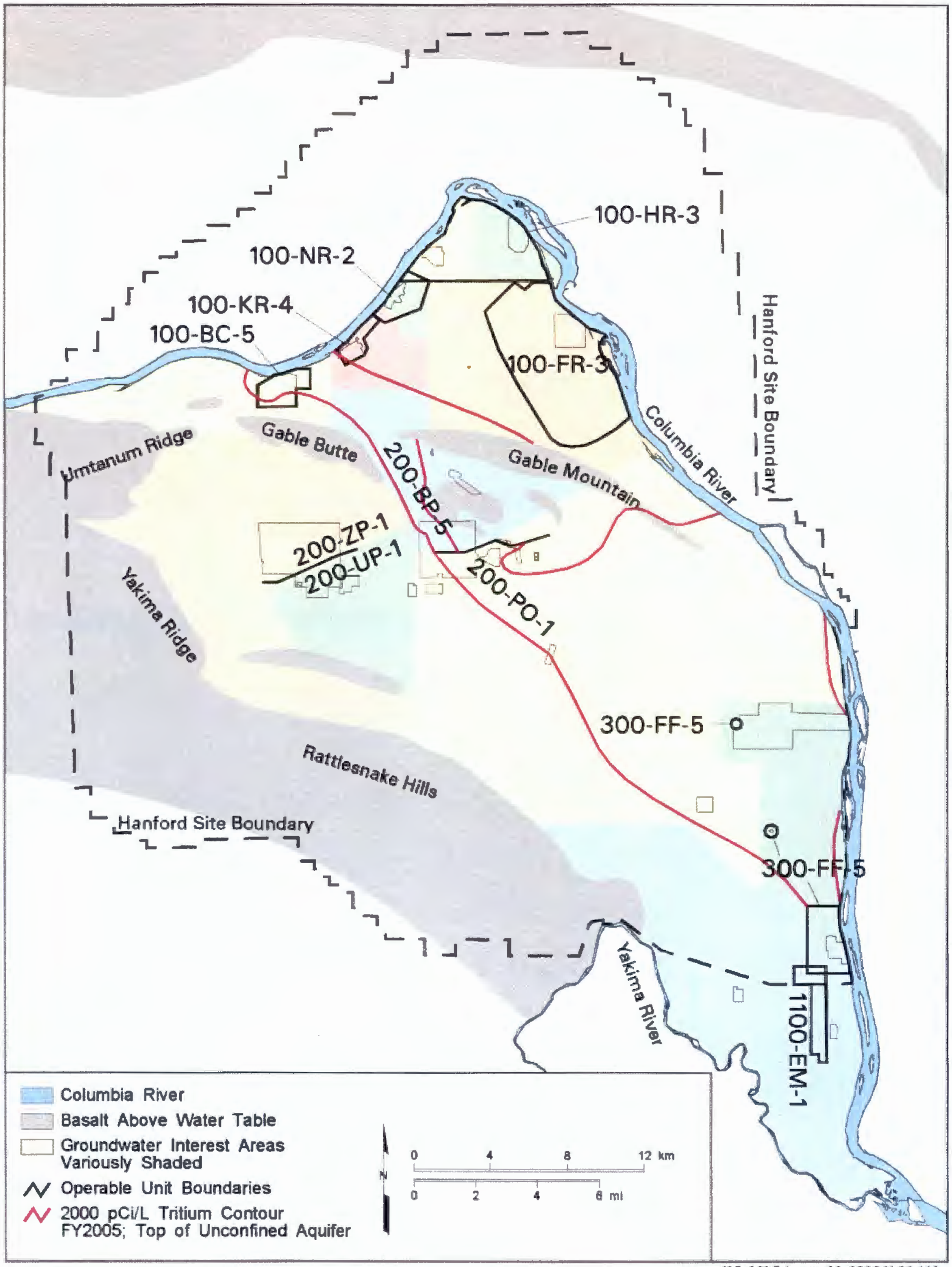


Figure 1-3. Scope of the 100 and 300 Area Component of the RCBRA Evaluation.

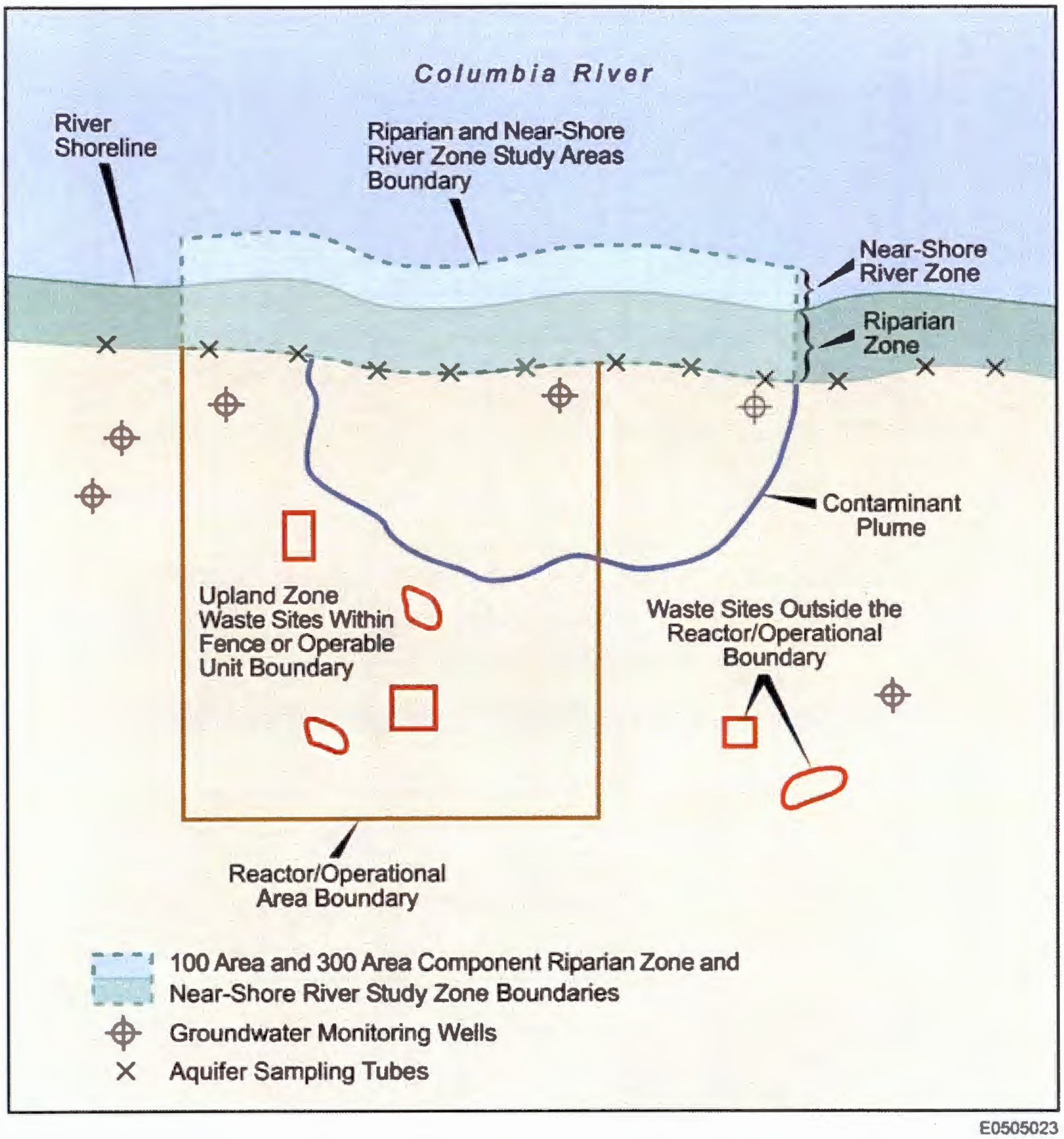


Figure 1-4. U.S. Environmental Protection Agency Two-Tier, Eight-Step Ecological Risk Assessment Process. (adapted from EPA/540/R-97/006).

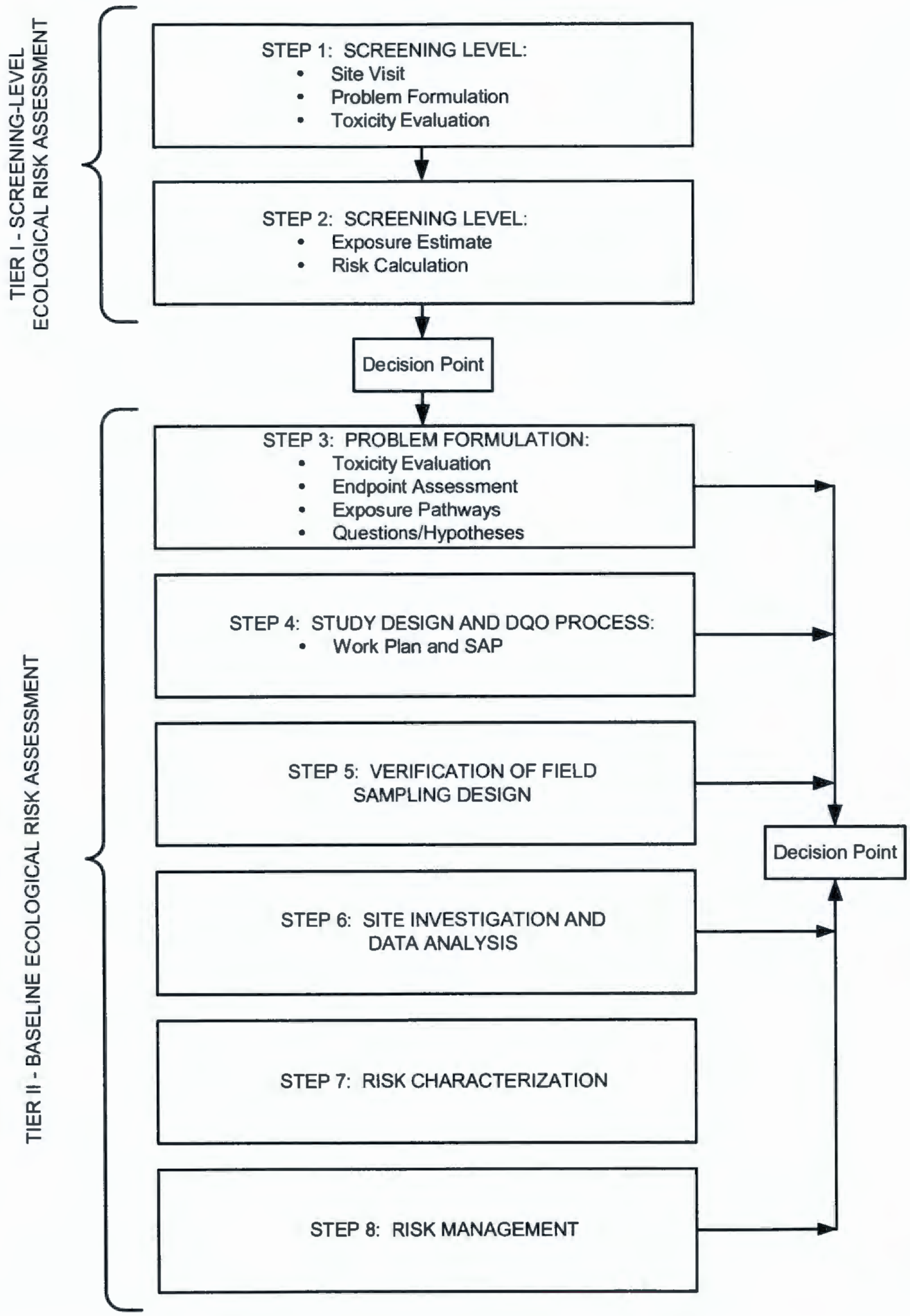


Table 1-1. Sampling Schedule for Abiotic and Biotic Samples for 100 Area and 300 Area Component Upland, Riparian, and Near-Shore River Environments.

Month (year)	Sampling Activity
October 2005 through June 2006	Groundwater (well water)
October 2005 through July 2006	Upland and riparian MIS soils
January and February 2006	Surface water, AT water, and sediment
February 2006	Fish
March through May 2006	Upland and riparian biota
July 2006	Birds
August 2006	Macroinvertebrates/bivalves
September and November 2006	AT water

AT = aquifer tube
MIS = multi-increment sampling

2.0 CONCEPTUAL SITE MODEL

The purpose of the CSM is to identify the sources of contamination and the environmental transport and exposure pathways that may be important in evaluating potential exposures of human and ecological receptors.

The CSM identifies and integrates the following types of information:

- Known and potential sources and/or releases of contamination
- Physical and ecological attributes of the Hanford Site
- Current and potential exposure scenarios for comparison purposes
- Potential media to be considered and exposure routes for human health exposure scenarios
- Potential ecological exposure pathways (e.g., trophic transfer) and representative ecological receptors.

Development of a CSM ensures that all relevant exposure media and scenarios are considered in the human health and ecological risk assessments. The CSM also provides a basis for conclusions regarding the adequacy of available environmental data to support assessment of potential human and ecological exposures. Section 2.1 describes the contaminant sources and the waste streams associated with the 100 Area and 300 Area, as well as the remedial action status for each area. Descriptions of the physical and ecological settings of the 100 Area and 300 Area are provided in Sections 2.2 and 2.3, respectively. Conceptual models of potential human and ecological exposures to residual contamination at the 100 Area and 300 Area are presented in Sections 2.4 and 2.5, respectively.

2.1 SITE HISTORY

An understanding of the operational history and in-progress CERCLA remedial actions in the River Corridor facilitates the development of CSMs for risk assessments. Operational history as well as cultural, archaeological, and pre-Hanford Site era background information pertinent to the 100 Areas and 300 Area is described Section 2.3 of the *Risk Assessment Work Plan for the 100 Area and 300 Area Component of the RCBRA* (DOE/RL-2004-37). The Hanford Site Historic District report (DOE/RL-97-01047)[1] also provides a history of the Hanford Site and its operations from 1943 through 1990.

To appreciate how the 100 Area and 300 Area Component of the RCBRA fits into the overall strategy for closure of the River Corridor, it is important to place it context with past and present risk assessments, characterization efforts, and remedial actions at the Hanford Site. Detailed descriptions of projects relevant to this effort are provided in Section 3.0, including cleanup

[1] Available on-line at http://www.hanford.gov/doe/history/docs/rl-97-1047/index.pdf

verification data and data collected for special investigations such as the river effluent pipeline waste sites (BHI-00538; BHI-01141; BHI 2004, 2005), the Inter-Areas shoreline risk assessment (DOE/RL-2005-42, Appendix E), the 100-NR-2 shoreline assessment (DOE/RL-2006-26), the 100-B/C Pilot Project risk assessment (DOE/RL-2005-40), the Central Plateau ecological risk assessment (DOE/RL-2004-42, DOE/RL-2005-30), and the Columbia River Component (CRC) of the RCBRA. There are numerous additional projects that provide supplemental data for the River Corridor, including the Surface Environmental Surveillance Program (SESP), the Near-Facility Environmental Monitoring program, and special studies conducted by PNNL. Data from these projects provide an understanding of the nature and extent of contamination along the River Corridor. Figure 2-1 represents how contaminant sources remaining in the Central Plateau and other reactor areas will affect future river conditions by contaminants transported in groundwater. However, it should be noted that the *RCBRA Stack Air Emissions Deposition Scoping Report* (DOE/RL-2005-49) concluded that there is no evidence that waste sites should exist in the River Corridor area as a result of historical air emission deposition. Air stack emissions are therefore an incomplete exposure pathway and are not evaluated in the human health or ecological risk assessments.

2.1.1 Contaminant Sources and Waste Streams

Contaminant sources include hazardous substances in the environment that may pose a threat of adverse effects to human health or ecological receptors. The reactors along the River Corridor used large quantities of water from the Columbia River for direct cooling of the reactor cores to dissipate the heat generated by nuclear fission reactions. The water was then discharged through large pipes into retention basins for short periods to allow for thermal cooling and decay of short-lived radionuclides. The water was later discharged into unlined cribs and trenches or to the Columbia River. The discharged cooling water contained activation products resulting from neutron activation of impurities in the river water, as well as radioactive materials (i.e., fission products) that escaped due to cladding failures of the uranium fuel elements during the irradiation process (DOE/RL-97-02, PNNL-13230).

Past waste disposal practices in the reactor areas resulted in radionuclide and chemical contamination of soil and groundwater near the reactors. The primary sources of these contaminant releases were leaks in the reactor cooling-water transfer systems, as well as intentional effluent disposal into cribs and trenches. Solid wastes containing radionuclides and chemicals were disposed in unlined burial grounds to isolate those wastes from ongoing operations. Chemical contaminants originated from laboratory process wastes (e.g., SVOCs) or use of treated building materials (e.g., railroad ties) (EPA 1995).

In addition to the liquid waste sites and solid waste burial grounds, there are many other waste sites, generally referred to as the "remaining sites" for administrative purposes. These remaining sites include a wide variety of sites such as septic systems from contaminated facilities, burn pits, french drains, pre-Hanford and Hanford-era waste dumps, small oil spills, and non-reactor effluent pipelines. Current contaminant source descriptions, including waste site types, are presented in the subsections that follow.

2.1.1.1 Major Categories of 100 Area Contaminant Sources. The first eight reactors (i.e., 105-B, 105-C, 105-KE, 105-KW, 105-D, 105-DR, 105-H, and 105-F) used large quantities of water from the Columbia River for direct cooling of the reactor cores. The water was then discharged through large pipes into retention basins and later discharged to subsurface cribs and trenches or released into the river. The 105-N Reactor had a modified design that recirculated purified water through the reactor core in a closed-loop cooling system. It was the only dual-purpose reactor, capable of producing electricity as well as plutonium.

Radioactive Liquid Effluent Waste Sites. Liquid waste sites include retention basins, trenches, cribs, french drains, and effluent pipelines. Cooling water from the single-pass reactors along the Columbia River was routinely routed to retention basins before being returned to the river. Thermal shock from the hot cooling water often cracked the basin walls, allowing potentially-contaminated cooling water to leak into the vadose zone. In addition, trenches were sometimes used for direct disposal of cooling water following fuel cladding failures. The disposed cooling water contained fission and neutron activation products and some chemicals and actinides. Of potentially greatest concern is the migration of tritium, strontium-90, nitrate, and chromium through the vadose zone to groundwater and, ultimately, to the Columbia River (PNL-6415). All of the radioactive liquid effluent waste sites in the 100 Area and 300 Area have been remediated.

Highly contaminated cooling water, such as water that had contacted broken fuel rods, was sent to trenches via retention basins and outfall structures rather than being returned to the Columbia River. This water contained large quantities of fission and neutron activation products. *Radiological Characterization of the Retired 100 Areas* (UNI-946) used borehole sampling to determine the amount of residual radioactivity in the retired 100 Area (at that time, all but the 100-N Area) retention basins, diversion cribs and trenches, pipelines, and leakage areas that were assumed to hold the bulk of the residual contamination. At that time, the principal radionuclides remaining associated with these retired structures were reported to be tritium, carbon-14, cobalt-60, nickel-63, strontium-90, cesium-137, europium-152, europium-154, europium-155, and plutonium-239/240 (UNI-946). Additional nonradioactive contaminants, such as sodium dichromate, were also common in the liquid waste sites.

Solid Waste Burial Grounds. Direct land burial was used in the 100 Area and 300 Area to dispose of low-level, solid radioactive waste associated with reactor operations from 1944 through 1973. Radioactive wastes in the 100 Area were segregated as soft waste (combustibles) or hard waste (greater than 99% metallic). The radioactive hard waste included process tubes, fuel element spacers, equipment, tools, and control rods (WHC-EP-087). Most of the combustible waste from reactor operations was burned in open pits or in a natural draft incinerator contained in a 100-K Area solid waste burial ground. Biological studies generated low-level soft waste containing radioactive tracers and low-level fission and activation products, which are buried in the 100-F Area.

Elements contained in materials disposed at the solid waste burial grounds included boron, cadmium, lead, and nickel, with lesser amounts of lithium-aluminum alloy, mercury, palladium, and zirconium. Additional miscellaneous solid waste items consisted of aluminum and steel. Only low-level waste is known to have been disposed in the solid waste burial grounds; waste containing plutonium or any other alpha emitters, cobalt-60 at activity greater than 1 mCi/g, or beryllium was packaged and shipped to the 200 Area for burial in designated trenches. The main radionuclide contaminants present in the 100 Area and 300 Area burial grounds are tritium, carbon-14, cobalt-60, nickel-63, strontium-90, cesium-137, silver-108m, europium-152, europium-154, and europium-155 (WHC-EP-087).

The Interim Action Burial Ground ROD (EPA 2000) directed that remedial actions at the solid waste burial grounds will involve removal, treatment if appropriate, and disposal of contaminated material at the Environmental Restoration Disposal Facility (ERDF). The same cleanup criteria used for the rest of the 100 Area waste sites are being used for remediation of the solid waste burial grounds.

100 Area River Effluent Pipelines. Between 1943 and 1988 at the Hanford Site, pipelines extending from outfall structures in the 100 Area into the Columbia River were used to discharge reactor cooling water to the river. Operation of most river effluent pipelines ended when the associated reactors were shut down between the late 1960s and mid-1980s. The inactive effluent pipelines remain in place on or beneath the river channel bottom to this date. The effluent pipelines constitute seven waste sites that include 15 separate pipelines.

Remaining Sites. Additional CERCLA sites in the 100 Area have been included in the "Remaining Sites" Interim Action ROD (EPA 1999c). The sites are scattered across the 100 and 600 Areas of the Hanford Site and include liquid and solid waste sites that received low levels of contaminants, oil spills, burn pits, foundations of previously removed facilities, septic systems, and areas (such as landfills) remaining from the former Hanford and White Bluffs Townsites. While some sites were chosen for removal actions, the nature and extent of contamination in most of these sites is uncertain, so the remedial action alternative chosen in the interim action ROD (EPA 1999c) is confirmatory sampling, with removal of any waste that is found to exceed 100 Area cleanup criteria (DOE/RL-96-17).

The levels of both radioactive and chemical contaminants within the remaining sites are expected to be considerably less than the levels in the liquid waste sites or solid waste burial grounds, and the infiltration of any contamination is expected to be much shallower than at the liquid waste sites. Because of the lower levels of contamination expected, many of these remaining sites are not kept free of vegetation, unlike the liquid waste sites and solid waste burial grounds.

2.1.1.2 CERCLA Waste Sites at the 100 Area and 300 Area Operable Units. Waste sites considered for investigation in the 100 Area and 300 Area Component of the RCBRA consisted of burn pits, cribs, dumping areas, french drains, landfills, outfalls, pits, ponds, process facilities, retention basins, septic tanks, solid waste burial grounds, storage tanks, sumps, sewers, trenches, and unplanned releases, among others. Additional information on the selection of upland, riparian, and near-shore aquatic sampling areas is provided in the SAP (DOE/RL-2005-42; Appendix C). The subsections below discuss the contaminant sources remaining in each reactor area and the 100-IU-2 and 100-IU-6 OUs, in terms of remediated and unremediated CERCLA waste sites. A list of the waste sites within each reactor area is presented in Appendix A of the *Risk Assessment Work Plan for the 100 Area and 300 Area Component of the RCBRA* (DOE/RL-2004-37), not including sites newly designated under the Orphan Sites program. The

Orphan Sites program reviews land parcels identifying potential CERCLA waste sites in the River Corridor that are not currently listed in existing CERCLA decision documents.

100-B/C. Remediation of waste sites began in the 100-B/C Area in 1995. A number of the highest priority waste sites have been remediated, backfilled with clean soil, and verified to meet interim cleanup criteria, as documented in regulator-approved CVPs (see Appendix A of DOE/RL-2004-37). Many of the area's pipelines have been removed, and Remaining Sites have been evaluated. Tri-Party Agreement Milestone M-16-45 requires completion of interim remedial actions at specific waste sites in the 100-B/C Area by June 30, 2007 (Ecology et al. 1989)[2].

Remaining contaminant sources in the 100-B/C Area include unremediated CERCLA waste sites and potential residual contamination within the excavation floor and sidewalls of remediated sites. Contamination may also exist in groundwater and along the Columbia River shoreline and near-shore river environment (where groundwater meets the surface soils), and Columbia River water.

100-K. Remediation of the highest priority waste sites began in the 100-K Area in 2003 (see Appendix A of DOE/RL-2004-37). Interim remedial actions for the 100-K Area are scheduled to be completed in 2012 in accordance with Tri-Party Agreement Milestone M-16-53 (Ecology et al. 1989). Remaining contaminant sources in the 100-K Area include unremediated CERCLA waste sites (including pipelines) and potential residual contamination within the excavation floor and sidewalls of remediated sites. Contamination may also exist in groundwater and along the Columbia River shoreline and near-shore river where groundwater mixes with the surface soils and Columbia River water.

100-N. Remedial action activities for the 100-N treatment, storage, and disposal units began in 2000, and backfill has been completed for several of the liquid waste sites (see Appendix A of DOE/RL-2004-37). Remaining contaminant sources in the 100-N Area include unremediated CERCLA waste sites and potential residual contamination within the excavation floor and sidewalls of remediated sites. Groundwater carrying mobile radioactive contaminants enters the Columbia River via a series of riverbank seeps, referred to as the N-Springs, which are also considered a contaminant source in the 100-N Area (WHC-SP-0480). Key contaminant plumes of the 100-N Area include strontium-90, metals, and total petroleum hydrocarbons.

100-D. Remedial action activities began in the 100-D Area in 1996. The largest of the 100-D Area liquid waste sites have been remediated and backfilled with clean soil (see Appendix A of DOE/RL-2004-37). Interim remedial actions at the 100-D Area are scheduled to be completed in 2011, in accordance with Tri-Party Agreement Milestone M-15-47 (Ecology et al. 1989). Remaining contaminant sources in the 100-D Area include unremediated CERCLA waste sites and potential residual contamination within the excavation floor and sidewalls of remediated sites. Contamination may also exist in groundwater and along the Columbia River shoreline and near-shore river where groundwater mixes with the surface soils and Columbia River water. Mitigative effects of in situ groundwater treatment systems are not

[2] The current version of the Tri-Party Agreement may be found at: http://www.hanford.gov/?page=90&parent=91

specifically evaluated in this assessment; however, efficacy of the treatment systems would be secondarily observed via analysis of affected media (i.e., groundwater and pore water). Outfall pipelines present in the 100-D Area extend to D-Island in the main channel of the Columbia River. Potential human and ecological risks related to residual contamination from the outfall pipelines were evaluated as part of the 100 Area and 300 Area Component. Hexavalent chromium is a key contaminant plume in the 100-D Area.

100-H. Remedial action activities began in the 100-H Area in 1999. The largest of the 100-H Area liquid waste sites have been remediated and backfilled with clean soil (see Appendix A of DOE/RL-2004-37). Remedial actions at the 100-H Area are scheduled to be completed in 2010, in accordance with Tri-Party Agreement Milestone M-16-51 (Ecology et al. 1989). Remaining contaminant sources in the 100-H Area include unremediated CERCLA waste sites and potential residual contamination within the excavation floor and sidewalls of remediated sites. Contamination may also exist in groundwater and along the Columbia River shoreline and near-shore river where groundwater mixes with the surface soils and Columbia River water.

100-F. Remedial action activities began in the 100-F Area in 2000. The largest of the 100-F Area liquid waste sites have been remediated and backfilled with clean soil (see Appendix A of DOE/RL-2004-37), including waste sites associated with the F Area Experimental Animal Farm. Upland effluent pipelines have been removed and a number of Remaining Sites have been evaluated. Remedial actions at the 100-F Area are scheduled to be completed in 2008, in accordance with Tri-Party Agreement Milestone M-16-49 (Ecology et al. 1998). Remaining contaminant sources in the 100-F Area include unremediated CERCLA waste sites and potential residual contamination within the excavation floor and sidewalls of remediated sites. Contamination may also exist in groundwater and along the Columbia River shoreline and near-shore river where groundwater mixes with the surface soils and Columbia River water.

300 Area Contaminant Sources. Operations in the 300 Area created both liquid and solid waste. Prior to 1973, a series of solid waste burial grounds were used for solid waste and debris generated by 300 Area operations. These burial grounds were located just north and west of the 300 Area complex. Prior to 1994, liquid waste was discharged to a series of unlined ponds and process trenches just north of the 300 Area. In 1989, the 300 Area was placed on the NPL because of soil and groundwater contamination that resulted from past operations. The primary contaminant in soil and groundwater in the 300 Area is uranium from the fuel fabrication processes. However, numerous other potential contaminants exist for individual waste sites, given the history of their use and operation (DOE/RL-2001-48).

Groundwater contaminant plumes from 200 Area waste sites have migrated southeast toward the 300 Area. These plumes were driven east and southeast by the natural groundwater gradient across the Hanford Site and the large-volume discharges of cooling water to ponds and ditches in the Central Plateau. Contaminant concentrations (e.g., tritium) reaching the 300 Area in these plumes are significantly lower than originating concentrations in groundwater underlying the 200 Area as a result of natural attenuation of the plumes through radioactive decay and dispersion (PNNL-15670).

The 300-FF-1 OU includes the major 300 Area liquid and process waste disposal sites and several solid waste burial grounds. The 300-FF-1 OU liquid and process waste sites were unlined trenches and ponds that routinely received discharges of millions of gallons of contaminated waste-water from 300 Area operations between 1943 and 1994. These sites are suspected to be the primary source of uranium contamination in 300-FF-5 groundwater OU. The 300-FF-2 OU sites are subdivided into four groups based on site type, waste content, and/or relative location. Waste site groupings in the 300-FF-2 OU include the following:

- 300 Area Complex source sites (40 sites)
- Outlying source sites (7 sites)
- General content solid waste burial grounds (7 sites)
- Transuranic-contaminated solid waste burial grounds (2 sites).

Uranium is a key contaminant of the 300 Area.

100-IU-2 and 100-IU-6 Operable Unit Contaminant Sources. CERCLA waste sites in the 100-IU-2 and 100-IU-6 OUs include burn pits, drain/tile fields, dumping areas, military facilities, ponds, pre-Hanford and Hanford-era community landfills, solid waste burial grounds, storage areas, trenches, and unplanned releases of oils (see Appendix A of DOE/RL-2004-37). Waste site characterization and remediation began in the 100-IU-2 and 100-IU-6 areas in 1997. Some sites were found not to pose a threat to human health or the environment and were consequently classified as "no-action" sites. Other sites were remediated and interim closed. Several of the waste sites have been reclassified as no-action sites or interim closed out (Waste Information Data System database). A number of additional waste sites have been evaluated and characterized for remediation at a later date. Remedial actions are scheduled to be completed in 2008, in accordance with Tri-Party Agreement Milestone M-16-56 (Ecology et al. 1989). Appendix A of the *Risk Assessment Work Plan for the 100 Area and 300 Area Component of the RCBRA* (DOE/RL-2004-37) includes a list of the waste sites in the 100-IU-2 and 100-IU-6 OUs, along with their remediation status. Remaining contaminant sources in the 100-IU-2 and 100-IU-6 OUs include unremediated CERCLA waste sites and potential residual contamination within the excavation floor and sidewalls of remediated sites. Annual monitoring has indicated groundwater contamination along the Columbia River shoreline and near-shore river where groundwater mixes with the surface soils and surface water, and beneath site 600-129 in the 100-IU-2 OU.

2.1.2 Remedial Action Status of the 100 Area

In 1991, the Tri-Parties (i.e., EPA, DOE, and Ecology) agreed to a "bias for action" approach to the CERCLA process for the Hanford Site. The agreement, known as the *Hanford Past-Practice Strategy* (DOE/RL-91-40), streamlined the RI/FS process to begin remediation of contaminated waste sites earlier than typically performed under the traditional CERCLA process in place at that time. This was consistent with later EPA initiatives to expedite cleanup actions, such as the *Superfund Accelerated Cleanup Model* (EPA540-R-98-025) and the *RCRA Facility Stabilization Initiative* (DOE/EH-231-076/0295r).

The cleanup objectives for source OUs in the 100 Areas were developed using the results from qualitative risk assessments and formally established in the associated interim action RODs. The selected remedies presented in these interim action RODs require removal of wastes, treatment (as necessary), and subsequent disposal at the ERDF or other approved facilities. Source unit cleanup actions in the River Corridor are generally being performed based on a rural-residential exposure scenario. While the rural-resident exposure scenario is inconsistent with the DOE Preferred Alternative land-use alternatives of conservation/preservation (100 Areas) and industrial/commercial (300 Area) designated in the CLUP (DOE/EIS-0222-F), cleanup levels for the rural-resident exposure scenario are presumed to be adequately protective of exposures under the land uses identified in the CLUP.

At many waste sites associated with the 100 Area source OUs, remedial actions were completed prior to September 2005 under the Environmental Restoration Contract. The remedial designs that supported these cleanup actions were based the requirements established in the interim action RODs, amendments, and explanation of significant differences (ESDs).

All of the Hanford Site production reactors have been deactivated, and waste sites within each of the 100 Area reactor areas and the 100-IU-2 and 100-IU-6 OUs are in some stage of cleanup, decommissioning, or restoration. Full-scale remediation of these waste sites began in 1996 and has continued to the present. Virtually all of the currently known CERCLA waste sites in these areas are covered by an interim action ROD, and about a quarter of these sites have been remediated in accordance with the interim action RODs and backfilled. Other sites are in various stages of completion (as detailed in Appendix A of DOE/RL-2004-37). There are currently nine approved interim action RODs, amendments, or ESDs that document the decisions to remediate the sites. In addition, many of the 100 Area facilities (such as the reactors and support buildings) are being remediated under separate CERCLA action memoranda.

Most CERCLA actions at the 100 Area and 100-IU-2 and 100-IU-6 OU waste sites are being completed to attain the same RAOs (DOE/RL-96-17) that were initially established in 1995 in the first ROD for the 100 Area waste sites (EPA 1995). At that time, the final land use for the 100 Area had not been established; per EPA (1995): "*For the purposes of this interim action, the remedial action objectives are for 'unrestricted use.'*" The RAOs established in the interim action RODs may be revised in final RODs based on information derived from this risk assessment and as a result of risk management decisions.

The interim action RODs indicate that, to establish numerical remediation goals to protect human health, the RAOs will be based on a rural-residential exposure scenario. Because radionuclide cleanup levels for the protection of human health were considered generally more conservative than ecological cleanup levels, it was concluded at that time that the interim action RODs would also protect ecological receptors. For example, removal of soil and debris exceeding the human health-based goals and replacement (i.e., backfilling) with clean material was expected to meet the objective of ecological receptor protection. However, this assumption will be reevaluated in the RI, as some interim action RODs may not be protective of particular ecological receptors. Also, additional human health exposure scenarios (i.e., a Native American scenario and recreational scenarios that include hunting and fishing) have been defined since the development of the interim action RODs that may be more restrictive than the rural-residential exposure scenario.

Eight of the nine reactors constructed along the Columbia River (105-B, 105-C, 105-D, 105-DR, 105-F, 105-H, 105-KE, and 105-KW) were included in the environmental impact statement for the *Decommissioning of Eight Surplus Production Reactors at the Hanford Site, Richland, Washington* (DOE/EIS-0119), which examined the alternatives for dispositioning the reactors. The ninth reactor, 105-N, has decision documents for decommissioning in place and it is anticipated to undergo in situ stabilization and future final disposition of the reactor core.

The radionuclide inventory for all eight of the reactors discussed in DOE/EIS-0119 includes tritium, carbon-14, chlorine-36, cobalt-60, cesium-137, and uranium-238. The dose to workers from cobalt-60 and cesium-137 was one of the main drivers leading to the decision to place the reactor cores in interim safe storage (ISS) for up to 75 years, as described below. Within 75 years, the dose from these short-lived radionuclides will be significantly reduced by decay, which will facilitate removal of the cores and transport to the 200 Area for long-term disposal (DOE/EIS-0119). Additional materials that may be considered hazardous substances are, or have been, present in the reactors, including mercury, friable asbestos, PCBs, cadmium, and lead (DOE/EIS-0119).

With the exception of the 105-B and 105-N Reactors, work is underway at each of the reactor areas to place the reactor facilities in ISS. Placing a reactor in ISS involves removing all ancillary and exterior structures at each reactor complex, leaving only the reactor core and its surrounding shield walls. Loose contamination is removed or stabilized, to the greatest extent possible, in accessible areas within the shield walls. The remaining structure receives a new roof, as well as lighting and electrical receptacles designed to provide adequate illumination for entry and exit during surveillance and maintenance activities. A system is also installed to monitor for potential flooding in below-grade areas.

The only facility access to a reactor in ISS is provided via a single doorway that is welded shut between surveillance and maintenance activities. All other openings in the shield wall are filled with concrete or other sealant materials to prevent wind, water, animal intrusions, and the possible release of radioactive materials. The ISS of 105-C, 105-D, 105-DR, 105-F, and 105-H Reactors have been completed. The final configuration of the 105-B Reactor is on hold until a decision on its status as a museum is made. The reactor cores will remain in this configuration until a decision is made for removal or treatment. The 105-N Reactor has decision documents for decommissioning in place and it is anticipated to undergo in situ stabilization and future final disposition of the reactor core.

The effluent pipelines that extend from the outfall structures into the river at each of the reactor areas are not currently addressed by an interim action ROD, action memorandum, or other decision document. The effluent pipelines for each reactor area are currently being evaluated by the Tri-Parties for final disposition. If remedial action is required, impacts to shoreline areas from the river pipeline projects will be limited to small areas, and restoration plans would be developed as appropriate. The Tri-Parties requested that risk analyses for the river pipelines are included in the scope of the RCBRA for completeness and consideration for risk management.

In 1998, a risk assessment was performed for the pipelines, which included an evaluation of their physical condition, additional sampling, and a pathway analyses (BHI-01141). The results of that evaluation and other pipeline risk assessments will be considered in this document.

2.1.3 Remedial Action Status of the 300 Area

Full-scale remediation of the 300-FF-1 OU began in July 1997 in accordance with the 1996 ROD for the 300-FF-1 and 300-FF-5 OUs (EPA 1996). Cleanup objectives for the 300-FF-1 OU are based on an industrial scenario. Remedial action operations at the 300-FF-1 OU waste sites were completed in August 2003. More than 553,382 metric tons (610,000 tons) of contaminated soil and debris were excavated from the 300-FF-1 OU waste sites and transported to ERDF for disposal. All 300-FF-1 sites have been closed by approved waste site reclassification forms and associated CVPs. In addition, several 300-FF-2 OU waste sites (300-10, 300-45, and 300-262) were addressed by 300-FF-1 OU remedial actions due to their proximity to other 300-FF-1 OU waste sites.

Like the 300-FF-1 OU, cleanup objectives for the 300-FF-2 OU are based on an industrial scenario. However, in May 2004 an ESD was issued, revising the selected cleanup action to achieve an unrestricted cleanup standard for eight outlying sites (EPA et al. 2004). Tri-Party Agreement milestone for completing 300 Area source unit cleanup actions is September 30, 2018 (Milestone M-016-00B).

Most of the 300-FF-2 OU source sites are located within the 300 Area complex, some parts of which are active industrial areas. Waste sites are frequently found beneath existing facilities and/or covered areas that are directly affected by active industrial operations in the area and/or by future economic development plans. Buildings and associated above-ground structures within the 300 Area are not included in the 300-FF-2 OU remedial action scope. The decontamination and demolition activities required to address the above-ground structures will be evaluated in engineering evaluation/cost analysis documents and authorized in CERCLA action memoranda (i.e., CERCLA removal authority). Most of the buildings in the 300 Area are scheduled for removal.

In addition to the 300-FF-2 waste sites known to require remedial action, 24 waste sites were identified as remaining sites that require additional characterization to determine whether remedial actions are warranted. Pursuant to the results of additional sampling, these sites may be added to the scope of the 300-FF-2 OU remediation at a later time. If remediation is not warranted, the sites will be closed in accordance with appropriate procedures and with approval of the Tri-Parties.

2.1.4 Status of Groundwater Remediation in the 100 and 300 Areas

Groundwater contamination is known to occur within the water table underlying the Hanford Site. Key contaminant plumes affecting groundwater in the 100 and 300 Areas include hexavalent chromium at the 100-D, 100-H, and 100-K Areas, strontium-90 at the 100-N Area, and uranium at the 300 Area. Additional contaminants originating from the Central Plateau are migrating through the aquifer, towards the Columbia River.

This risk assessment captures current conditions of groundwater, both as well water, and emergent water in the riparian zone and near-shore Columbia River (i.e., as seeps and pore water). This assessment does not account for potential future effects of groundwater migrating towards the Columbia River from the Central Plateau, nor does it account for potential mitigative effects of groundwater remediation systems currently in place or planned for future installation.

Selected remedies for groundwater remediation include active pump-and-treat systems, and natural attenuation. Groundwater remediation systems currently in operation are described below.

- **100-HR-3 (100-D and 100-H Areas) and 100-KR-4 (100-K Area)** – In the 100-K, 100-D, and 100-H Areas, interim action pump-and-treat systems are reducing the amount of chromium reaching the river. Also in the 100-D Area, an innovative treatment method is immobilizing chromium in the aquifer (PNNL-15670).

- **100-NR-2 (100-N Area)** – DOE has operated a pump-and-treat system for strontium-90 as an interim action since 1995 and is investigating alternative remediation methods (apatite sequestration and phytoremediation; EPA 1999d) (PNNL-15670).

- **300-FF-5 (300 Area and satellite areas to the north)** – The interim action involves natural attenuation of the cis-1,2-dichloroethene, trichloroethene, and uranium plumes in the 300 Area. While concentrations of the organic contaminants generally are low, uranium remained elevated (EPA 1996). DOE and EPA are investigating alternative forms of remediation via a remedial investigation/feasibility study process.

At the 100-BC-5 and 100-FR-3 groundwater OUs, monitoring indicates there is no imminent threat to human health or the environment, so no interim remedial actions are in progress. Remedial investigations and feasibility studies will be conducted to support final remediation decisions for these OUs. Meanwhile, source waste sites and groundwater contaminant plumes will continue to be monitored.

2.2 PHYSICAL SETTING

This section provides a summary of the physical characteristics of the 100 Area and 300 Area and the 100-IU-2 and 100-IU-6 OUs. A more detailed discussion of Hanford Site climatology, geology, surface water, vadose zone, and groundwater characteristics, including climatological monitoring and summary data, is presented in Appendix B of DOE/RL-2004-37.

The Hanford Site is located within the semiarid shrub-steppe Pasco Basin of the Columbia Plateau in south-central Washington State. Average annual precipitation on the Hanford Site is 17 cm (6.8 in.), and the climate is characterized by warm, dry, sunny summers, and cool winters. Daytime temperatures in mid-summer can exceed 38 °C (100 °F), and winter temperatures can drop to below -18 °C (-0 °F) (DOE/RL-2001-54). Most precipitation that falls on the Hanford Site is lost through evapotranspiration (PNL-10285). However, some precipitation infiltrates the soil and eventually recharges the groundwater flow system. Moisture movement through the vadose zone is important at the Hanford Site because it is the driving force for migration of most contaminants to the groundwater.

Key geologic characteristics of the Hanford Site include surface water features and a number of ridges. The Columbia River flows through the northern part of the Hanford Site and, turning south, forms part of the Site's eastern boundary. The Yakima River runs near the southern boundary of the Hanford Site and joins the Columbia River at the City of Richland, which bounds the Hanford Site on the southeast. Rattlesnake Mountain, Yakima Ridge, and Umtanum Ridge form the southwestern and western boundaries. Saddle Mountain forms the northern boundary of the Hanford Site. Two small east-west ridges, Gable Butte and Gable Mountain, rise above the plateau of the central Hanford Site.

Hanford Site soils include strata consisting of unconsolidated sands and gravels, coarse-grained sand and gravel deposited by the Columbia River, and some fine-grained deposits. *Soil Survey: Hanford Project in Benton County, Washington* (BNWL-243) describes as many as 15 different surface soil types on the Hanford Site, including sand, sandy loam, and silt. The soil column (vadose zone) to groundwater underlying the 100 Area and 300 Area generally consists of materials belonging to the Hanford and Ringold Formations. The shallower Hanford formation consists predominantly of medium-to-dense sand and gravel, with varying amounts of silt and cobble. The underlying Ringold Formation consists primarily of dense, well-cemented gravels with sand and silt interbeds.

The hydrogeologic characteristics of the 100 Area and 300 Area are affected by their proximity to the Columbia River. The unsaturated vadose zone ranges in depth from near 0 m (0 ft) at the edge of the Columbia River, to more than 80 m (280 ft) at the interior of the Central Plateau. Groundwater beneath the Hanford Site is found in both an upper unconfined aquifer system and in deeper, basalt-confined aquifers. Portions of the upper, suprabasalt aquifer system are locally confined, but because the entire suprabasalt aquifer system is interconnected on a site-wide scale, it is referred to as the Hanford unconfined aquifer system. The deeper, basalt-confined aquifer system is important because there is a potential for significant groundwater movement, and consequently contamination movement, between the two systems.

Historically, the volume of artificial recharge from Hanford Site operations and wastewater disposal was significantly greater than the natural recharge from precipitation. Due to the reduction in discharges since 1984, groundwater levels are falling, particularly around the Hanford Site operational areas (PNNL-13080). The seepage of groundwater into the Columbia River has been known to occur for many years and varies with river stage. In addition, water can also flow from the river into the aquifer at high river stage and then return to the river at low river stage, a phenomenon known as "bank storage."

The flow of the Columbia River through the Hanford Site fluctuates significantly and is controlled primarily by releases from three upstream storage dams. The groundwater flow direction is generally toward the river, although the flow direction may reverse immediately adjacent to the river during high-river stage. Groundwater beneath the Hanford Site originated as either natural recharge from rain and snowmelt, or as artificial recharge during Hanford Site operations. There is no longer artificial recharge due to operations, as all liquid-generating processes have ceased.

2.3 ECOLOGICAL SETTING

A number of studies provide basic environmental information about the Hanford Site, including the 100 Area and 300 Area. The annual *Hanford Site National Environmental Policy Act Characterization Report* (PNL-6415) provides a detailed summary of the ecology, biological resources, and hydrology for the entire Hanford Site, with selected information grouped by major operational areas (e.g., 100 Area, 200 Area, and 300 Area). The document is updated annually and has been used extensively in the preparation of this ecological summary. The *Hanford Reach of the Columbia River: Comprehensive River Conservation Study and Environmental Impact Statement* (DOI 1996) also provides general and specific information on the riparian and aquatic environments found within the Hanford Reach. Other detailed characterization data for the 100 Area and 300 Area, including comprehensive lists of plant and wildlife species occurring in or near the study area, are presented and discussed in *Literature Review of Environmental Documents in Support of the 100 Area and 300 Area River Corridor Baseline Risk Assessment* (PNNL-SA-41467).

To better characterize the ecological setting of the 100 Area and 300 Area for the baseline risk assessment, three key ecological study zones were evaluated: the upland, riparian, and near-shore river zones (Figure 2-2). Delineating the 100 Area and 300 Area in this manner facilitates characterization, sampling, and receptor identification necessary for constructing exposure scenarios and subsequent risk analyses.

This section briefly describes the three ecological zones that will be addressed in the baseline risk assessment, including the characteristic habitat and wildlife species present. More detail on each ecological zone is presented for each reactor area in PNNL-SA-41467.

2.3.1 Upland Environment

The upland zone consists of land above the main channel of the Columbia River (approximately 3 m [10 ft] above the river high-water mark) that is generally dry, not readily influenced by river flow, and depends largely on precipitation for its water supply. For the purposes of the baseline risk assessment, the upland zone is defined as the upland areas contained within the perimeter fences of each reactor area in the 100 Area and 300 Area. In the 100-IU-2 and 100-IU-6 OUs, the upland zone consists of the CERCLA waste sites identified in these OUs.

2.3.1.1 Historical Setting and Original Plant Communities. Historically, much of the habitat in the River Corridor was likely a community dominated by big sagebrush (*Artemisia tridentata*), with lesser amounts of rabbitbrush (*Chrysothamnus nauseosus*) and an understory of Sandberg's bluegrass (*Poa sandbergii*). During the Euro-American settlement of the area, a large portion of the reactor area was disturbed by farming. Construction activities for the reactor projects further disturbed the vegetation and soils in the area. These two major changes in land use resulted in changes to the native plant community, creating areas that have been kept free of vegetation and areas that have partially recovered to various levels of plant succession. None of the affected areas have recovered to pre-disturbance conditions, nor are they expected to due to the presence of invasive non-native species such as cheatgrass (*Bromus tectorum*) in the old farm fields and the disturbed soils in the reactor areas.

2.3.1.2 Current Ecological Setting. Most of the upland environment within the 100 Area and 300 Area operational area fencelines is associated with mechanically disturbed rocky areas and mostly graveled surfaces adjacent to reactor facilities. Vegetation that occurs in these disturbed areas is typically sparse and consists of early successional species such as cheatgrass (*Bromus tectorum*), Russian thistle (*Salsola kali*), tumblemustard (*Sisymbrium altissimum*), and bur ragweed (*Ambrosia acanthicarpa*). Upland plant communities have been altered by the proliferation of nonnative plant species, such as cheatgrass, Russian thistle, knapweed (*Centaurea* spp.), and yellow star thistle (*Centaurea solstitialis*). These invasive plants compete with native plants, affect the animals that inhabit an area, and can increase the magnitude of wildfires. Most operations areas, including waste sites, were historically maintained free of vegetation for contamination control, fire prevention, and maintenance purposes.

Some areas that are no longer used for waste disposal, construction activities, or site operations have begun to revegetate naturally to communities dominated by gray rabbitbrush with an understory of Sandberg's bluegrass, bulbous bluegrass (*Poa bulbosa*), and cheatgrass. Sagebrush is present but infrequent within the upland zone adjacent to CERCLA remediation areas. Each of these species is well adapted to the rocky soils characteristic of remediated areas of the upland zone. To promote the reintroduction and colonization of native species, remediated upland CERCLA waste sites are revegetated with the goal of reestablishing sagebrush/ Sandberg's bluegrass communities with a mixture of other native grasses and forbs adapted to rocky soils. Following restoration, the vegetation type, density, and species diversity may not be the same as before initial disturbance, due to the change in soil structure. As the restored plant communities mature, however, improvements in shrub coverage will provide important habitat for native wildlife species. In addition, plants that rely on fine-textured soils may occur on restored or naturally recovering sites, but typically are not expected to be abundant.

The current vegetation association most common to the less-disturbed soils of the upland zone is Sandberg's bluegrass-cheatgrass with incidence of gray rabbitbrush. Large areas of cheatgrass and exotic annual species present in the 100-D, 100-F, White Bluffs, and Hanford Townsite areas that resulted from pre-Hanford farming and homesteading are described as "abandoned old fields." An association of sagebrush-gray rabbitbrush is present within the perimeter fencelines of the 100-K, 100-D, and 100-F Areas. Higher quality sagebrush-bunchgrass associations are present in the 100-D and 100-F Areas (PNNL-SA-41467).

Upland vegetation at the Hanford Townsite differs from the other areas due to the presence of trees scattered along the remains of roadways and walkways associated with previous homesteads, the town itself, and the Hanford Construction Camp. The trees present along old streets of the town/construction camp provide important habitat for a number of mammals and birds. More detailed descriptions of these vegetation cover types are given in *Vascular Plants of the Hanford Site* (PNNL-13688).

Upland vegetation that is representative of current or reasonably anticipated future exposed plant communities or that could serve as exposure pathways to humans or wildlife was evaluated. PNNL-SA-41467 provides complete ecological summaries of the upland zones, including vegetation maps for each reactor area.

Mammals of the upland environment that might be found in and adjacent to the 100 Area and 300 Area include the mule deer (*Odocoileus hemionus*), badger (*Taxidea taxus*), coyote (*Canis latrans*), Great Basin pocket mouse (*Perognathus parvus*), northern pocket gopher (*Thomomys talpoides*), black-tailed jackrabbit (*Lepus californicus*), and cottontail rabbit (*Sylvilagus nuttalii*) (WHC-EP-0620). The abundance of these species and the occurrence of others vary according to the soil type and vegetative community. While other large mammals, such as elk (*Cervus elaphus*), are infrequently observed in the 100 Area and 300 Area upland reactor areas, the number of individual large mammals present per unit area may increase as habitat quality and shrub cover improve through natural recovery and waste site restoration. A complete list of mammals observed and expected in all habitats of the 100 Area is provided in *100 Areas CERCLA Ecological Investigations* (WHC-EP-0620). PNL-6415 presents a complete listing of Hanford Site wildlife species.

Soil type and depth, and vegetation types, densities, and stature influence the animal species that use the upland areas. The soils in the industrialized 100 Area and 300 Area have been disturbed, and most of the area is covered with sandy gravel and cobble soil. This soil matrix limits the diversity of small mammals to species that live on the surface or in very shallow burrows. The dominant small-mammal species associated with remediated sites is the deer mouse (*Peromyscus maniculatus*). Other species that may be present, but likely in very small numbers, are the house mouse (*Mus musculus*) and the harvest mouse (*Reithrodontomys megalotis*). Animals such as burrowing rodents, their predators, and invertebrates that rely on a fine-textured soil for their habitat are expected only incidentally at the remediated CERCLA waste sites given the remediated site's gravel/cobble conditions and lack of plant communities. Burrowing species such as the Great Basin pocket mouse and the pocket gopher are limited to areas where fine-grained soils are at least 30 cm (12 in.) deep (PNL-4140, RHO-SA-211). These species are not found at remediated waste sites backfilled with sandy gravels.

Several species of birds present in the upland zone rely on structures such as buildings, fences, and utility poles for some of their habitat needs. Raptors, such as red-tailed hawks (*Buteo jamaicensis*), are present and frequently nest on buildings, utility poles and towers, and trees along the river. Nonvegetated areas provide nesting habitat for nighthawks (*Chordeiles minor*) and killdeer (*Charadrius vociferus*). Canada geese (*Branta canadensis*) use open cheatgrass areas for winter grazing. Following restoration, improvements in shrub coverage will provide important habitat for native shrub-steppe bird species such as the horned lark (*Eremophila alpestris*), western meadowlark (*Sturnella neglecta*), savannah sparrow (*Passerculus sandwichensis*), loggerhead shrike (*Lanius ludovicianus*), and possibly sage sparrow (*Amphispiza belli*). Raptors will continue to be present, but as the shrubs develop and the open grassy areas shrink in size, wintering geese will likely avoid the area, preferring the cheatgrass areas associated with nearby abandoned farm fields and orchards. A list of bird species observed in the 100 Area is available in WHC-EP-0620. A catalogue of Hanford Site avian species is presented in PNL-6415. Common reptiles found in upland environments at the Hanford Site include the rattlesnake (*Crotalus viridis*), gopher snake (*Pituophis melanoleucus*), yellow-bellied racer (*Coluber constrictor*), and side blotch lizard (*Uta stansburiana*) (PNL-8942, WHC-EP-0601).

The dominant ground-dwelling invertebrate species in the upland environment are harvester ants (*Pogonomyrmex owyheei*) and darkling beetles (family Tenebrionidae). Harvester ants can exist on vegetated and nonvegetated soils and have been documented on waste sites (PNL-2774). Darkling beetles, however, rely on vegetative matter in the soil during their larval stage and therefore are not expected to occur in areas void of vegetation (PNL-2465). Areas that were not used as waste sites or have not been affected by Hanford Site operations likely have less soil disturbance and may support a more robust and diverse community of soil-dwelling fauna than previously disturbed or remediated sites.

2.3.1.3 Expected Future Ecological Setting. Most liquid waste sites in the 100 Area and 300 Area have undergone remedial action where contamination was removed. Because most available backfill material is river-deposited gravel, silt loam soils to restore areas to their original condition are lacking. Restoration has begun on some of the remediated sites and will eventually be completed for all of the sites. The goal of the restoration plan is to revegetate the areas to re-establish a sagebrush/Sandberg's bluegrass community with a mixture of other native grasses and forbs that are adapted to the rocky soils. The plant density and species diversity may not resemble pre-disturbance conditions because the backfill soil type is not the same. Plants that rely on fine-textured soils may occur but will not be abundant. Animals such as burrowing rodents and their predators and invertebrates that rely on fine-textured soil for their habitat will likely be present only as incidental occurrences until the vegetative community becomes reestablished. Areas that were not used as waste sites will have less soil disturbance and may support a more robust and diverse community of soil-dwelling fauna.

As the restored plant community matures, sagebrush will provide roosting and nesting habitat for shrub-steppe birds. The nesting species currently found in the recovering shrub habitats of the Hanford Site are expected to occur in this upland habitat. The dominant species will include the horned lark, meadowlark, savannah sparrow, loggerhead shrike (*Lanius ludovicianus*), and possibly sage sparrow (*Amphispiza belli*). Raptors will continue to be present and, as the shrub communities mature and the open grassy areas shrink in size, geese will avoid these areas, preferring the cheatgrass areas of the adjacent old fields. The large mammal species currently utilizing this area should remain the same and it is expected that the number of individuals per unit area will increase over time due to increased shrub cover, improved forage conditions, and less human activity.

2.3.2 Riparian Environment

Riparian zones are areas of transition between aquatic and upland ecosystems. The riparian zone along the 100 Area and 300 Area extends from the shoreline of the Columbia River to the point on the riverbank where upland vegetation becomes dominant (Figure 2-2). The riparian zone along the Hanford Site is typically narrow and varies in width between the reactor areas, depending on the slope of the riverbank. Vegetation and wildlife species associated with the riparian zones of the 100 Area and 300 Area are identified below, with greater detail presented in PNNL-SA-41467 and WHC-EP-0620.

2.3.2.1 Historical Setting and Original Plant Communities. The riparian zone along the Columbia River varies in width with the steepness of the riverbank. The lateral extent of the shoreline vegetation varies along the Hanford reach and the extent near the reactors is generally similar to downstream areas, which have not been disturbed, indicating that reactor construction activities had relatively little impact on the width of the riparian zone. The original native vegetation was likely dominated by grasses and sedges (*Carex* spp.), with a sparse distribution of willows (*Salix* spp.). Historically, there were very few trees along the Hanford Reach of the Columbia River before the construction of Priest Rapids Dam.

2.3.2.2 Current Ecological Setting. Dominant vegetation within the riparian zone includes mulberry (*Morus alba*), willow (*Salix* spp.), Siberian elm (*Ulmus pumila*), northern wormwood (*Artemisia campestris*), sweet clover (*Melilotus alba* or *M. officinalis*), and reed canarygrass (*Phalaris arundinacea*). The riparian zone along the 100 Area and 300 Area shoreline generally consists of a cobble shoreline with varying densities of vegetation. WHC-EP-0620 list plant and animal species that have been observed along the Columbia River shoreline.

Changes to the composition of shoreline vegetation over time have been influenced by a moderation in the river elevation changes, which are controlled by the operation of Priest Rapids Dam, approximately 18.5 km (10 mi) upstream of the Hanford Site. Due to the steepness of the shoreline, the transition from riparian to upland vegetation is abrupt. Dominant plants in the riparian-upland transition area are bulbous bluegrass, Sandberg's bluegrass, cheatgrass, Russian thistle, and gray rabbitbrush. Detailed characterization information of the riparian environs associated with each reactor area is presented in PNNL-SA-41467.

There is considerable overlap of wildlife use between the riparian and upland zones. Wildlife use of the riparian zone is likely higher than that of the upland zone associated with the CERCLA waste sites due to its proximity to the Columbia River, which results in greater species diversity and the presence of higher density and higher stature vegetation that remains productive over a longer period of time.

Some mammals common to the upland environment are also likely to use and inhabit the riparian environment, including the western harvest mouse, the Great Basin pocket mouse, and the deer mouse (PNNL-14516).

Downs and Tiller (PNNL-14516) provide information on bird populations with respect to riparian vegetation. Location data are available in the electronic Environmental Monitoring and Compliance Project database managed by PNNL. Research efforts have assessed winter bird populations in cottonwood/willow (*Populus/Salix*) communities of the Columbia River shoreline (Rickard 1964, Rickard and Rickard 1972), quantified shorebird response to water fluctuations in the Columbia River near-shore environment (Books 1985), and evaluated habitat selection and use by spring migrant passerines (Duberstein 1997). The information gathered during these research efforts has been used to document the status and ecology of the Hanford Site's avian wildlife.

A variety of snakes common to the upland areas may also use the riparian habitat. Other reptiles that may be found in the riparian zone include the western terrestrial garter snake (*Thamnophis sirtalis*) and the painted turtle (*Chrysemys picta*) (Hallock 1998, PNNL-14516). Amphibians in the riparian and near-shore environments of the Hanford Reach include mostly Woodhouse's toads (*Bufo woodhousii*), but bullfrogs (*Rana catesbeiana*) and Great Basin spadefoot toads (*Scaphiopus intermontanus*) may also be present (PNNL-14516).

2.3.2.3 Expected Future Ecological Setting. The ecological setting along the Columbia River shoreline is not expected to change significantly in the near future. For example, the width of the riparian zone is not expected to increase because it is limited by the steep shoreline. The number of white mulberry and Siberian elm trees may increase, but the area remaining for colonization is limited. Effluent pipelines extend from the reactor areas into the Columbia River and are currently being evaluated by the Tri-Parties for final disposition. If remedial action is required, impacts to shoreline areas from the river pipeline projects will be limited to small areas, and restoration plans would be developed as appropriate. In the future, changes to the composition of the shoreline vegetation will continue to be influenced by changes in average river elevation, which is controlled by the operation of the Priest Rapids Dam, located approximately 18.5 km (10 mi.) upstream.

2.3.3 Near-Shore River Environment

The near-shore river zone consists of a narrow band of the Columbia River shoreline adjacent to the 100 Area and 300 Area. The near-shore river zone includes the surface water of the Columbia River from the area that is permanently inundated by river water, extending from the low-water mark (i.e., a "green line" where the periphyton [sessile algae] remains green year-round) into the river to a water depth of approximately 2 m (6 ft). The Columbia River is the dominant aquatic ecosystem on the Hanford Site and supports a large and diverse community of plankton, benthic invertebrates, fish, and other communities. The 100 Area and 300 Area Component of the RCBRA specifically addresses the near-shore river zone associated with the reactor areas, while the remainder of the Columbia River (i.e., depths greater than 2 m [6 ft]) is being addressed in the CRC of the RCBRA.

The river environment adjacent to the 100 Area is shallow, with a mixture of boulders, cobbles, and gravel substrate in the near-shore area. The main river channel follows the left shoreline across from the 100 Area and 300 Area. Near-shore river zone features include sloughs, rapids, and shoreline areas with varying water velocities. Sloughs are present in or near the Hanford Townsite and White Bluffs shorelines and serve as important habitat for a number of aquatic species. Columbia River channel classifications along each of the reactor areas shorelines are based on planform and geomorphology criteria determined by the Army Corps of Engineers during bathymetric studies performed in the 1980s (PNNL-SA-41467). Geomorphic classifications are defined in Table 2.6 of PNNL-SA-41467. The key features of the near-shore river environment for each of the river study areas within the scope of the 100 Area and 300 Area Component of the RCBRA are as follows:

- **100-K Area.** Columbia River classification: wide asymmetric and narrow symmetric (PNNL-SA-41467). A major feature is the presence of Coyote Rapids located upstream of the 100-K Area.

- **100-D Area.** Columbia River classification: wide asymmetric river channel changing to wide asymmetric with islands (PNNL-SA-41467). D-Island is a major feature in the downstream portion of the 100-D Area shoreline.

- **100-H Area.** Columbia River classification: wide asymmetric with islands (PNNL-SA-41467). A shallow channel of water separates the shoreline from islands.

- **White Bluffs (100-IU-2 OU).** The White Bluffs river habitat is dominated by the White Bluffs slough that opens to a narrow symmetrical channel. Sloughs serve as important habitat for a number of aquatic species. At high water, the river breaks through the upstream end of the slough, forming a flowing channel.

- **100-F Area.** Columbia River classification: wide asymmetric with islands (PNNL-SA-41467). A shallow channel of water separates the shoreline from islands.

- **Hanford Townsite (100-IU-6 OU).** The Hanford Townsite near-shore river habitat includes the Hanford Slough, which opens to a long segment of narrow symmetrical river channel extending downstream to Savage Island.

- **300 Area.** Columbia River classification: wide asymmetric and narrow symmetric (PNNL-SA-41467).

2.3.3.1 Current River Setting. The Columbia River is the dominant aquatic ecosystem on the Hanford Site and supports a large and diverse community of plankton, benthic and lotic invertebrates, and resident and anadromous fish. Vegetation in the near-shore river zone consists of macrophytes and periphyton. Macrophytes are sparse in the Columbia River because of strong currents, rocky bottom, and frequently fluctuating water levels. Where macrophytes are found, they commonly include duckweed (*Lemna* spp.) and the native rooted pondweeds (*Potamogeton* spp. and *Elodea canadensis*). Macrophytes provide food and shelter for juvenile fish and spawning areas for some species of warm-water game fish. Eurasian milfoil (*Myriophyllum spicatum*), an introduced macrophyte, has increased to nuisance levels since the late 1980s and may encourage increased sedimentation of fine particulate matter. Periphyton communities develop on suitable solid substrate wherever there is sufficient light for photosynthesis and adequate currents to prevent sediment from covering the colonies.

More than 45 species of fish have been identified in the Hanford Reach of the Columbia River. Of these species, Chinook salmon (*Oncorhynchus tshawytscha)*, sockeye salmon (*Oncorhynchus nerka)*, coho salmon (*Oncorhynchus kisutch)*, and steelhead (*Oncorhynchus mykiss)* use the river as a migration route to and from upstream spawning areas and are of the greatest economic importance. Other fish of importance to sport fishermen are the native mountain whitefish (*Prosopium williamsoni)* and white sturgeon (*Acipenser transmontanus)*. Introduced species like smallmouth bass (*Micropterus dolomieui)*, black crappie (*Pomoxis nigromaculatus*), channel catfish (*Ictalurus punctatus)*, and walleye (*Stizostedion vitreum)* are also popular. Other large fish populations include introduced common carp (*Cyprinus carpio)* and native species such as redside shiner (*Richardsonius balteatus*) and largescale suckers (*Catostomus macrocheilus)*. Smaller fish, such as sculpin (*Cottus* spp.), are associated with shoreline habitats and have small home ranges.

2.3.3.2 Expected Future River Setting. The Columbia River environment is not expected to change significantly in the near future. If the decision is made to remove the effluent pipelines from the river, there will be a temporary disruption of the river bottom and benthic organisms. A major factor to be considered in making this decision is whether the benefit of removing the outfall pipelines outweighs the destruction of the shoreline and benthic river habitat that would result from this effort. Characterization of potential risks or impacts from disposition alternatives for the effluent pipelines is not within the scope of this risk assessment.

2.3.4 Consideration of Endangered and Threatened Species

A variety of species have been recognized by state or federal agencies as having special status based on the species' risk of extinction. Publications describing the occurrence of threatened and endangered (T&E) species on the Hanford Site are summarized in PNNL-SA-41467. Bald eagles (*Haliaeetus leucocephalus*), currently listed as Threatened, and potentially de-listed in July 2007, are present during the nesting season in riparian environments on the Hanford Site. There are eight plant (Columbia milkvetch, dwarf evening primrose, Hoover's desert parsley, *Loeflingia*, persistent sepal yellowcress, Umtanum desert buckwheat, White Bluffs bladderpod, and white eatonella) and five bird (American white pelican [*Pelecanus erythrorhynchos*], bald eagle, ferruginous hawk [*Buteo regalis*], Sandhill crane [*Grus canadensis*], and greater sage grouse [*Centrocercus urophasianus*]) species listed as threatened or endangered under the Washington Natural Heritage Program (PNNL-SA-41467). However, no plants, invertebrates, reptiles, amphibians, or mammals on the federal list of T&E wildlife and plants are known to occur on the Hanford Site (PNNL-SA-41467). Threatened and endangered species are considered at risk and, as such, these species were not identified for sacrificial sampling and subsequent analyses for the risk assessment effort. Data for selected surrogate species were required for contaminant or biological characterization based upon the guild in which the special status species were identified (Table 5-1 of DOE/RL-2004-37).

Potential effects of contaminants on T&E species were evaluated using a three-step process: (1) surveys for T&E species likely to be exposed to the contaminants, (2) estimation of the degree of exposure, and (3) evaluation of potential effects from these levels of exposure. The first step was to determine those T&E species that could potentially inhabit or reside for significant exposure periods within the areas of study. The list of potential species in the 100 Area and 300 Area was developed based on site-specific surveys. Results of site-specific surveys for T&E species and potential habitat are documented in WCH-139. Potential exposure for T&E species is evaluated by concentrations in abiotic and biotic media, contaminant uptake in surrogate species and food-chain modeling. Exposure is compared to toxicity thresholds for COPCs. A number of toxicity benchmarks prescribed to be protective of populations, such as

WAC and biota dose assessment guidelines, are not necessarily indicative of individual-level effects: exposure will be compared to no-effect levels for characterizing risk to T&E species.

2.4 CONCEPTUAL EXPOSURE MODEL FOR HUMAN HEALTH

This section provides a description of the human health conceptual exposure model (HHCEM) for the 100 Area and 300 Area Component of the RCBRA. The HHCEM considers previously described contaminant sources, release mechanisms, and transport media (Section 2.1.1). The HHCEM is used to identify potentially complete human exposure pathways for a variety of hypothetical exposure scenarios.

The HHCEM is an extension of the information presented in the preceding sections of the CSM, taking into account additional information related to potential exposure scenarios and receptors, exposure media, and exposure routes. As described in EPA risk assessment guidance (EPA/540/1-89/002), an exposure pathway describes the course a contaminant takes from a source to a receptor. Assuming that exposure occurs at a location other than the source, every complete exposure pathway contains the following elements (EPA/540/1-89/002):

- Known and potential sources and/or releases of contamination
- Chemical migration pathways
- Potential exposure scenarios (for human health risk assessments)
- Potential exposure media
- Potential exposure routes and receptors.

In the absence of any one of these components, an exposure pathway is considered incomplete, and by definition, there is no risk or hazard (EPA/540/1-89/002, EPA/540/1-89/001). With the exception of radionuclides, environmental contaminants must come into physical contact with the receptor for an exposure to occur. External radiation exposure can occur when a receptor comes within close proximity but does not physically contact radiologically contaminated media. The following subsections describe the exposure areas that were evaluated as part of the risk assessment and identify potentially complete human exposure pathways and receptors.

2.4.1 Present-Day and Potential Future Exposure Scenarios and Human Receptors

Present-day exposures in the six reactor areas, the CERCLA waste sites of the 300 Area, and the 100-IU-2 and 100-IU-6 OUs, are controlled by access restrictions. Present-day activities in these areas are limited to security surveillance and remedial action and sampling activities conducted by remedial action workers. Activities conducted by Hanford Site workers are managed under a Site Health and Safety Plan which addresses worker training to minimize potential exposures and requires monitoring of potential radiological exposure, where necessary. Because potential exposures and associated risks are controlled for these workers, they are not considered potential receptors for the human health risk assessment.

The nature of potential future exposure scenarios in the 100 Area and 300 Area has been the subject of recent planning and discussion among stakeholders (Exposure Scenarios Task Force 2002). One outcome of these discussions was a decision to implement a pilot human health and ecological risk assessment for the 100-B/C Area. Later in 2002, a preliminary risk-based evaluation of post-remediation conditions at the 100-B/C Area cited a rural residential exposure scenario as a basis for evaluating the protection of human health (BHI-01669). This evaluation also noted that it was the intention of the Tri-Parties to address Native American exposure concerns when information to conduct such an exposure assessment became available (BHI-01669).

The 100-B/C Pilot Project risk assessment (DOE/RL-2005-40) employed the following hypothetical exposure scenarios in the human health risk assessment:

- Hypothetical Future Rural-Residential Scenario
- Hypothetical Future Industrial Worker Scenario
- Hypothetical Future Resident National Monument Worker Scenario
- Hypothetical Future Recreational Use Scenarios: Avid Wild Game Hunter, Avid Angler, and Casual User applications.

In addition to these exposure scenarios, the Confederated Tribes of the Umatilla Indian Reservation (CTUIR) had submitted an exposure scenario report to DOE (Harris and Harper 2004). As noted in DOE/RL-2005-40, several local and regional Tribes have ancestral ties to the Hanford Reach of the Columbia River and surrounding lands. Each Tribe has been requested by DOE to provide an exposure scenario(s) that reflects their traditional activities. At this time, only the CTUIR has provided such a scenario. However, exposure via this scenario was not assessed in the 100-B/C Pilot Project risk assessment because the authors concluded that the submitted report did not provide a complete set of exposure assumptions (DOE/RL-2005-40).

The four exposure scenarios employed in the 100-B/C Pilot Project risk assessment (Rural-Residential, Industrial/Commercial, Resident National Monument/Refuge, and Recreational) will also be employed in this human health risk assessment for the 100 Area and 300 Area Component of the RCBRA. Additionally, the "Fish-Based Diet" variant of the CTUIR exposure scenario described in Harris and Harper (2004) will be implemented in this human health risk assessment. The specific exposure pathways and receptors associated with each of these exposure scenarios are described in Section 2.4.2.

It is important to recognize the hypothetical nature of the exposure scenarios used in the 100 Area and 300 Area Component of the RCBRA relative to future conditions in the 100 and 300 Areas. The purpose of assessing potential risks under a variety of hypothetical exposure conditions is to provide risk managers with information on how potential risks may vary as a function of exposure intensity under a variety of exposure assumptions. However, the assumptions underlying these hypothetical exposure scenarios may be inconsistent with intended future land uses as stated in the CLUP (DOE/EIS-0222-F) and the designation of the Hanford

Reach National Monument (65 FR 37253). The use of these scenarios in this risk assessment does not imply any endorsement of either the scenarios or the underlying assumptions by DOE or other stakeholders with respect to future land use.

Potential risks related to the hypothetical Rural-Residential and CTUIR scenarios in particular are not representative of potential future exposures when DOE maintains its anticipated land use and institutional controls. Because no decisions on final land use had been made when the Interim Action RODs for the 100 Area were written, a conservative assumption of "unrestricted use" via a hypothetical rural resident was assumed for developing cleanup goals. While the CLUP (DOE/EIS-0222-F) later identified future uses of the Hanford Site, the interim action RODs have not been changed to deviate from a goal of unrestricted use. In addition, the proclamation for the Hanford Reach National Monument (65 FR 37253) stated that the Monument lands would not be developed for residential or commercial use in the future. As of May 2007, no changes have occurred with respect to land uses under the monument designation.

2.4.2 Potentially Complete Human Exposure Pathways and Receptors

Contaminant sources, release mechanisms, and transport mechanisms were described in Section 2.1. Exposure media and exposure routes are described in the following subsections. A graphical depiction of potentially complete exposure pathways evaluated in the 100 Area and 300 Area Component of the RCBRA is provided in Figure 2-3.

2.4.2.1 Exposure Media. Exposure media may be divided into two classes for consideration. The first class of affected media, including soils, groundwater, and sediments, is the principal reservoirs of residual environmental contamination in the 100 Area and 300 Area. These media have been potentially affected by releases from historical operations, including historical air stack releases. A second class of media, including biota, air, and surface water, may be affected due to migration of contaminants from air, soils, groundwater, and sediments. Decommissioned structures may also remain on site and have embedded contamination; however, structures, with the exception of the effluent pipelines, are not part of the scope of this assessment. The effluent pipelines represent a special case and also represent a unique source material and exposure medium.

Soil. In each of the exposure scenarios described, direct and indirect human exposures to environmental contaminants present in soil are likely to be a key aspect of the risk assessment. Direct soil exposure includes exposure routes such as incidental ingestion, inhalation of dust (i.e., suspended soil), dermal absorption, and external irradiation. Indirect exposure refers to human exposure that is mediated by transport from soil to a secondary exposure medium. For example, indirect exposure to soil contaminants may occur via plants and/or animals whose tissues contain contaminants that have been taken up from soil.

Shallow zone soil is defined as extending from the ground surface to a depth of 4.6 m (15 ft) bgs based on definition in WAC 173-340-740(6)(d) as follows: "For soil cleanup levels based on human exposure via direct contact or other exposure pathways where contact with the soil is required to complete the pathway, the point of compliance shall be established in the soils throughout the site from the ground surface to fifteen feet below the ground surface.

This represents a reasonable estimate of the depth of soil that could be excavated and distributed at the soil surface as a result of site development activities."

Although exposure may potentially occur to soils as deep as 4.6 m (15 ft), it is much more likely that direct receptor exposure to soils will be dominated by soils within a few inches of the ground surface. There are some obvious exceptions to this statement, such as exposure by construction workers during trenching and excavation and by residents during outdoor projects (i.e., fencing, local excavation for landscaping). Nevertheless, these exposures are quite brief when compared to long-term exposure periods measured in decades. The quantity of subsurface soils potentially relocated to the ground surface, where chronic exposure may occur, will depend on the nature of the excavation. For example, basement excavation will generate a much larger volume than will excavation for utilities. Such relocation might have a significant effect on soil contaminant concentrations for localized residential and industrial exposures, but would probably have minimal effect on soil concentrations contacted during recreational exposure over much broader areas. Indirect exposure to soils below the first few inches may be mediated by plant root uptake in garden vegetables, fruit trees, or native vegetation. Deeper soils may also be redeposited to the ground surface over time due to digging or burrowing activities of wildlife.

Residual contamination in soils is primarily characterized for the 100 Area and 300 Area Component of the RCBRA using two types of samples: CVP and remaining sites verification package (RSVP) samples from the sidewalls and floors of excavated waste sites or the surface of unexcavated "native soil" sites, and MIS soil samples from the 0- to 15-cm (0- to 6-in.) soil interval. MIS samples from several investigation areas in the 100 Area and 300 Area representing elevated and low-medium categories of residual contamination, as well as unaffected reference areas, will be employed in the risk assessment (DOE/RL-2005-42). Soil contaminant concentrations represented by operational area MIS data reflect current residual surface soil concentrations at and around remediated waste sites. Soil data from remediated waste site verification samples collected within 4.6 m (15 ft) of the ground surface will also be used to evaluate risks from potential soil exposure. Use of these data from sites where clean fill has been placed following remediation implies that humans have excavated this soil and relocated it to the ground surface where exposure may take place. A basement excavation model will be employed in the risk assessment to reflect this process. Soil data from CVP samples below 4.6 m (15 ft) are also used to evaluate the potential effects related to deposition of drill cuttings from a residential water supply well on the ground surface. If volatile organic compounds (VOCs) are measured at significant concentrations in soil, soil data from below 4.6 m (15 ft) may also be relevant for assessing exposure to contaminants that can migrate to the ground surface via gas-phase diffusion.

<u>Groundwater</u>. As described in the Environmental Setting, groundwater at the 100 Area and 300 Area is relatively shallow and flows in the direction of the Columbia River. In addition to local sources of contamination, groundwater at some 100 Area and 300 Area wells may at some time harbor contamination from upgradient releases in the 200 Area.

Exposure to groundwater is evaluated for the CTUIR, Rural-Residential, and Resident Monument Worker exposure scenarios. However, the purpose of this human health assessment is primarily to evaluate the adequacy of soil remediation efforts at individual waste sites.

Protection of groundwater from residual soil contamination was addressed in the development of existing waste site soil remediation criteria for the 100 Area and 300 Area, and groundwater is being addressed via a program instituted in parallel with waste site remediation. For these reasons, potential exposures to groundwater are assessed independently of other pathway risks. The purpose of calculating risks related to groundwater is primarily to provide an approximate measure of the relative significance of soil and groundwater as exposure media in the 100 Area and 300 Area.

Direct exposure to contaminants in groundwater may occur during household uses of groundwater for drinking and cooking (ingestion), and bathing (dermal absorption). Additionally, if VOCs are measured in groundwater, indirect exposure by inhalation of VOCs in air may occur while bathing or when using groundwater in the home for other purposes. In the CTUIR scenario, exposures may also occur via the use of groundwater in the sweat lodge. Although indirect exposures to contaminants in groundwater extracted via a water well may also occur when contaminated groundwater is used to irrigate a garden or provide water for livestock, such modeling of exposure to groundwater contaminants is not assessed in the risk assessment.

Residual contamination in groundwater is characterized in the risk assessment by the use of groundwater monitoring well data. RCBRA data from approximately 60 wells in the 100 Area and 300 Area will be used to characterize residual groundwater contaminant concentrations for the risk assessment (DOE/RL-2005-42).

Sediments. Exposure to contaminants in Columbia River sediments via inadvertent ingestion, dermal absorption, and external irradiation is potentially applicable to the CTUIR, Recreational, and Resident Monument Worker exposure scenarios. Thirty sediment sampling sites were selected specifically for evaluation based on locations of known groundwater plumes, the results of a 2005 conductivity survey, and past biota sampling locations and results (DOE/RL-2005-42). The sampling sites were located within the 300 Area (uranium plume), 100-D and 100-K Areas (chromium plumes), and 100-N Area (strontium plume). Seven reference sediment samples were also collected.

Biota. Exposure to contaminants via exposure pathways that are mediated by plants or animals is part of the Rural-Residential scenario, CTUIR scenario, and the “Avid Angler” and “Avid Hunter” applications of the Recreational exposure scenario. Home-grown fruits and vegetables may have elevated levels of contaminants if they are grown in contaminated soils and/or are irrigated using contaminated groundwater. Similarly, wild plants may absorb contaminants in soil or sediment through their roots. Livestock such as beef cattle or poultry, and wild game such as deer or elk, may also uptake contaminants from soil and accumulate them in their tissues. Exposure may occur both through the ingestion of plants growing on contaminated soils as well via direct ingestion of soil while grazing.

A variety of biota data have been collected for the 100 Area and 300 Area Component of the RCBRA, including contaminant concentrations in vegetation, ground-dwelling invertebrates, fledgling birds, small mammals, aquatic macroinvertebrates and bivalves, and finfish. Some of these data may be directly applicable for estimating potential exposure concentrations for the human health risk assessment. However, potential contaminant concentrations in some biotic exposure media may need to be modeled from contaminant concentrations in soil. An important consideration for such modeling is the size of potential habitat or grazing areas relative to the area of contamination. Cultivated crops and livestock that pertain to both Rural-Residential and CTUIR exposure scenarios include garden produce, fruits and berries, poultry, and livestock such as beef cattle. Other potentially relevant biotic media include Columbia River fish, shellfish, and crustaceans for the Avid Angler and CTUIR scenarios, game birds and animals for the Avid Wild Game Hunter and CTUIR scenarios, and wild plants used for food, medicine, and in a variety of traditional Native American cultural/subsistence practices.

Air. Inhalation exposure to contaminants on suspended soil (dust) or in the gas phase (VOCs and some radioisotopes) may occur in indoor or outdoor environments for the Rural-Residential, CTUIR, and Industrial/Commercial exposure scenarios. Exposures in the Recreational and Resident Monument Worker scenarios are presumed to occur outdoors. Although contaminant concentrations in outdoor air may be measured directly, localized air concentrations used in the 100 Area and 300 Area Component of the RCBRA will be modeled from concentrations in soil due to the absence of applicable air data. Concentrations of contaminants on dust in outdoor air are calculated from soil data using air dispersion modeling.

Indoor concentrations of dust-borne contaminants may be evaluated as a fraction of those in outdoor air. If VOCs are identified as COPCs in soil, indoor concentrations of gas-phase contaminants emanating from the vadose zone may be modeled as a function of diffusion through the soil column, and diffusion or advection into a hypothetical building. Similarly, if VOCs are identified as COPCs in groundwater, they may contribute to contamination in indoor air via volatilization from domestic uses of water in the bathroom and kitchen. In the CTUIR scenario, inhalation exposure to contaminants in water may also occur in the sweat lodge.

Surface Water. Ingestion of surface water at springs or seeps on the ground surface, and from the Columbia River, is a potentially complete exposure pathway in the CTUIR exposure scenario. Surface water samples from the Columbia River were collected at the locations (described above) where sediment and pore water samples were acquired. Reference river water samples from seven reference locations were also obtained (DOE/RL-2005-42). If available, analytical data from samples of spring and seep water will also be employed in the risk assessment. Alternatively, or as a supplement to seep/spring data, groundwater analytical data from locations upgradient of seeps and springs may be employed to characterize potential contaminant concentrations at seeps and springs.

2.4.2.2 Exposure Routes and Receptors. Exposure routes and receptors for each of the hypothetical future exposure scenarios for the 100 Area and 300 Area Component of the RCBRA are described below.

Future Rural-Residential Scenario. The potentially exposed population for this exposure scenario includes adults and children. As shown in Figure 2-3, residents could potentially be directly exposed to site contaminants in shallow-zone soil through external irradiation, incidental ingestion, dermal absorption, inhalation of dust, and inhalation of gas-phase constituents in indoor air. Possible exposure to contaminants in in situ deep-zone soil (soils greater than 4.6 m [15 ft] depth) is limited to inhalation of gas-phase constituents diffusing through the soil column into indoor air. Limited exposure to deep-zone soils may also occur by deposition of water well drill cuttings on the ground surface. Residents may potentially be exposed to groundwater contaminants through ingestion, dermal absorption, and inhalation of volatiles released to indoor air during showering, dishwasher use, or other household activities.

Adults and children may also be indirectly exposed to shallow-zone soil contaminants from consumption of produce (fruits and vegetables) raised in a backyard garden. Exposure from consumption of products from domestic livestock is also feasible for a rural homestead. Such products may include beef, poultry and eggs, and milk. Nationally, about 60% of rural households have home gardens (National Gardening Association 1987), and probably fewer households raise livestock for domestic consumption. Therefore, not all potential residential receptors are likely to be exposed via these biotically mediated exposure pathways. Individuals in households engaged in raising livestock and/or gardening therefore represent a subpopulation of rural residents whose activities may cause them to have a higher rate of exposure to residual contaminants in environmental media. Similarly, individuals in some households may fish in the Columbia River and supplement their diet in this manner. Exposure via ingestion of fish will therefore also be considered in the hypothetical Rural-Residential scenario.

Future Industrial/Commercial Worker Scenario. The potentially exposed population for this exposure scenario includes adult workers. As shown in Figure 2-3, exposure routes for contaminants in shallow-zone soil evaluated in this exposure scenario include external irradiation, incidental ingestion, dermal absorption, inhalation of dust, and (if VOCs are identified in soils) inhalation of gas-phase constituents in indoor air. Possible exposure to contaminants in deep-zone soil is limited to inhalation of gas-phase constituents in indoor air.

Future Resident Monument Worker Scenario. The potentially exposed population for this exposure scenario includes adult workers. As shown in Figure 2-3, adult workers could potentially be exposed to site contaminants in upland or riparian soil through external irradiation, incidental ingestion, dermal absorption, and inhalation of dust. Additionally, workers in this exposure scenario may be exposed to contaminants in river sediments via external irradiation, incidental ingestion, and dermal absorption. These workers are assumed to be exposed primarily in an outdoor environment as they lead tours, conduct ecological education, or similar activities. When not working, these receptors are envisioned to live in an on-site residence associated with the refuge. A major distinction between the Rural-Residential and Resident Monument Worker scenarios is that the latter does not include agricultural activities such as gardening and raising livestock.

Future Recreational Use Scenarios. The recreational exposure scenario involves three distinct applications that relate to different types of activities. The Casual User application addresses occasional recreational use and is focused primarily on activities such as walking, picnicking, and swimming near the river. The Avid Wild Game Hunter is focused on individuals who are recreational hunters (as opposed to those engaged in subsistence hunting). Game species may include deer and elk, as well as birds such as grouse. This application is likely to be associated primarily with upland regions of the 100 Area and 300 Area. The Avid Angler, like the Avid Wild Game Hunter, is focused on individuals who are not engaged in a subsistence lifestyle. The

Avid Angler application is associated primarily with near-shore regions of the 100 Area and 300 Area.

Casual User. The potentially exposed population for this exposure scenario includes adults and children. Adults and children may be exposed to shallow-zone soil contaminants via external irradiation, incidental ingestion, dermal absorption, and inhalation of dust. Because this scenario is focused primarily on activities such as walking, picnicking, and swimming near the river, riparian soils are employed as the key exposure medium. Although these receptors may also be exposed in theory to contaminants in river sediments, exposure to sediments is a focus of the Avid Angler scenario and so is not considered in this scenario.

Avid Wild Game Hunter. The potentially exposed population engaged in hunting for this exposure scenario includes adults and older children.[3] These receptors may exposed while hunting to shallow-zone soil contaminants via external irradiation, incidental ingestion, dermal absorption, and inhalation of dust. The potentially exposed population for ingestion of wild game is not restricted to older children and adults who actively hunt but may also include younger children at home.

The signature exposure pathway associated with this application of the Recreational Use scenario is exposure to site contaminants through the consumption of wild game. As shown in Figure 2-3, wild game may be exposed to contaminants in shallow-zone soil through direct ingestion of soil as well as ingestion of plants containing contaminants absorbed from soil. Wild game may also be exposed to contaminants in sediments and surface water. Although not explicitly shown in Figure 2-3, contaminants incorporated into plants growing on contaminated sediments may also contribute to contaminant concentrations in game tissues. In this scenario, it is assumed that muscle tissue is the portion of the game animal that is ingested.

Avid Angler. The potentially exposed population engaged in hunting for this exposure scenario includes adults and older children. These receptors may be exposed while fishing to shallow-zone soil contaminants in the riparian zone via external irradiation, incidental ingestion, dermal absorption, and inhalation of dust. Additionally, avid anglers in this scenario may be exposed to surface sediment in the Columbia River through external irradiation, incidental ingestion, and dermal absorption while fishing or swimming in the Columbia River. As with the Avid Wild Game Hunter scenario, the potentially exposed population for ingestion of fish is not restricted to older children and adults who actively fish but may also include younger children at home. Although Figure 2-3 lists finfish, shellfish, and crustaceans as potential exposure media, this exposure scenario is focused primarily on recreational and sport fishing for species such as salmon and trout. In this scenario, it is assumed that muscle tissue (*i.e.*, fillets or steaks) is the portion of the fish that is ingested. Some incidental ingestion of river water may also be anticipated for these receptors during swimming. Because contaminant exposure via river water is likely to be negligible relative to potential exposures from soils and sediments, exposures mediated by river water are not quantified for the recreational receptors.

[3] EPA traditionally defines child receptors as between the ages of 1 and 6. In the Avid Wild Game Hunter and Angler scenarios, child receptors engaged in frequent hunting or fishing are envisioned to be older than age 6.

CTUIR Scenario. Exposure routes and receptors have been defined by the CTUIR for a traditional subsistence lifestyle scenario (Harris and Harper 2004). A complete lifetime is reflected in this scenario, from infancy through old age. Some of the exposure routes are identical to those described for the Rural-Residential, Avid Wild Game Hunter, and Avid Angler scenarios, although the specific exposure media and parameter values may differ in the CTUIR scenario. There are a number of potentially unique exposure media in this scenario including surface water, and wild plants used as medicines, smoking materials, smudges, dyes, and for various crafts. The types of animals hunted and fished, and the tissues eaten or otherwise used, may differ from what is assumed in the Recreational Use scenarios. Similarly, the types of garden produce and livestock, and their uses, are not necessarily analogous to those that are applicable in the Rural-Residential scenario.

Receptors for the CTUIR exposure scenario described in Harris and Harper (2004) have been defined both by age (infant, child, youth, adult, and elder) and, for adults, by lifestyle (suburban resident, rural residential farmer-gardener, and subsistence forager). Exposure parameter values for daily incidental soil ingestion, inhalation rate, and drinking water ingestion rate are differentiated for these lifestyle groups in Table 3 of Harris and Harper (2004). Dietary components of a traditional fish-focused diet within a subsistence foraging lifestyle are provided in Table 5 of Harris and Harper (2004). This diet includes approximately 40% of daily calories from fish, with additional contributions from undomesticated roots, greens and berries, and some wild game. Although Harris and Harper (2004) describe apportionment of time across numerous potential activities and locations for different individuals, this assessment considers an individual who spends essentially all of their time in and around their residence. This assumption considerably simplifies the potential calculations related to this scenario and also results in maximum exposure with respect to residual contamination associated with an individual remediated waste site.

2.4.2.3 Exposure Areas. The exposure routes for the various exposure scenarios shown in Figure 2-3 are potentially associated with very different spatial scales of exposure. For many of the soil and sediment exposure routes (incidental ingestion, dermal absorption, external irradiation), the spatial scale on which exposure occurs (i.e., the exposure area) is related to the nature of the exposure activities for the exposure scenario. For the Industrial/Commercial Worker exposure scenario, contact with soil may occur only in a limited area surrounding a workplace. An appropriate exposure area for these exposure routes may therefore represent only a small fraction of an acre in this scenario. By contrast, soil contact that occurs during upland recreational game hunting may conceivably take place over hundreds of acres. Because activities such as game hunting may occur over spatial scales that are considerably larger than individual waste sites, the representation of potential exposure point concentrations for soil is more challenging than in cases where the spatial scales of waste sites and exposure activities are more congruent.

The concept of the exposure area is also applicable to exposure routes involving foodstuffs. Some foodstuffs, such as garden produce or poultry products, may be raised in a relatively small area near a residence. In these cases, soil exposure point concentrations appropriate for modeling concentrations in foodstuffs may be analogous to concentrations used to calculate exposure via incidental ingestion, dermal absorption, and external irradiation around the home. However, the home range of certain game species can be very large, and contaminant tissue concentrations may be expected to reflect exposure across the entire home range.

The approximate sizes of the assessment areas for 100 Area and 300 Area Component of the RCBRA are as follows:

100-B/C Area	295 ha (730 acres)
100-D/DR Area	283 ha (700 acres)
100-F Area	255 ha (630 acres)
100-H Area	150 ha (370 acres)
100-K Area	97 ha (240 acres)
100-N Area	65 ha (160 acres)
300 Area	405 ha (1,000 acres)

The 100-IU-2 and 100-IU-6 assessment areas contain various waste sites that are not spatially contiguous, so an analogous approximate size for these assessment areas does not exist.

The number of remediated "interim-closed" waste sites in the seven assessment areas for which sizes are provided varies from 12 sites in the 100-K Area to 88 sites in the 300 Area. For the Industrial/Commercial Worker exposure scenario, as well as the Rural-Residential exposure scenario (excepting exposure via free-ranging beef cattle or dairy cows), soil-related risk assessment calculations can be performed on the scale of the individual waste sites. For the Recreational and Monument Worker exposure scenarios, risk assessment calculations for direct exposure to soil or sediment are more appropriate on the scale of an entire assessment area.

An appropriate soil exposure area for game animals is a function of home range and seasonal use patterns, while for beef cattle or dairy cows it relates to assumptions for grazing area, pasture rotation, and similar considerations. For fish, a major consideration is whether they are resident in the Columbia River or anadromous fish with more limited exposure to the local environment. The relationship of soil or sediment/water exposure areas to biota contaminant concentrations is particularly an issue when contaminant concentrations in environmental media are used to model biota concentrations. For such modeling, an appropriate area within which to estimate contaminant concentrations from environmental data must be defined in a manner consistent with the habitat and resource needs of the animals in question.

Alternatively, or as a supplement to modeling, contaminant data from biota samples may be directly used in the risk assessment calculations. As described in Section 2.5.2, a variety of biota data have been collected to support the human and ecological risk assessments for the 100 Area and 300 Area Component of the RCBRA. Animals such as invertebrates, small mammals, and sculpin were selected because they have limited home ranges commensurate with the size of many waste sites. In this way, comparison of contaminant tissue concentrations in exposed and unexposed (reference) animals is feasible. However, application of such data in the human health risk assessment must still account for the ecological viability of obtaining sufficient plants and animals within a localized area to support chronic exposure. Extrapolation from existing animal data to other animal species relevant to human exposure must also be done in an ecologically informed manner.

2.5 POTENTIALLY COMPLETE ECOLOGICAL EXPOSURE PATHWAYS AND RECEPTORS

This section provides the preliminary ecological conceptual models of contaminant transport and exposure for the 100 Area and 300 Area Component of the RCBRA. For an ecological exposure pathway to be considered complete, it must contain a contaminant source, contaminated media, and a route of exposure to the receptor (EPA/540-R-97-006). Exposure of ecological receptors results from contact with contaminated media at specific exposure points within the upland, riparian, and near-shore river zones of the 100 Area and 300 Area. Following risk assessment guidance (EPA/540-R-97-006) and using professional judgment and site-specific information for the Hanford Site, this section identifies potentially complete ecological exposure pathways.

A general understanding of the construction and operation of 100 Area and 300 Area facilities and recent remedial action activities is relevant for interpreting the potential for ecological risks from these sites. In contrast to typical baseline risk assessments, the focus of this assessment is on residual contamination from remediated waste sites and adjoining areas where contaminants may have come to be located. These remediated operational sites were located in the upland environment and consisted primarily of engineered features including cribs, trenches, and ponds. These features have since been excavated and covered with clean material. The depth of excavation depended on the depth at which the cleanup criteria were met and the depth of the original engineered structure (if present). The remediated sites were then backfilled approximately to grade with the surrounding ground surface. Because this is a post-remediation risk assessment, the removal of contaminated soil resulted in low concentrations of COPCs; residual contamination remaining is at levels protective of human health and groundwater as described in interim action RODs. The 100 Area and 300 Area also contained a number of buildings (including reactors) that are undergoing removal or encasement, preventing migration of contaminants at the surface. The reactor infrastructures included above-ground and subsurface effluent pipelines and outfall structures discharging to the Columbia River. Reactor effluent contributed to aquatic pathways for contaminant migration.

2.5.1 Exposure Areas, Pathways and Media

As described in Section 2.1.1, contaminant sources in the 100 Area and 300 Area historically consisted of solid and liquid wastes generated by Hanford Site reactor operations. For the purpose of the risk assessment, the upland, riparian, and near-shore river zones discussed in Section 2.2 are treated as "exposure areas." The exposure area encompasses the locations in each ecological zone where ecological receptors are potentially exposed to contaminated media. The upland, riparian, and near-shore river zones are described in greater detail in Section 2.3, with supplemental information provided in PNNL-SA-41467. The conceptual exposure models for the 100 Area and 300 Area Component of RCBRA includes remediated waste sites located in upland areas and pathways associated with past releases into locations that represent potentially complete exposure pathways to biota. To simplify the conceptualization of various exposure routes across the three major geographic zones, separate models have been developed for the terrestrial upland zone (Figure 2-4) and for the riparian and near-shore aquatic zones (Figure 2-5). General descriptions of the contaminant sources and migration pathways within each exposure zone are provided below. Ecological exposure modeling may be localized to a specific zone, or integrate inputs from multiple ecological zones, depending on the home ranges, habitat requirements, and food sources of the selected receptors.

Upland Zone. The upland zone within the 100 Area and 300 Area is defined as the CERCLA waste sites and their immediate surroundings. Potential sources of contamination within the 100 Area and 300 Area upland zone are described in Section 2.1.1. The primary release mechanisms in the upland zone transporting the COPCs from the source, via environmental media, to potential receptors include infiltration, percolation, and leaching of COPCs from the upland zone and external irradiation from soil containing COPCs, and generation of dust emanating from the soil surface to ambient air from wind. Environmental media evaluated in the upland zone included shallow-zone soil (0 to 4.6 m [0 to 15 ft] bgs [per WAC 174-340-7490]), and biota (including vegetation and wildlife). Deep-zone soils (greater than 4.6 m [15 ft] depth) were not evaluated for ecological risks as exposures are typically restricted to the biologically active zone in soils shallower than 4.6 m (15 ft) (WAC 174-340-7490). In addition, terrestrial plants and animals are unlikely to be exposed to groundwater in the upland zone, as the depth to groundwater exceeds the depth of the biologically active zone where root growth and burrowing occur. Consequently, the pathway from groundwater to terrestrial receptors is largely incomplete.

Through transport pathways such as biotic uptake from soil, secondary media may become contaminated. These secondary contaminated media, in turn, may be consumed by receptor species, contributing to ecological exposure routes identified for the upland zone of the 100 Area and 300 Area include the following:

- Inhalation of contaminated dust or volatilized contaminants
- Incidental or intentional ingestion of contaminated soil or biota
- Dermal contact with contaminated soil
- Exposure of terrestrial vertebrates, invertebrates, and plants to external radiation emitted by contaminated soil
- Uptake or absorption of soil-bound contaminants.

The upland ecological exposure routes that are quantified in the ecological risk assessment include incidental or intentional ingestion of contaminated soil and biota. The farthest ranging receptors, badger and hawk (see Section 2.5.2), can also access surface water from the river for drinking. Exposure from external radiation is considered in comparison of contaminated soil to radionuclide-specific biota concentrations guidelines. While there is a potentially complete exposure pathway via inhalation of fugitive dust and dermal contact, these are generally considered minor exposure routes for ecological receptors (EPA 2003a).

Riparian Zone. The boundaries of the riparian zone are defined as extending from the shoreline of the Columbia River to the point on the riverbank where upland vegetation becomes dominant. The riparian zone of the Columbia River along the shoreline of the 100 Area and 300 Area is typically narrow because of the dominantly steep riverbank. Potential sources of contamination within the 100 Area and 300 Area include seep water (upwelling of groundwater in the riparian zone) and adjacent near-surface sediments. Additionally, past COPCs originating from waste sites within the upland zones could have been transported through several release mechanisms affecting the soil surface, surface sediment, or surface water within the riparian zone.

Potentially, COPCs could be transported through surface drainage from:

- Precipitation contacting surface soil or waste and running off of the associated waste site
- Landslides or slumping of contaminated soil from upland areas into the riparian zone
- Fugitive dust could be transported through wind or work activities on the waste sites.

The primary release mechanisms in the riparian zone transporting the COPCs from the source, via environmental media, to potential receptors include the following:

- External radiation from surface soil or surface sediment containing COPCs (receptor contact with surface soil or surface sediment replaces release and transport)

- Generation of dust emanating from surface soil to ambient air from wind

- Volatilization of chemicals emanating from surface soil or surface sediment to ambient air at the site

- Transport of COPCs in groundwater to release locations in the riparian area (i.e., seeps)

- Shoreline seeps/springs containing COPCs (receptor contact with surface water replaces release and transport).

Environmental media evaluated in the riparian zone included surface soil, riverbank seep water (groundwater emerging in the riparian zone), and biota (wildlife and vegetation). External dosimetry measurements were also evaluated.

Through transport pathways such as upwelling of groundwater in a riverbank seep, secondary media, such as riparian soil may become contaminated. These secondary contaminated media, in turn, may be consumed by receptor species, contributing to exposure.

Ecological exposure routes identified for the riparian zone of the 100 Area and 300 Area include the following:

- Inhalation of contaminated dust or volatilized contaminants
- Incidental or intentional ingestion of contaminated soil, water, or biota
- Dermal contact with contaminated soil, water, or biota
- Exposure of terrestrial and aquatic vertebrates, invertebrates, and plants to external radiation emitted by contaminated soil or biota
- Uptake or absorption of soil- or water-bound contaminants.

The riparian ecological exposure routes that are quantified in the ecological risk assessment include incidental or intentional ingestion of contaminated soil, surface water, and biota. Exposure from external radiation is considered in comparison of contaminated soil to radionuclide-specific biota concentrations guidelines. While there is a potentially complete exposure pathway via inhalation of fugitive dust and dermal contact, these are generally considered minor exposure routes for ecological receptors (EPA 2003a).

Near-Shore River Zone. The near-shore river zone is defined as the area that is permanently inundated by river water, extending from the seasonal low-water mark (i.e., a "green line" where the periphyton [sessile algae] remains green year round) into the river to a water depth of approximately 2 m (6 ft). The remaining aquatic environment of the Columbia River (i.e., depths greater than 2 m [6 ft]) will be addressed by the CRC of the RCBRA [DOE/RL-2003-65]) and is not within the scope of this assessment. Potential sources of contamination within the 100 Area and 300 Are near-shore river zone include contamination along the Columbia River shoreline at riverbank seeps/springs and where upwelling groundwater reaches the surface water.

The primary release mechanisms transporting the COPCs from the source, via environmental media, to potential receptors include the following:

- Transport of COPCs in groundwater to release locations in the near-shore area
- Seep/spring water or surface water containing COPCs
- External irradiation from surface sediment containing COPCs (receptor contact with sediment replaces release and transport).

Environmental media evaluated in the near-shore river zone included river sediment, pore water from horizontal and vertical aquifer tubes, surface water, and biota.

The conceptual exposure models for the 100 Area and 300 Area Component of RCBRA includes remediated waste sites located in upland areas and pathways associated with past releases into locations that represent potentially complete exposure pathways to biota. To simplify the conceptualization of various exposure routes across the three major geographic zones, separate models have been developed for the terrestrial upland zone (Figure 2-4) and for the riparian and near-shore aquatic zones (Figure 2-5).

Through transport pathways such as biotic uptake or upwelling of groundwater, secondary media, such as surface water, sediment, or biota may become contaminated. These secondary contaminated media, in turn, may be consumed by receptor species, contributing to exposure. While there is a potentially complete exposure pathway via inhalation of fugitive dust, inhalation of particulates is generally considered a minor exposure route for ecological receptors (EPA 2003a).

Ecological exposure routes identified for the near-shore zone of the 100 Area and 300 Area include the following:

- Incidental or intentional ingestion of contaminated sediment, groundwater, surface water, or biota
- Dermal contact with contaminated sediment, biota, groundwater, or surface water
- Exposure of aquatic vertebrates, invertebrates, and plants to external radiation emitted by contaminated sediment, or biota
- Uptake or absorption of sediment- or water-bound contaminants.

The near-shore ecological exposure routes that are quantified in the ecological risk assessment include incidental or intentional ingestion of contaminated sediment, surface water, and biota. Exposure from external radiation is considered in comparison of contaminated sediment and water to radionuclide-specific biota concentrations guidelines. While there is a potentially complete exposure pathway via dermal contact, this is generally considered a minor exposure route for ecological receptors (EPA 2003a).

2.5.2 Receptors

Consideration of ecological receptors in the risk assessment requires an understanding of relationships among biotic community members. One such relationship, trophic transfer of contaminants, is an important element in ecological risk assessments. To develop a conceptual model based on trophic guilds, EPA (EPA/540-R-97-006) recommends defining the functional ecosystem components with regard to their role in the food web. Given the complexity of trophic interactions, food webs are a simplification of the ecosystem showing broad relationships limited to trophic transfer. At a base level, some organisms prey on plants (herbivores), plants and animals (omnivores), or just animals (carnivores). More specific feeding classes exist with a particular trophic category. Considering the terrestrial environment, for example, herbivores are represented by granivores (seed-eating animals), folivores (stem- and leaf-eating animals), fungivores (fungi-eating animals), and nectivores (nectar-drinking animals). Feeding guilds possess additional ecologically important attributes; e.g., while shrubs may have leaves and seeds for food, they also provide structural habitat for nesting birds. And while nectar- and pollen-feeding animals may be relatively unimportant in terms of nutrient and energy transfer through the food web, they are important as plant pollinators. The same generalities are applicable to considerations of trophic linkages in the aquatic environment; e.g., many aquatic invertebrates consume periphyton and utilize this autotrophic component of the aquatic food web as a refuge from predation. Ultimately, depiction of trophic-level relationships from a functional perspective allows for ready identification of the feeding guilds most at risk from ingestion of contaminated plant and animal materials.

This framework is used to describe a simplified trophic structure for the ecological community of the 100 Area and 300 Area Component of the RCBRA (Figure 2-6). For the most part, trophic linkages among aquatic and terrestrial biota are stronger within habitats than between habitats. In recognition of this, receptors are delineated into aquatic near-shore (blue shading) and terrestrial (yellow shading) food webs. Trophic levels are represented by rows across habitats. Of course, some organisms can utilize both aquatic and terrestrial habitat. For example, bats and kingbirds are aerial insectivores that live on land and meet their dietary demands primarily through the consumption of emergent aquatic insects. Trophic components of the food web that can bridge aquatic and terrestrial habitats are depicted by an overlap in these habitats (green shading). The highest trophic level consists of avian predators that can traverse all environments, and this trophic level is represented as the topmost row on a scale between aquatic, riparian, and terrestrial habitats. For the sake of simplicity, only modeled or measured (tissue concentration) trophic pathways are shown.

Hanford Site-specific receptors are recommended as surrogates for the WAC 173-340-7490 feeding guilds because they represent relevant ecological and societal endpoints that also address management goals (BHI-01757). Receptor trophic-based guilds are representative of the upland, riparian, and near-shore environments and include decomposers, producers, and consumers (herbivores, omnivores, insectivores, and carnivores). While categories such as omnivory and herbivory are useful constructs to simplify a complex ecosystem, it is important to note that animals do not typically restrict themselves to narrow food sources. Considerable dietary overlap exists among the middle trophic levels, because all species are, to some degree, opportunists. For example, while mallards (*Anas platyrhynchos*) eat mainly vegetation, they will consume invertebrates if available. Other species are primarily insectivorous only at times when insects are abundant (WDFW 2003). Given the dietary overlap it would be an artificial distinction to focus on a specific category; modeling specific diets (e.g., strict herbivory) is done to set the exposure bounds in trophic-transfer analyses.

To evaluate potential assessment endpoints, adverse-effect potential is based on the toxicological characteristics of the COPC, the sensitivity of the receptor, and the likely degree of exposure (WAC 173-340-7493 (2), "Site-Specific Terrestrial Ecological Evaluation Procedures," "Problem Formulation Step"). Regarding COPC characteristics, Hanford Site contaminants are predominantly inorganic chemicals such as heavy metals and radionuclides (PNL-9394).

Because such COPCs do not typically increase in concentration through trophic transfer, the risks posed to higher trophic-level organisms are generally of less concern than risks to organisms lower in the food web. To the extent that inorganic chemicals do accumulate in biotic tissues, there is a greater propensity for invertebrate uptake compared to plant uptake (WAC 173-340-900, Table 749-5). Therefore, relative to plant-eating wildlife (or to wildlife that eat a variety of foodstuffs), invertivorous (invertebrate-eating) wildlife should experience relatively greater exposure to radionuclides and metals and are valuable assessment endpoint entities because they are potentially more exposed indicators for evaluating the adverse effects of inorganic COPCs. Based on overall management goals and trophic relationships among Hanford Site biota, assessment endpoints were developed that are representative of terrestrial and aquatic biota potentially at risk from COPCs (Figure 2-7).

Considering the aquatic food web, the assessment endpoints include decomposers, plants, herbivorous invertebrates, and vertebrates (e.g., periphyton, benthic macroinvertebrates and juvenile suckers); omnivorous invertebrates, fish, and birds (e.g., clam [*Corbicula fluminea*], caddisfly [*Trichopterans*], carp, and mallard); invertivorous amphibians, fish, birds, and mammals (e.g., Woodhouse's toad, sculpin, kingbirds [*Tyrannus* sp.] and bats); and carnivorous fish and birds (e.g., Chinook salmon, great blue heron [*Ardea herodias*]). The aquatic invertebrates are functionally represented by the community of organisms that colonized the submerged rock baskets.

In the terrestrial environment, decomposers consist of soil biota and invertebrates. Plants could include many species, like reed canary grass (*Phalaris arundinacea*), Sandberg's bluegrass, and sagebrush, as representatives for primary producers. Darkling beetles are abundant and important components of the upland terrestrial food web (Rogers and Fitzner 1980, Rogers et al. 1988) and are representative of soil macroinvertebrates (DOE/RL-2001-54). Harvester ants are also appropriate species for this trophic level. The Great Basin pocket mouse and the mourning dove (*Zenaida macroura*) are representative species for the mammalian and avian herbivores, respectively. The meadowlark and deer mouse represent omnivores, whereas the insectivorous mammal guild is represented by the grasshopper mouse (*Onychomys leucogaster*) and, for insectivorous birds, the killdeer. A suitable representative for insectivorous reptiles is the side-blotch lizard. Top carnivores in the upland zone are represented by the Great Basin gopher snake (*Pituiphis melanoleucus*), red-tailed hawk, and badger.

2.6 SUMMARY

The conceptual model for the 100 Area and 300 Area Component of the RCBRA identifies known and potential sources of contamination based on site history, process knowledge, and characterization and remediation activities performed to date. The CSM for the 100 Area and 300 Area Component of the RCBRA is placed in the context of past and concurrent assessment, characterization and remedial activities at the Hanford Site. Liquid waste disposal sites have been identified as the dominant contributors of contaminants to the Hanford Site environs, and therefore remediation has historically been prioritized to address these sites first in the CERCLA process. Chemicals and radionuclides used in Hanford Site operations and resultant waste streams have been documented for decades. Historical records such as these inform the conceptual model and are tested and/or validated through the risk assessment process.

Physical attributes of the site, such as climate, topography, soil structure, and dominant flow of groundwater were also discussed in the CSM. Because groundwater underlying the 100 Area and 300 Area moves towards the Columbia River, it is important to consider the contaminants that have migrated via groundwater to the riparian and near-shore river zones. Environmental attributes of the 100 Area and 300 Area, including upland, riparian, and near-shore habitat types and species present, not only define the environmental setting for the site, but also are used to inform or predict conceptual exposure models for humans and the environment. High-intensity recreational uses such as hunting and fishing involve the collection or consumption of natural resource within the River Corridor environs, whereas low-intensity recreation, such as boating, hiking, or picnicking may only result in intermittent contact with contaminated media. Ecologically, it is important to understand the environmental setting of the 100 Area and 300 Area because site utilization by specific receptors varies based on species' needs. Understanding the trophic organization of the upland, riparian, and near-shore environments is also important for testing assumptions of contaminant transfer and subsequent risks to all levels of receptor species.

This CSM describes the sources of contamination and the environmental transport and exposure pathways between contaminant sources and applicable human and ecological receptors. Particular attention is focused on the lower and middle trophic levels given the limited role that trophic transfer of inorganic chemicals and radionuclides plays in ecological exposure. Organizing relevant information in this manner allows for testing assumptions and targeting data required to validate the model.

Figure 2-1. Conceptual Model of Contaminant Sources Potentially Affecting the River Corridor and Concurrent Risk Assessment Activities at the Hanford Site.

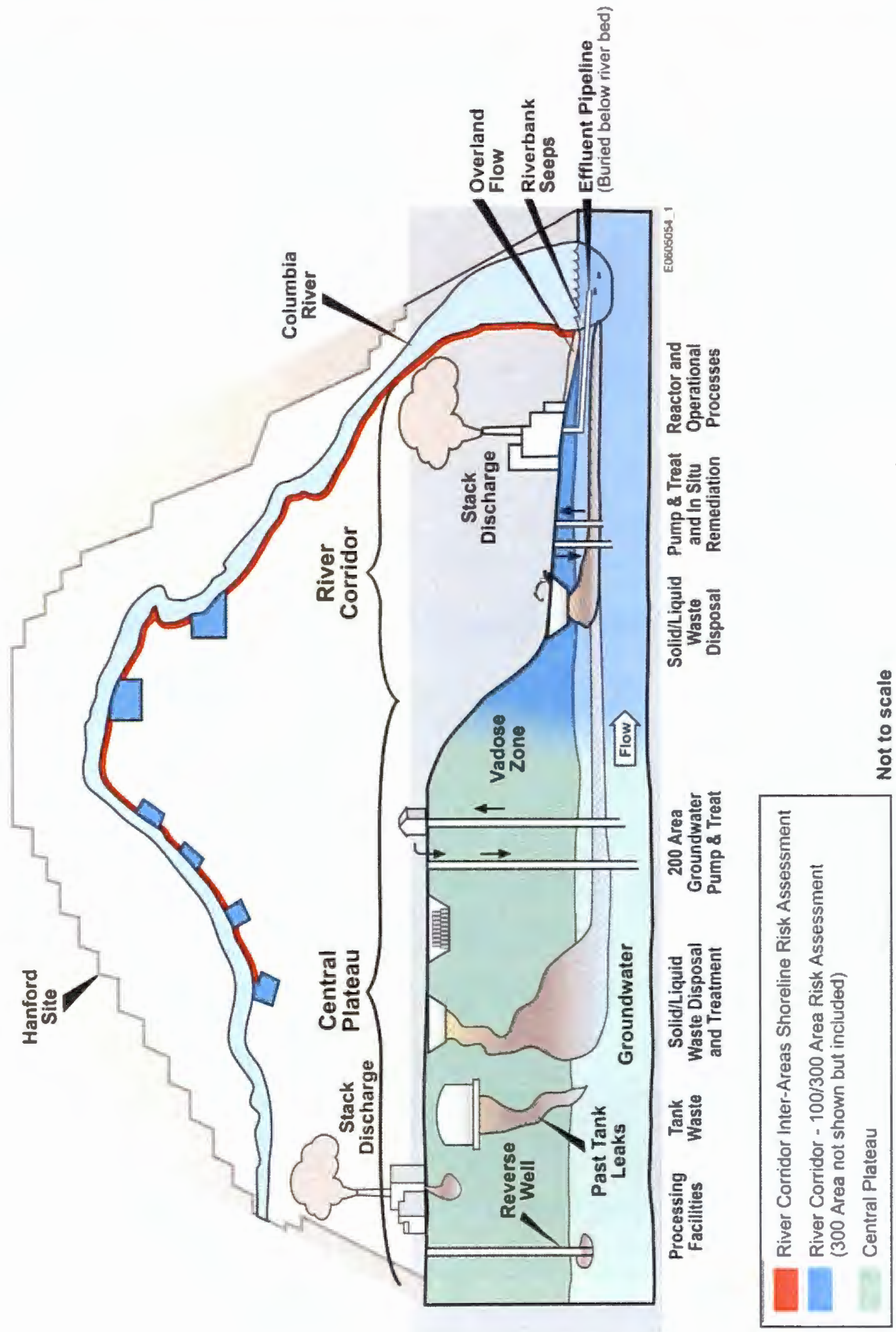


Figure 2-2. Conceptual Model of the Upland, Riparian, and Near-Shore River Zones.

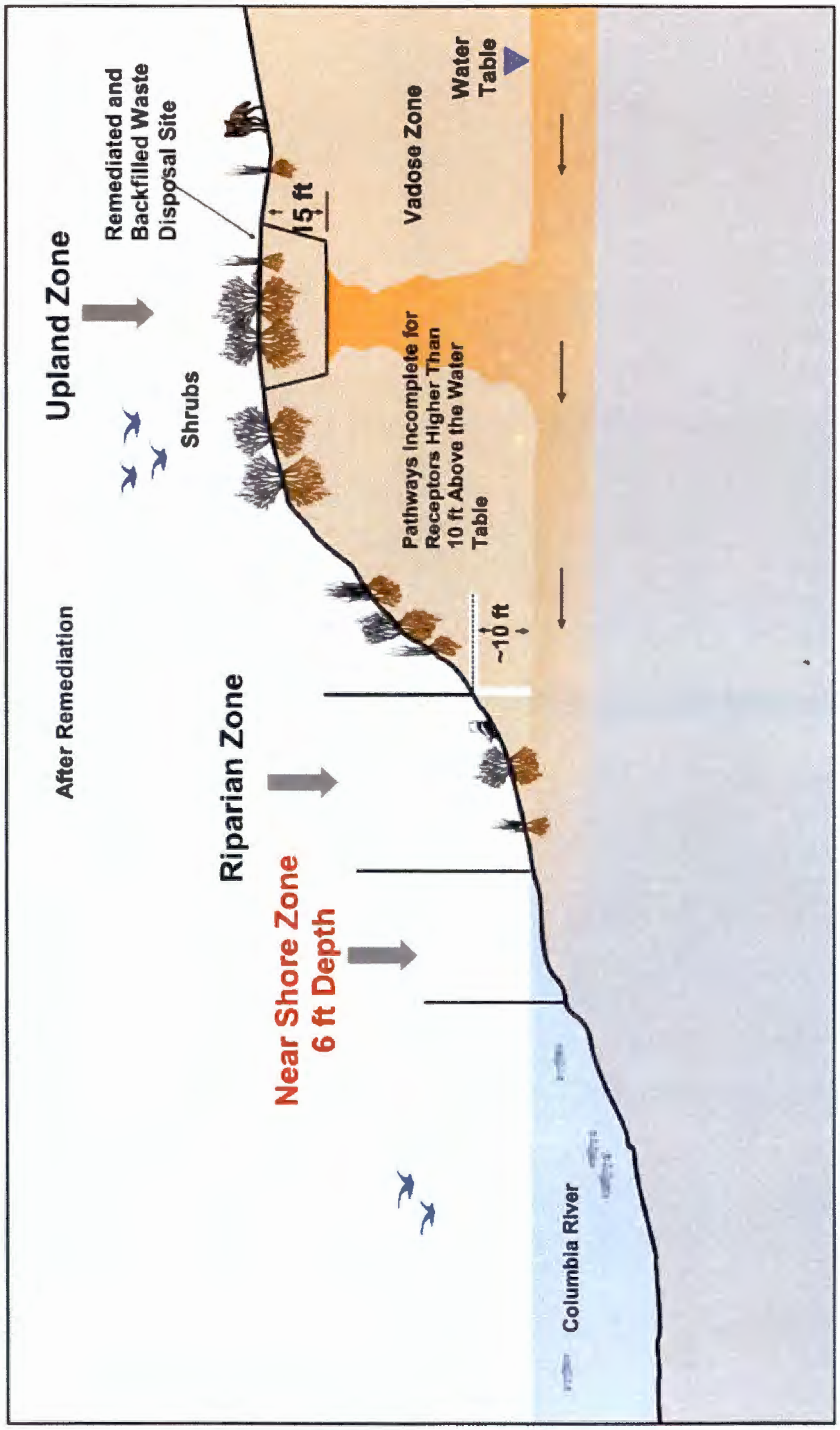
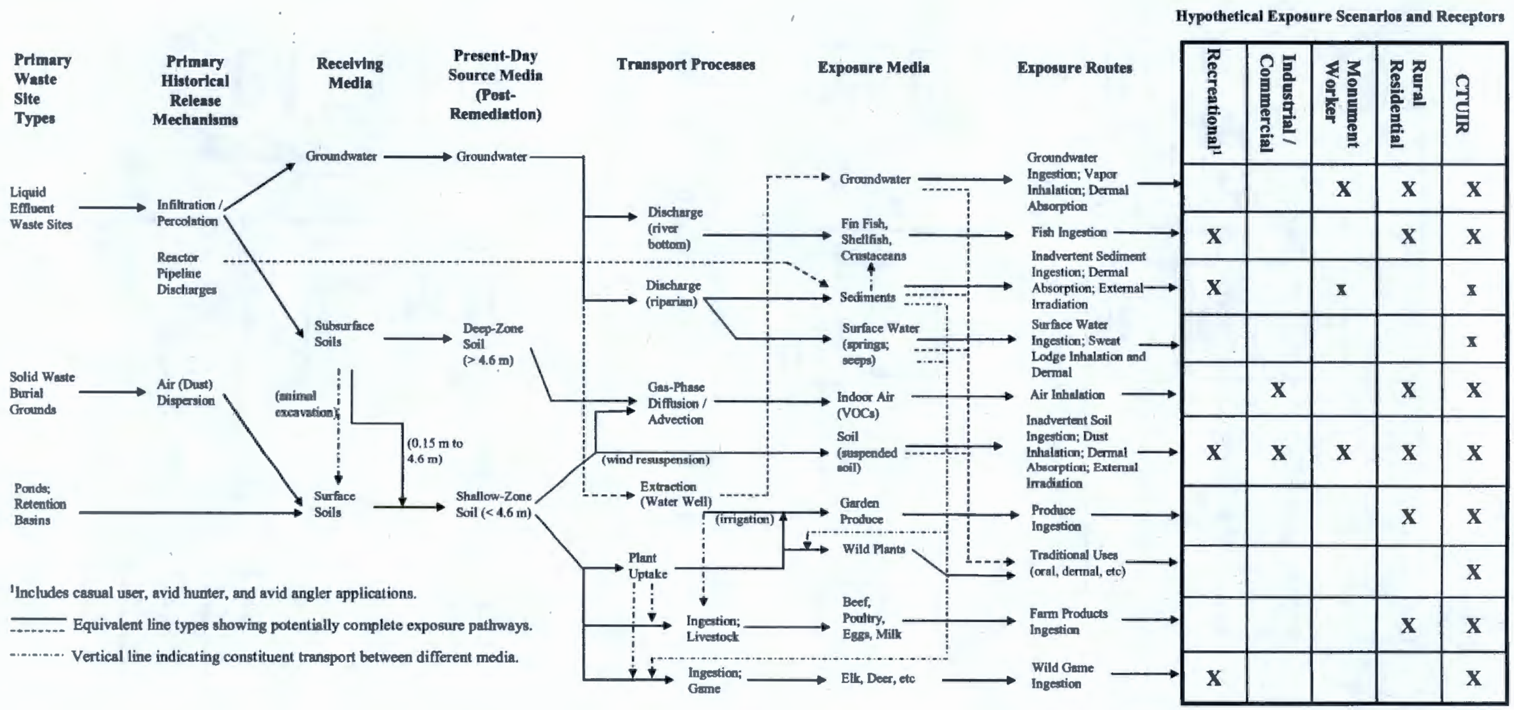


Figure 2-3. Human Health Conceptual Exposure Model.



Exposure Routes	Recreational[1]	Industrial / Commercial	Monument Worker	Rural Residential	CTUIR
Groundwater Ingestion; Vapor Inhalation; Dermal Absorption			X	X	X
Fish Ingestion	X			X	X
Inadvertent Sediment Ingestion; Dermal Absorption; External Irradiation	X		x		x
Surface Water Ingestion; Sweat Lodge Inhalation and Dermal					x
Air Inhalation		X		X	X
Inadvertent Soil Ingestion; Dust Inhalation; Dermal Absorption; External Irradiation	X	X	X	X	X
Produce Ingestion				X	X
Traditional Uses (oral, dermal, etc)					X
Farm Products Ingestion				X	X
Wild Game Ingestion	X				X

Figure 2-4. Ecological Conceptual Exposure Model for the Upland Zone.

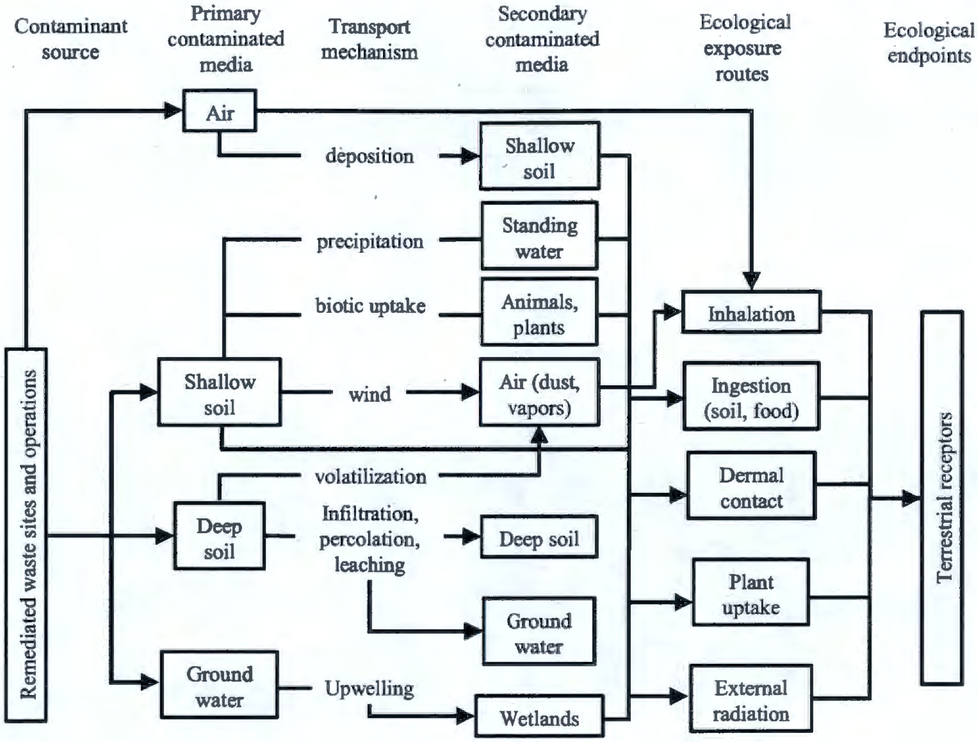


Figure 2-5. Ecological Conceptual Exposure Model for the Aquatic Environment (Combined Riparian and Aquatic Near-Shore Zones).

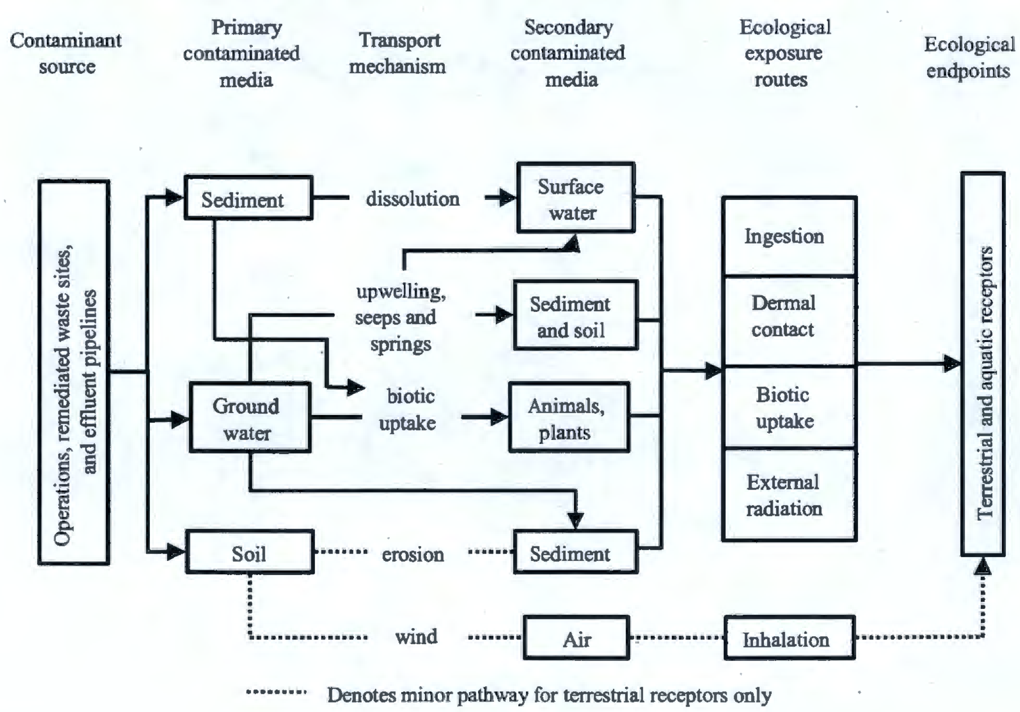


Figure 2-6. Ecological Food Web Represented by Simplified Feeding Guilds in the 100 Area and 300 Area Component of the RCBRA.

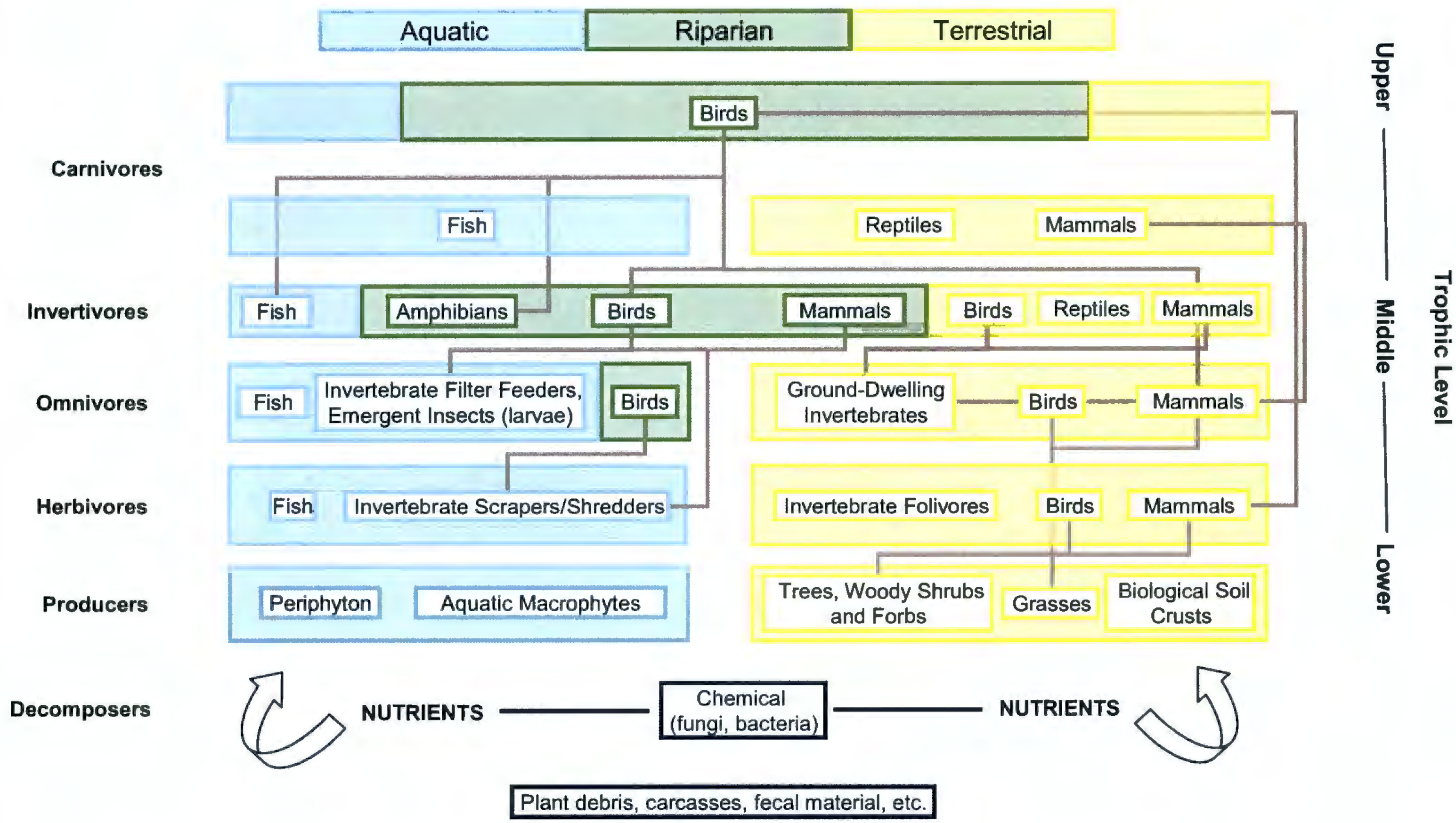
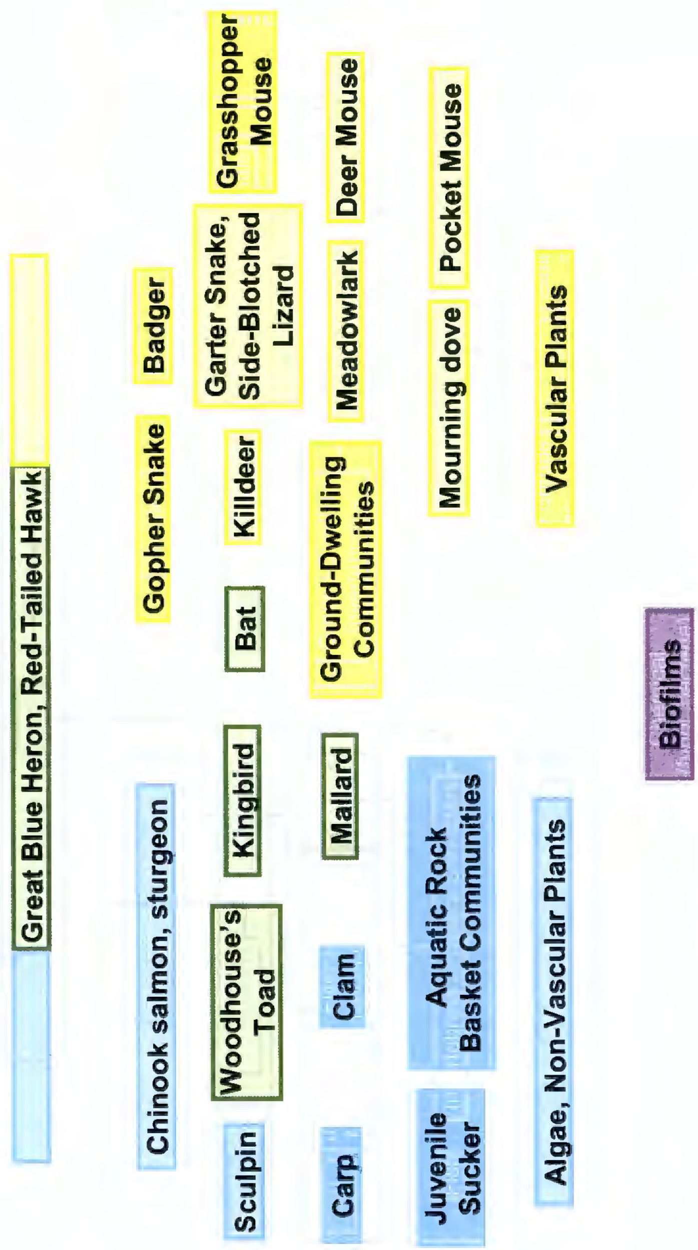


Figure 2-7. Hanford Site Assessment Endpoints for the 100 Area and 300 Area Component of the RCBRA.



3.0 OTHER HANFORD SITE INVESTIGATIONS AND RISK EVALUATIONS

This section describes several other Hanford Site investigations and risk evaluations that provide supplemental information to the 100 Area and 300 Area Component of the RCBRA. These projects were either undertaken historically as characterization efforts (i.e., 100-D Island evaluation and river effluent pipelines evaluation) or as data collection efforts for risk assessment purposes (100-B/C Pilot Project risk assessment, 100-NR-2 shoreline investigation, and the CRC of the RCBRA).

The subsections below summarize the purpose, scope, and the data resulting from each investigation. The types and quantity of data produced by each of these investigations and their use in the 100 Area and 300 Area Component of the RCBRA are also addressed.

3.1 100-B/C PILOT PROJECT RISK ASSESSMENT

3.1.1 Purpose and Scope

The 100-B/C Pilot Project risk assessment (herein referred to as the 100-B/C Pilot) addressed post-remediation residual contaminant concentrations in the 100-B/C Area and the potential transport of these contaminants into Columbia River riparian and near-shore environments adjacent to the remediated waste sites. The purpose of the 100-B/C Pilot was to develop a process to evaluate the protectiveness of CERCLA remedial actions performed for the 100-B/C Area OUs with the intent that lessons learned would be applied to subsequent risk assessments performed within the River Corridor.

The 100-B/C Pilot characterized potential risks to human health and the environment under the cleanup standards implemented in remedial actions performed to date. The scope of the project included all remediated liquid and solid waste sites in the upland 100-B/C Area, as well as the riparian shoreline and near-shore Columbia River adjoining the 100-B/C Reactor operations area.

While ecological and human health risk conclusions were developed as part of the 100-B/C Pilot, it was intended that the results of the 100-B/C Pilot risk assessment would be integrated with the RCBRA and the conclusions evaluated within the context of new information generated by the RCBRA.

3.1.2 Summary of Investigation Data

The 100-B/C Pilot investigation yielded analytical data for abiotic and biotic media, biological health metrics information for selected receptors, and numerous records of contaminants in abiotic media from a compilation of cleanup verification results and Hanford Site monitoring data. Historical and recent analytical data evaluated for the 100-B/C Pilot included shallow-zone soil (0 to 4.6 m [0 to 15 ft] bgs), deep-zone soil (greater than 4.6 m [15 ft] bgs), surface sediment, riverbank seep water, surface water from the Columbia River, aquifer tube water (emergent groundwater present in interstitial gravels), groundwater, and biotic tissues. Sampling and analytical data collected between June 1995 and January 2004 were evaluated in the risk assessment. Sources of data for the 100-B/C Pilot investigation included the following:

- All 100-B/C Area soil data residing in the Environmental Restoration database (ENRE), maintained for remedial action projects
- All soil and water analytical data residing in the Hanford Environmental Information System (HEIS) database, maintained by Fluor Hanford, Inc.
- Analytical results for data contained in the *100-B/C Pilot Project Data Summary for 2003 and 2004* (BHI-01724).

A total of 320 shallow-zone and 94 deep-zone samples from remediated 100-B/C waste sites were included in the 100-B/C Pilot risk assessment. Groundwater, aquifer tube, riverbank seep, and Columbia River surface water samples included in the assessment were collected and analyzed as part of the Hanford Site monitoring program and were reported in yearly Hanford Site environmental reports (PNNL-12088, PNNL-13230, PNNL-13487, PNNL-13910, PNNL-14295, PNNL-14687). Water samples collected within the past 5 years were considered to represent the most recent "snapshot" of current water conditions. Additional investigative sampling and analyses were conducted in the 100-B/C Area and reference areas during 2003 and 2004 to support the risk assessment, and the results were presented in BHI-01724.

3.1.3 Use of 100-B/C Pilot Data in the 100 Area and 300 Area Component

The dataset initially evaluated for the 100-B/C Pilot has been integrated with the dataset for the 100 Area and 300 Area Component. The 100-B/C Area data were evaluated in conjunction with supplemental data gathered from the 100-B/C Area since the completion of Draft B of the risk assessment report. Additional information collected since the issuance of the Draft B report includes additional cleanup verification sampling data, groundwater monitoring well data, and the development of a Native American human exposure scenario. All data relevant to the 100-B/C Area are evaluated in context of the new lines of evidence for the 100 Area and 300 Area Component, namely toxicity testing results, and evaluation of additional reference locations.

3.2 100-NR-2 SHORELINE EVALUATION

The 100-NR-2 shoreline evaluation was conducted during 2005 by Fluor Hanford, Inc., in coordination with PNNL. A report entitled *Aquatic and Riparian Receptor Impact Information for the 100-NR-2 Groundwater Operable Unit* (DOE/RL-2006-26) describes the objectives, methods, and findings of the investigation. Data compiled and collected during the investigation are relevant to the 100 Area and 300 Area Component risk assessment work. Key objectives and findings of the 100-NR-2 study are summarized below. In addition, the types of data collected in the 100-NR-2 shoreline evaluation and their use in the 100 Area and 300 Area Component risk assessment are described.

3.2.1 Purpose and Scope

The objective of the 100-NR-2 Shoreline Investigation was to evaluate the impact of contaminant plumes in the Hanford Site's 100-NR-2 OU on adjacent aquatic and riparian receptors. Areas investigated by the 100-NR-2 project included a strontium-90 plume area, a suspected diesel-contaminated area, and an elevated metals area.

Previous monitoring data and additional data obtained during 2005 were used for the assessment. Data collected in 2005 met project-specific DQOs and the associated SAP. Water, sediment, soil, and aquatic and terrestrial biota were collected during calendar year 2005 and analyzed for COPECs including strontium-90, uranium, technetium-99, heavy metals, PCBs, and petroleum hydrocarbons.

The scope of the 100-NR-2 Shoreline Investigation was to evaluate riparian zone receptors, near-shore aquatic receptors, including the hyporheic zone, and potential human exposure to contaminated seeps along the Columbia River shore. The completeness of exposure pathways was evaluated to answer the following risk questions.

- Are receptors present?
- Are the receptors exposed to an elevated concentration in the environment?
- Does the receptor's exposure result in a health impact?

Exposure pathways are incomplete if receptors are not present. The relative "elevation" of contaminant concentration was determined by comparing 100-NR-2 concentrations to reference site concentrations in the first tier of assessment. "Elevated" concentrations were then compared to Federal criteria for the protection of aquatic and terrestrial receptors. Ecological health was assessed using various lines of evidence of biological condition (e.g., body condition indices, histology, relative abundance, species richness). Results were summarized by investigation area (i.e., strontium-90 plume, diesel contamination area, high metals area).

3.2.2 Summary of Investigation Data

Data collected in the 100-NR-2 investigation included analytical data for surface water, pore water, sediment, and soils. Data were also collected for several species of aquatic and riparian biota, including clams, clam shells, sculpin, milfoil, and periphyton in the Columbia River, and plants, small mammals, and terrestrial invertebrates in the riparian environment. Abiotic and biotic media were analyzed for radionuclides, metals, PCBs, and total petroleum hydrocarbon.

3.2.3 Summary of Investigation Results

In the strontium-90 plume area, strontium-90 concentrations in clams were elevated relative to reference site concentrations. However, estimated radiological doses to benthic aquatic animals (clams or other benthic invertebrates) were 2.4E-3 rad/day, which is less than screening levels considered to be protective of aquatic ecological receptors (1 rad/day). Sample locations with elevated strontium-90 concentrations in clams corresponded with co-located aquifer tube results, indicating a complete exposure pathway from contaminated groundwater. In addition, barium, cadmium, nickel, vanadium, and zinc were detected at levels above ecological benchmarks in the strontium-plume area.

In the suspected diesel-contaminated area, data for shallow aquifer tubes (10 cm beneath the riverbed) indicate the impacted area is anoxic with elevated dissolved iron and manganese concentrations that exceed water quality benchmarks for the protection of aquatic life. The occurrence of elevated iron and manganese concentrations is consistent with anaerobic microbial oxidation of petroleum hydrocarbons through the reduction of iron and manganese oxides present in the hyporheic zone, suggesting that this diesel-related contaminant plume will decline by natural biodegradation processes.

Maximum concentrations of barium, manganese, lead, and zinc in water; arsenic, barium, cadmium, lead, and nickel in soil; and cadmium and zinc in biota exceed benchmarks for wildlife in the elevated-metals area. However, exposure modeling using median soil, water, and sediment concentrations of metals did not indicate unacceptable risk for these metals. A WOE conclusion was based on contaminant concentrations, biological health indicators, and general habitat conditions. Distribution of aquatic mollusk species was indicative of unimpacted water quality conditions in the 100-NR-2 OU contaminant plume study areas. Asiatic clam demographics (size class distribution) observed at the two sites surveyed within the 100-N study area (suspected diesel plume and elevated metals area; strontium-90 plume area not surveyed) generally were comparable to the demographics observed at the two reference area samples sites.

A survey of aquatic invertebrates conducted in September and October 2005 indicated diversity and numbers of macroinvertebrates at the elevated metals area and suspected diesel area are not obviously different compared to macroinvertebrate communities found on similar substrates at upstream locations and at other sampling locations along the river; the samples for the strontium-90 plume area had a higher diversity index than one of the reference areas (which had the lowest diversity index), but the index was lower than at the other two reference areas. Terrestrial or riparian habitat indicators were less definitive. This was, in part, because of major physical disturbances in the study area and the use of herbicides to prevent growth of mulberry and other nuisance vegetation in the strontium plume area. However, small mammals also appear to be reproductively active in the study area and had a higher relative abundance than the reference area, probably due to the presence of riprap along the shoreline.

3.2.4 Use of 100-NR-2 Shoreline Investigation Data in the 100 Area and 300 Area Component

Analytical data compiled and collected during the 100-NR-2 Shoreline Investigation, including chemical and radionuclide concentrations in sediment, groundwater, and biota, have been integrated into the database for the 100 Area and 300 Area Component investigation. Because risk conclusions for the 100-NR-2 Shoreline Investigation are based on criteria and calculations that depart from the 100 Area and 300 Area Component risk assessment approach, the resultant laboratory data are reevaluated in conjunction with upland data. Field surveys of abundance and diversity from the 100-NR-2 Shoreline Investigation will also be used to help develop risk conclusions for the 100-N Area.

3.3 INTER-AREAS COMPONENT OF THE RIVER CORRIDOR BASELINE RISK ASSESSMENT

The Inter-Areas Component of the RCBRA is one of the evaluations comprising the RCBRA; the others include the 100 Area and 300 Area Component (this document) and the CRC. Risk assessments for groundwater will complete the evaluations needed for all the 100 Area and 300 Area final RODs.

3.3.1 Purpose and Scope

The primary purpose of the Inter-Areas Component is to evaluate risks from current concentrations of chemicals and radionuclides between operational areas in the 100 Area and 300 Area riparian and near-shore aquatic zones. Special attention is focused on the sediment depositional areas in sloughs along the Columbia River shoreline. Other sites were selected based on presence of emergent groundwater contamination plumes from the 200 Area.

Because the Inter-Areas assessment is effectively an expansion of the shoreline evaluation performed for the 100 Area and 300 Area Component, the DQOs and study design are similar between projects. Data collected for the Inter-Areas assessment will also fill data gaps for the 100 Area and 300 Area Component. The Inter-Areas DQOs and study design are documented in Appendix E of the *Sampling and Analysis Plan for the 100 Area and 300 Area Component of the RCBRA* (DOE/RL-2005-42).

3.3.2 Use of Inter-Areas Component Data in the 100 Area and 300 Area Component

Results of the sampling and subsequent risk analyses for the Inter-Areas Component will be published at a later date within the remedial investigation report(s) for the River Corridor source OUs. The Inter-Areas assessment will complement the 100 Area and 300 Area results to provide a contiguous risk evaluation in the sensitive shoreline areas of the Hanford Site.

3.4 COLUMBIA RIVER COMPONENT OF THE RIVER CORRIDOR BASELINE RISK ASSESSMENT

The CRC of the RCBRA is the third in a series of three evaluations that comprise the RCBRA. The first component of the RCBRA is the 100 Area and 300 Area Component, and the second component is the Inter-Areas Component. The CRC task was initiated in 2004 and has included numerous scoping and planning workshops with the regulatory agencies, trustees, stakeholders, tribal representatives, contractors, universities, and other interested public.

3.4.1 Purpose and Scope

The CRC is focused on an overall review of Columbia River environmental data, upstream, downstream, and adjacent to the Hanford Site. The purpose is to gain a better understanding of the Columbia River as a whole and identify if there are other areas beyond the boundaries of the Hanford Site that may require additional information to proceed with final risk management decision making.

3.4.2 Historical Data Compilation

In 2005, a massive effort was undertaken to identify, compile, review, and evaluate existing analytical (i.e., on radionuclides and hazardous constituents) and characterization data for Hanford Site-related contaminants released to the Columbia River; data have been collected for almost 600 miles of river. A summary of the process used to compile, classify relevant source documents, and manage the data is provided in the *Columbia River Component Data Evaluation Summary Report* (WCH-91). The Data Compilation and Evaluation task was initiated on behalf of the DOE-RL under the Environmental Restoration Contract managed by Bechtel Hanford, Inc. in December 2004. However, this task was concluded under the River Corridor Closure Contract managed by WCH.

The purpose of the CRC Data Evaluation Summary Report (WCH-91) is to describe the data evaluation for defining the extent of Hanford Site-related contamination within the defined boundaries of the CRC (initially identified as below Grand Coulee Dam to Astoria, Oregon). This information will also be used to develop an initial understanding of river conditions and contaminant distribution within the river and several of the major tributaries.

A primary objective of the data evaluation is to determine if the current boundaries of the CRC have been adequately characterized to define the downriver extent of Hanford Site-related contaminants. This information can also be used to identify data gaps and information that are needed to gain a better understanding of existing levels of contaminants in river sediments; assist in the development of a preliminary CSM; and identify information and data gaps that need to be addressed to better understand the location, character, and long-term fate of contaminants in sediment and surface water, as well as the current risk to plants, animals, and people that may contact these media.

3.4.3 Use of Existing Data Compiled for Columbia River Component Data in the 100 Area and 300 Area Component

Data that are relevant to the Hanford Reach portion of the Columbia River (i.e., slightly upstream of the Vernita Bridge area to the 300 Area) were extracted from the CRC data set for use in nature and extent analyses in Section 4.0 of this risk assessment report. The nature and extent analyses compare contaminant concentrations for a variety of media within the Hanford Reach, collected from a variety of sources. Because of uncertainties in the quality of data from the CRC Data Evaluation Summary Report (WCH-91) and difficulties with statistically comparing data from multiple sources, these data are evaluated for comparative nature and extent purposes only and are not assessed quantitatively in the risk assessment.

3.5 100-D ISLAND EVALUATIONS

The 100-D Island is located in the Columbia River approximately 250 m (820 ft) offshore of the 100-D Area of the Hanford Site. The 100-D Island is a low-lying island that becomes partially submerged due to daily fluctuations in the river level. Most of the 10-ha (25-acre) island is covered by a layer of sediments predominated by cobbles, 2.5 to 15 cm (1 to 6 in.) in diameter, and coarse sandy gravel. Sediments grade to coarse sands where slack-water condition exists as evidenced by a coarse sandy beach located on the downstream end of the island. Vegetation, present on the higher elevations of the island, consists of grass, small bushes, and a few small trees.

This section summarizes two radiological survey efforts at the 100-D Island geared towards identifying radiological contamination and its potential source. The first investigation was conducted in 1992 by the Westinghouse Hanford Company. The second investigation was conducted in 1995 by the Washington State Department of Health (WDOH) (WDOH/ERS-96-1101).

3.5.1 Purpose and Scope

The purpose of the 100-D Island radiological surveys was to determine the extent of identifiable radiological contamination on the island and to attempt to determine the source term of the contamination. The surveys conducted by Westinghouse Hanford Company involved approximately 5 ha (12.5 acres) of reconnaissance across the upstream portion of 100-D Island. The WDOH evaluation looked at particle density of speck contamination on downstream portions of the island.

3.5.2 Summary of Investigation Data

From April 12 to April 18, 1992, a series of radiological surveys were performed at the upstream half of 100-D Island. Radiological surveys were completed using the Ultrasonic Ranging and Data System and conducted using both a digital count rate meter with a sodium iodide detector reporting in counts per minute and a dose rate meter reporting in μ Roentgen per hour (μR/h). Twelve and a half acres of 100-D Island were surveyed with Ultrasonic Ranging and Data System equipment. The radiological survey indicated discrete contamination by cobalt-60 on the island's surface. Results of the radiological survey are published in *100-D Island USRADS Radiological Surveys Preliminary Report – Phase II* (BHI-00134).

An additional radiological survey was conducted by the WDOH on a sandy downstream section of 100-D Island in 1995. A walking survey of exposed island shoreline was conducted when river levels were at their lowest. All surveys were performed using μR meters suspended approximately 2 to 4 cm (approximately 0.78 to 1.5 in.) above the ground. Background exposure rates along the river shore ranging from 7 to 8 μR/hr were measured. A pressurized ion chamber was used to measure variations in background at three island locations. Ambient background measurements recorded by the pressurized ion chamber varied from 8.8 to 9.5 μR/hr.

Conclusions reached by the WDOH were consistent with findings of previous studies. The ambient gamma radiation level measured at several island locations was near background. Burial depth and contact radiation levels of excavated discrete particles were within the range of values previously reported. No particles were found on the sandy downstream section of the island. The number of particles per unit volume was 1.3×10^{-1} particles per cubic meter. Three discrete particles were detected and contact measurements ranged from 85 to 2,000 μR/hr.

The WDOH (WDOH/ERS-96-1101) concluded that radiological hazards and potential health effects from exposure to cobalt-60 particles on the downstream section of 100-D Island are consistent with evaluations documented in previous correspondence and reports. The net results from the survey support a conclusion that cobalt-60 contaminated particles in downstream 100-D Island sediments do not pose significant human health risks. Radiological postings are consistent with Hanford Contractor protocols since ownership of the island is retained by DOE.

3.6 RIVER EFFLUENT PIPELINES

Between 1943 and 1988 at the Hanford Site, pipelines extending from outfall structures in the 100 Area into the Columbia River were used to carry reactor cooling water for discharge to the river. Operation of most river effluent pipelines ended when the associated reactor was shut down variously between the late 1960s and mid-1980s, but today the effluent pipelines remain in place on or beneath the river channel bottom. The effluent pipelines constitute 7 waste sites that include 15 separate pipelines. The five river effluent pipeline waste sites in the 100-B/C, 100-D, 100-H, 100-F, and 100-K Areas and the two effluent pipeline waste sites in the 100-NR-1 OU are described in Table 3-1.

3.6.1 Purpose and Scope

Most of the river effluent pipelines are known or suspected to contain small amounts of residual contamination from past reactor operations. Two past characterization efforts obtained samples of the river effluent pipelines from the 105-B, 105-C, 105-D, 105-DR, and 105-F Reactors (Table 3-2). Effluent pipelines from the 105-H Reactor could not be sampled because of hazardous river conditions (e.g., high flow velocities and cold temperatures). Effluent pipelines at the 100-KE and 100-KW Reactors were not sampled because the pipes were actively being used for disposal of sanitary sewage. Effluent pipelines from 100-N Reactor and the Hanford Generating Plant (HGP) were excluded from the sampling efforts because of expected low levels of contamination. Characterization data collected during the river pipelines evaluations were used to evaluate risks from contaminants within the pipelines and to propose remedial action alternatives, such as pipeline removal.

3.6.2 Summary of Investigation Data

In 1984, the *Discharge Lines Characterization Report* (UNI-3262) discussed samples of scale (flakes of mostly rust) from the interior surfaces and enclosed sediment of the effluent pipelines from 105-C, 105-DR, and 105-F Reactors. The pipelines were also visually inspected by an underwater diver, and their positions and physical conditions were assessed. Samples of scale and sediment were analyzed for radionuclides. The major radionuclides found included cobalt-60, cesium-137, europium-152, europium-154, and europium-155. Radionuclide concentrations were greater in the scale than in the sediment. Direct beta-gamma readings were also obtained for interior and exterior pipe surfaces. The contact dose rates on the interior of the pipe surfaces were less than 1 mrem/hr, while readings on the exterior were less than instrument detection limits.

In 1994, a comprehensive geophysical survey (WHC-SD-EN-TI-278) located and mapped all effluent pipelines except for the 100-N-80 site. The study relied mainly on remote sensing geophysical techniques, including navigation and echo sounding, side-scanning radar, sub-bottom profiling, seismic reflection profiling, and ground-penetrating radar. The results indicated that the pipelines have not broken loose and moved downriver, but that portions of some pipelines are no longer buried and are exposed. Exposed pipe sections were believed to be associated with areas of turbulent flow conditions at the river bottom.

In 1995, pipe scale and sediment from the interior of the effluent pipelines from the 100-B and 100-D Areas were sampled and physically characterized using a robotic transporter (BHI-00538). Analytical data from these two effluent lines were intended to complement the 1984 radionuclide data and were expected to represent "worst-case" conditions with respect to radiological contamination based on years of pipeline service and historical effluent volume. The samples taken in 1995 were analyzed for a larger suite of radionuclides than in 1984 and were also assayed for metals and total organic carbon. In most cases, the radionuclide concentrations of the samples taken in 1995 are lower than 1984 concentrations when both are decayed to 2005. Most metals had concentrations below the analytical detection limits. However, the concentrations of total chromium and mercury were above detection limits; total chromium detections were over 1,000 ppm in the scale of some samples (the direct exposure cleanup level for total chromium is 120,000 ppm).

The analytical results from the 1984 and 1995 characterization work at 100-B-15, 100-D-60, and 100-F-39 may reasonably be extrapolated to effluent pipelines at 100-H-34 and 100-K-80 because operations were similar at these reactor areas. However, operational histories for effluent pipelines 100-N-77 or 100-N-80 suggest contamination would be found at negligible levels because operations at the 100-N Area differed significantly from the other 100 Area reactor areas. The 100-N-77 effluent pipeline primarily discharged raw river water that was used to remove heat from the secondary cooling system at the 100-N Reactor. It also provided a disposal method, on an emergency basis, for primary cooling water and fuel storage basin water. Effluent in the 100-N-77 effluent pipeline would have normally contained zero or very low levels of radioactive fission products (DOE/RL-95-111).

The 100-N-80 effluent pipeline served the same purpose as 100-N-77, but serviced only the HGP facilities. Effluent in the 100-N-80 HGP pipeline first passed through the 1908-NE HGP outfall structure. Analytical results for water and sediment samples, combined with radiological survey data and process knowledge, show that the 1908-NE HGP outfall is an uncontaminated structure that currently meets required cleanup standards. As a result, the Tri-Parties selected "continued institutional control" as the interim action for this outfall structure under the 100-NR-1/

100-NR-2 ROD (EPA 1999d), and no removal action is required (Energy Northwest 2004). The analytical results from the 1908-NE HGP outfall may reasonably be extrapolated to the 100-N-80 HGP effluent pipeline because both sites were exposed to the same effluent during operations.

Risk Evaluation for River Effluent Pipelines. Evaluations of risk have been performed for the river effluent pipelines as they are today, located on or beneath the river channel bottom, and for a scenario in which a pipeline section breaks away from the main pipeline and is washed onto the shore of the river. Both the 1996 and 1998 risk assessment efforts (BHI-00538 and BHI-01141, respectively) relied upon data collected from the 1984 and 1995 characterization work. The evaluation of human health and ecological risk performed in 1998 (BHI-01141) concluded that, with the pipelines as they are today at the river bottom, concentrations of radionuclides and metals inside the pipelines pose no risk to humans. The concentrations of chromium and mercury in the scale and sediment within the pipelines had been reported to pose minimal ecological risk because they have been in contact with river water since the reactors were shut down in 1971 without dissolving. Based on the results of the 1998 risk evaluation of the pipelines under current conditions, there were no unacceptable risks and therefore no requirement under CERCLA to remediate the river effluent pipelines.

A supplementary risk assessment was performed to analyze risk associated with a scenario in which a 12-m (40-ft) section of large-diameter pipeline breaks away from the river bottom and is washed ashore, allowing access to the beached pipeline section by river recreationists, including a child and an adult fisherman (BHI 2004, 2005). Input parameters were based on the "Avid Recreational Visitor" scenario developed as part of the Columbia River Comprehensive Impact Assessment (DOE/RL-96-16), which involves an outdoor enthusiast that is exposed to radiological contamination through frequent participation in recreational activities along the river shoreline in close proximity to the beached pipeline section. The RESidual RADioactivity (RESRAD) computer code was used to evaluate radiological dose received by an individual using maximum pipeline radionuclide concentrations from the 1984 and 1995 characterization efforts, decayed to the year 2005.

The analysis determined that maximum dose rates to exposed individuals occurs at year zero (2005) and that the dominant pathway for dose rate is external exposure. The primary radionuclide contributing to the external exposure pathway is europium-152. The analysis identified a short-term risk for an avid child recreationist during which dose rate exceeds 15 mrem/yr above background for 17 years beyond 2005 and the NCP overall incremental cancer risk range of 10^{-6} to 10^{-4} would also be exceeded. The EPA has used a dose of 15 mrem/yr above background as an operational guideline for remediation to achieve the goal of attaining the 10^{-6} to 10^{-4} target risk range. After 17 years, radionuclide concentrations in the pipeline section will have decayed to the point that the dose rates would be below 15 mrem/yr above background, radionuclide excess lifetime cancer risk would be within required limits, and exposure to beached pipeline sections would not pose an unacceptable human health risk.

3.6.3 Use of River Pipelines Evaluation Data in the 100 Area and 300 Area Component

The 100 Area and 300 Area Component will consider data and results reported from the river effluent pipeline characterization reports (i.e., BHI-00538, BHI -01141; BHI 2004, 2005) as part of the human health risk assessment (Section 5.0) and Appendix G-2 of this report.

Table 3-1. River Effluent Pipeline Waste Sites. (4 Pages)

Operable Unit	Site Name	Number of Effluent Pipelines	Description	Media/ Material	Potential Contamination [a]
100-BC-1	100-B-15	1	The effluent pipeline in the 100-B/C Area extending from the 116-B-7 outfall is constructed of 107-cm (42-in.)-diameter carbon steel pipe with a 1.3-cm (0.5-in.)-thick wall. The line is 228 m (750 ft) long. When last investigated, 13 m (40 ft) of the pipe near the discharge was exposed and the remainder was buried (WHC-SD-EN-TI-278).	Steel, concrete	Am-241, C-14, Cs-137, Co-60, Eu-152, Eu-154, Eu-155, H-3, Ni-63, Pu-238, Pu-239/240, Sr-90, U-133/234, U-235, U-238, Cr (total), Hg.
		1	The effluent pipeline in the 100-B/C Area extending from the 132-B-6 outfall is constructed of 168-cm (66-in.)-diameter carbon steel pipe with a 1.3-cm (0.5-in.)- thick wall. The line is 211 m (692 ft) long. When last investigated, 30 m (100 ft) of the pipe near the discharge was exposed and the remainder was buried (WHC-SD-EN-TI-278).	Steel, concrete	Am-241, C-14, Cs-137, Co-60, Eu-152, Eu-154, Eu-155, H-3, Ni-63, Pu-238, Pu-239/240, Sr-90, U-133/234, U-235, U-238, Cr (total), Hg.
		2	The effluent pipelines in the 100-B/C Area extending from the 132-C-2 outfall structure consist of two 137-cm (54-in.)-diameter steel pipes with 1.3-cm (0.5-in.)-thick walls. The lines are 204 m (670 ft) long. When last investigated, the pipes were exposed at various locations along their lengths (WHC-SD-EN-TI-278).	Steel, concrete	Am-241, C-14, Cs-137, Co-60, Eu-152, Eu-154, Eu-155, H-3, Ni-63, Pu-238, Pu-239/240, Sr-90, U-133/234, U-235, U-238, Cr (total), Hg.
100-DR-1	100-D-60	2	The effluent pipelines in the 100-D Area extending from the 116-D-5 outfall are constructed of two 107-cm (42-in.)-diameter reinforced concrete/steel pipes. The steel pipes have a 1.3-cm (0.5 in.)-thick wall. The pipes extend approximately 576 m (1,850 ft) into the river, passing through 100-D Island. The outlets were not exposed on the river bottom when last inspected in 1994.	Steel, concrete	Am-241, C-14, Cs-137, Co-60, Eu-152, Eu-154, Eu-155, H-3, Ni-63, Pu-238, Pu-239/240, Sr-90, U-133/234, U-235, U-238, Cr (total), Hg.

Table 3-1. River Effluent Pipeline Waste Sites. (4 Pages)

Operable Unit	Site Name	Number of Effluent Pipelines	Description	Media/ Material	Potential Contamination [a]
		1	The effluent pipeline in the 100-D Area extending from the 116-DR-5 outfall is constructed of a 168-cm (66-in.)-diameter carbon steel pipe with a 1.3-cm (0.5 in.)-thick wall. The line extends approximately 549 m (1,800 ft) into the river, passing through 100-D Island. The outlet was exposed on the river bottom when last investigated (WHC-SD-EN-TI-278).	Steel, concrete	Am-241, C-14, Cs-137, Co-60, Eu-152, Eu-154, Eu-155, H-3, Ni-63, Pu-238, Pu-239/240, Sr-90, U-133/234, U-235, U-238, Cr (total), Hg.
100-FR-1	100-F-39	2	This site consists of the river effluent pipelines in the 100-F Area that extend from the 116-F-8 outfall structure into the main channel of the Columbia River. Two parallel pipelines were constructed of 107-cm (42-in.)-diameter reinforced concrete/steel pipes with 1.3-cm (0.5 in.)-thick walls. Conflicting information exists about whether the pipelines are 137 m (450 ft) long or 91 m (300 ft) in length. According to visual inspection by divers in 1984 (UNI-3262), pipelines and their anchors appeared to have moved a short distance from their original positions, and pipe sections of unknown length appeared to be missing. When last investigated, the pipelines could not be clearly identified (WHC-SD-EN-TI-278).	Steel, concrete	Am-241, C-14, Cs-137, Co-60, Eu-152, Eu-154, Eu-155, H-3, Ni-63, Pu-238, Pu-239/240, Sr-90, U-133/234, U-235, U-238, Cr (total), Hg.

Table 3-1. River Effluent Pipeline Waste Sites. (4 Pages)

Operable Unit	Site Name	Number of Effluent Pipelines	Description	Media/ Material	Potential Contamination[a]
100-HR-1	100-H-34	2	This site includes two 152-cm (60-in.)-diameter (1.3-cm [0.5-in.]-thick walls) steel effluent pipelines in the 100-H Area that extend 230 m (753 ft) from the face of the 116-H-5 outfall structure into the main channel of the Columbia River. The total drop from the face of the outfall structure to the discharge end of the pipeline is 8.5 m (28 ft). The pipelines are separated by approximately 90 cm (35 in.) and are covered by a minimum of 1 m (3 ft) of sediment over their entire length, as well as large pieces of basalt riprap extending from the face of the outfall to the shoreline. When last investigated, the two pipelines appeared to be completely buried (WHC-SD-EN-TI-278).	Steel, concrete	Am-241, C-14, Co-60, Cs-137, Eu-152, Eu-154, Eu-155, H-3, Ni-63, Pu-238, Pu-239/240, Sr-90, U-233/234, U-235, U-238, Cr (total), Hg.
100-KR-1	100-K-80	2	The effluent pipelines in the 100-K Area extending from the 116-K-3 outfall structure are constructed of a 213-cm (84-in.)-diameter carbon steel pipe with a 1.3-cm (0.5-in.)-thick wall. The west and east pipelines are parallel lines extending approximately 400 m (1,313 ft) into the river. The tops of both pipelines were exposed along most of their length when last investigated (WHC-SD-EN-TI-278), protruding 0.3 to 0.9 m (1 to 3 ft) above the riverbed. The east pipeline is still used (as of February 2005) as a National Pollutant Discharge Elimination System discharge point by DOE's Spent Nuclear Fuels Program.	Steel, concrete	Am-241, C-14, Co-60, Cs-137, Eu-152, Eu-154, Eu-155, H-3, Ni-63, Pu-238, Pu-239/240, Sr-90 U-233/234, U-235, U-238, Cr (total), Hg.
100-NR-1	100-N-77	1	The site is located in the 100-N Area and consists of a 260-cm (102-in.) river effluent pipeline that extends from the 1908-N outfall structure into the main channel of the Columbia River approximately 265 m (871 ft). This pipeline is downstream of the 100-N-80 effluent pipeline. When last investigated (WHC-SD-EN-TI-278), the pipeline outlet was exposed on the river bottom.	Steel, concrete	Received raw river water. Potential radioactive contamination from emergency discharges.

Table 3-1. River Effluent Pipeline Waste Sites. (4 Pages)

Operable Unit	Site Name	Number of Effluent Pipelines	Description	Media/ Material	Potential Contamination [a]
100-NR-1	100-N-80	1	The site is located in the 100-N Area and consists of a 335-cm (132-in.)-diameter river effluent pipeline that extends from the 1908-NE Hanford Generating Plant outfall structure into the main channel of the Columbia River approximately 313 m (1,028 ft). This pipeline is upstream of the 100-N-77 river effluent pipeline.	Steel, concrete	None.[b]

[a] Based on actual analyses of river effluent pipeline sediment and scale (BHI-00538, BHI-01141, BHI-01724).

[b] 100-N-80 river effluent pipeline contaminants are expected to be analogous to those of the 1908-NE outfall structure because the pipeline received the same effluent as the outfall structure. The 1908-NE outfall structure was closed out because none of the contaminants of potential concern had concentrations that exceeded protectiveness criteria (Energy Northwest 2004).

DOE = U.S. Department of Energy

Table 3-2. Sampling of Hanford Site River Effluent Pipelines.

Effluent Pipelines Site Number	Reactor Area or Facility	Number of River Effluent Pipelines	Characterized? (Yes or No)
100-B-15	100-B 100-C	2 2	Yes Yes
100-D-60	100-D 100-DR	2 1	Yes Yes
100-F-39	100-F	2	Yes
100-H-34	100-H	2	No
100-K-80	100-KE and 100-KW	2	No
100-N-77	100-N	1	No
100-N-80	Hanford Generating Plant	1	No

4.0 DATA SOURCES, NATURE AND EXTENT, AND REPRESENTATIVE CONCENTRATIONS

This section describes the sources and treatment of data from various sources used in the data analysis for the 100 Area and 300 Area Component of the RCBRA. Sections 4.1 and 4.2 describe data sources and types. Section 4.3 describes the methods and results for identifying COPCs including data quality, identification of detected constituents, and data usability. Section 4.3 also includes discussion of COPCs in terms of their site-relatedness, toxicological relevance, and constituent concentration comparisons to statewide and area background concentrations and reference site values. Results of exploratory data analyses that identify trends across locations, media, and time are summarized in Section 4.4. Methods for the computation of representative concentrations for human health and ecological risk assessments are presented in Section 4.5. A summary of the external dosimetry readings is provided in Section 4.6.

The data evaluated in this report are available electronically through a web-based interface. The Guided Interactive Statistical Decision Tools (GiSdT) interface for the Hanford Site 100 Area and 300 Area Component of the RCBRA was developed as a repository and interface for analytical data used in this report. Appendix B provides a description of the database as well as instructions for the user interface. The data repository can be located on the Internet at http://rcbra100-300.gisdt.org/. Appendix E provides additional information on the selection of reference sites. Appendix F-1, "Statistical Methodology," describes the statistical approaches for calculating the exposure concentrations used in the human health and ecological risk assessments.

4.1 DATA COLLECTED FOR THE 100 AREA AND 300 AREA COMPONENT

Data used for this assessment are inclusive of all data collected under the SAP (DOE/RL-2005-42). Biotic and abiotic samples were collected from on-site investigation areas and reference sites between October 2005 and December 2006. Analytical results include tissue concentration data for vegetation, invertebrates, small mammals, birds, fish, and clams; multi-increment soil data; sediment data; multi-increment sediment data; and analytical results for pore water, groundwater, and surface water. Site descriptive information and species/habitat metrics were also recorded for use in data interpretation and risk analyses. The subsections below describe the types and quantities of biotic and abiotic data collected for this assessment under the guidance of the SAP. Table 4-1 provides a summary of these data as well as other data used in the assessment that were not collected under the SAP. Application of these data is discussed more thoroughly in the human health and ecological risk assessments, in Sections 5.0 and 6.0, respectively. Fundamental to the data collected for this report are "reference sites" and a contamination "gradient." Reference sites are selected based on ecological and contamination characteristics to represent the area of lowest impact or lowest measured concentrations. Additional information on reference sites is provided in Section 4.1.4 and Appendix E.

4.1.1 Biotic Data

Biotic samples were collected from upland, riparian, and aquatic investigation areas and reference sites. Biota collected for tissue analysis included upland and riparian vegetation (leaves), terrestrial invertebrates, mice (whole organism, liver, kidney), kingbirds (crop contents, carcass), clams (soft tissue, shells), aquatic invertebrates, and sculpin (whole organism, liver, and kidney). Biotic samples were analyzed for metals (including mercury), radionuclides (including gamma energy analysis [GEA], isotopic uranium and thorium, and total beta radiostrontium in samples meeting mass requirements), semivolatile organic analytes, and pesticides/PCB compounds.

Analytical results from fall 2005 and spring 2006 sampling events are presented in the *100 Area and 300 Area Component of the RCBRA Fall 2005 Data Compilation* (WCH-85) and *100 Area and 300 Area Component of the River Corridor Baseline Risk Assessment Spring 2006 Data Collection* (WCH-139). A summary of the biotic samples collected for the 100 Area and 300 Area Component of the RCBRA is presented in Table 4-2.

In addition to the collection and chemical/radiological analysis of biotic and abiotic media, descriptive, informational, and site characterization data were also collected for use in risk estimation and interpretation. Observations and measurements collected to support the ecological risk assessment include the following:

- Vegetative canopy cover
- Species abundance and diversity
- Community indices
- Organism histopathology.

These data are described in detail and are incorporated as lines of evidence for the ecological risk assessment, as explained in Section 6.0.

Some of the biological data planned to be collected for this project were not obtained. These missing data and reasons why they were not included in this report are as follows:

- Sandberg's bluegrass bioassay results were not useable due to data quality problems with the analytical laboratory.

- Amphibian tissue concentrations were not obtained due to a lack of tadpoles (river conditions likely flooded amphibian breeding areas).

- Relative abundance of terrestrial invertebrates was not obtained because sample collection methods included some hand-collected invertebrates in addition to some invertebrates collected using systematic sampling methods (pitfall traps).

- Nest success for kingbirds was not measured due to frequent nest predation by ravens and crows.

These data were planned to be used only in the ecological risk assessment; their absence is considered in Section 6.0.

4.1.2 Abiotic Data

Abiotic data collected for the 100 Area and 300 Area Component of the RCBRA included sediment, upland and riparian soils, groundwater (well) water, pore water, and surface water of the Columbia River. Analyses conducted for soil and water included metals (including mercury), radionuclides (including GEA, isotopic uranium, plutonium, thorium, tritium, and total beta radiostrontium), semivolatile organic analytes, and pesticides/PCBs. Field measurements for water such as conductivity, pH, temperature, and turbidity, and soil type for soil/sediment sites were also recorded for use in data analysis and interpretation. Thermoluminescent dosimeters were used to record external radiation dose at upland and riparian sites for a period of 6 months.

Analytical results from fall 2005 and spring 2006 sampling events are presented in the *100 Area and 300 Area Component of the RCBRA Fall 2005 Data Compilation* (WCH-85) and *100 Area and 300 Area Component of the River Corridor Baseline Risk Assessment Spring 2006 Data Collection* (WCH-139). A summary of abiotic samples collected and analytical suites performed is presented in Table 4-3.

4.1.3 River Environment Observations

Water level fluctuation is a key variable affecting the concentration of Hanford Site's legacy materials entering the river environment from contaminated groundwater. The shoreline areas of the Hanford Reach of the Columbia River may fluctuate daily and seasonally in response to both natural seasonal cycles and hydroelectric operations at upstream dams. These fluctuations can be up to 2 to 3 m (6.6 to 9.8 ft) vertically (river surface elevation relative to mean sea level) during any given day.

In late 2005 and early 2006, a 1.2-L capacity horizontal pore water tube perforated with 1/1000-in. slots was deployed at 37 sites: 30 operational sites and 7 reference sites. Persistent periphyton growth on rock surfaces was used to visually identify the low-water mark for consistent placement of the devices at each site. The pore water tubes were buried at approximately 10 cm (4 in.) depth (biotic zone) into the matrix substrate. Pore water samples were subsequently collected using peristaltic pumps during moderate and low river flow conditions in an effort to capture maximum groundwater representation. A single sample consisted of 15 to 22 L of water in order to analyze for all of the COPCs. Water depth and specific conductance, along with other water quality indicators (temperature, dissolved oxygen, pH), were measured at each site during the sample collection events. Specific conductance readings of river water greater than 180 µS/cm indicate the sample contains some amount of shallow groundwater.

The first round of sampling took place between January and February 2006. Water levels during this time were highly variable. Water discharge rates from Priest Rapids ranged from 71 KCFS to 213 KCFS. Water depths measured at the uranium study sites during the sampling events ranged between 0.44 m (1.4 ft) and 1.61 m (5.3 ft). Water depths measured while collecting samples at the chromium study sites ranged between 0.46 m (1.5 ft) and approximately 1.8 m (5.9 ft). Water depths measured while collecting samples at the strontium-90 study sites ranged between 0.14 m (0.46 ft) to 1.85 m (6.1 ft). Specific conductance readings of water sampled from the pore water tubes were generally similar to the river water readings except at some sites when river water depths were less than 1.0 m (3.3 ft).

As a result of these highly variable flows and low values of specific conductance in the pore water samples, a second round of sampling was conducted in September 2006 at selected sites where the highest contaminant concentrations were known or suspected. Field samplers measured specific conductance and surface water depths at each of the chromium and uranium study sites, and four samples of water (two from the uranium plume, one from the chromium plume, and one from the strontium-90 plume) were collected for analyses of the contaminant concentrations and bioassays. Surface water depths during the second round sampling ranged from approximately 0.0 m (0.0 ft) to 0.41 m (1.34 ft) and river discharge rates ranged between 39.9 KCFS to 54.0 KCFS. Specific conductance measured in pore water from the Uranium study sites ranged from 273 µS/cm to 504 µS/cm. Specific conductance measured in the pore water from the five chromium sites suspected to contain the highest concentrations of chromium ranged from 200 µS/cm to 395 µS/cm. Specific conductance at the other five chromium study sites were similar to values observed in the surface river water.

The field samplers noted a dramatic decline of specific conductance while the 15-L to 22-L samples were being drawn from several of the pore water tubes in the chromium plume. In response to the concern that this large sample volume was diluting the pore water samples with surface water, a third sampling event took place at chromium sites 2, 4, and 6 and strontium site 4 to obtain just enough pore water (approximately 3 L) to analyze for the target contaminants. The third round of sampling took place on November 25 and 26, 2006, when discharge rates from Priest Rapids were approximately 40 KCFS.

A one-dimensional, unsteady river flow model was used to examine river conditions (river elevation fluctuation patterns) over the course of sampling (Richmond and Perkins 1998). The model calculates river elevation (+/- 6 in.) using bathymetric data and time specified water discharge rates (cubic feet per second [CFS]) recorded from the upstream hydroelectric facility. The river elevation fluctuation patterns observed during the sampling events were expressed as the percent of time these conditions occurred from October 2005 to December 2006. Figure 4-1 illustrates the two sampling events that took place in the uranium plume in context to water fluctuation patterns.

4.1.4 Reference Site Selection Rationale

This section provides the rationale behind selection of the reference areas used for the 100 Area and 300 Area Component of the RCBRA and also documents why other areas that were considered were not selected.

The risk assessment study areas (upland, riparian, and near-shore) are first generically described, as the physical and biological conditions of the locations being assessed should be used to help determine the reference locations. Second, the general considerations used to select reference sites are described, along with a description of the areas evaluated for use as references, but not selected. The individual upland reference areas that are being used are each described, followed by the individual near-shore/riparian reference sites selected.

4.1.4.1 Risk Assessment Study Area Description

Upland. The following two types of remediated closed-out waste sites are included in the risk assessment:

1. Areas with significant amounts of excavation, contaminated soil removal, and imported backfill. These large sites are typically liquid waste sites constructed in or near the operations areas. The backfill used during initial construction of these areas (as well as the backfill for the waste site excavation) came from one of the several borrow pits on the Hanford Site, which are usually made up of coarse materials such as sandy cobble.

2. Areas with much less excavation, which include discrete contamination patches, are usually much smaller with little to no imported backfill. These sites are typically in and near the old White Bluffs and Hanford Townsites and are much farther from the operations areas. The soils tend to be native soils, are less coarse than the backfill areas, and have revegetated to a mix of both native and non-native species such as rabbitbrush (*Chrysothamnus nauseousus*), Sandberg's bluegrass (*Poa sandbergii*), and cheatgrass (*Bromus tectorum*).

Riparian. The riparian study sites are below the operations areas and extend to the approximate extent of the contaminated groundwater plumes. These sites are more uniform, with a mix of reed canary grass, mulberry trees (usually heavily browsed), and willows. The steepness of the bank and amount of adjacent flatter, more frequently flooded areas, vary from site to site. Riparian areas adjacent to the 100-F Area and 100-H Area sloughs are much flatter and wider than those below the 100-D Area, which are much steeper and much narrower.

Near-shore. The near-shore study sites in the Columbia River are more homogenous because most of the near-shore river bed adjacent to the operations areas consists of sand and embedded cobbles. Finer grained sediments have settled out in some backwater areas; however, other areas have much larger cobbles and boulders. Vegetation in the near-shore zone areas is very sparse because of the coarse substrate and widely varying river flows each day and from season to season.

4.1.4.2 Reference Site Selection. With the study site characteristics previously described in mind, the rationale for choosing each reference area to help with evaluating the study sites is provided below.

4.1.4.2.1 General Considerations for Upland Reference Site Selection. An important consideration in selecting reference areas is the management and isolation of the Hanford Site:

since its inception, the site has excluded casual public access and livestock grazing, keeping many nonoperational areas in a relative physically pristine condition (excluding pre-Hanford Site farm towns and farms). The size of the Hanford Site has also limited the amount of wind-blown material, such as agricultural pesticides, in the soils away from the perimeter. Non-native weeds, especially cheatgrass, have colonized most of the site to varying degrees.

The large number of study areas in the risk assessment (20 remediated waste sites, 10 riparian areas, and 30 near-shore sites) required that there be more than one upland, riparian, and near-shore reference location to cover the range of substrate types and habitat conditions. Consequently, 10 upland sites (5 from borrow pits and 5 from native habitats) dominated by both sagebrush and rabbitbrush, 5 riparian, and 7 near-shore reference sites were selected.

Per EPA guidance (e.g., *ECO Update*, "Using Toxicity Tests in Ecological Risk Assessment" [EPA/540-F-94-012]), "The investigator should try to locate the reference site as close as possible to the Superfund site so that the reference site will accurately reflect the site's conditions. Yet the reference site should lie at a great enough distance from the Superfund site to be unaffected by site contamination."

Other relevant guidance includes EPA's *ECO Update,* "Selecting and Using Reference Information in Superfund Ecological Risk Assessments" (EPA/540-F-94-050), which states that ideally, on-site reference samples are collected from unaffected portions of contaminated habitats. More commonly, on-site samples are taken along a gradient from lowest to highest contaminant concentration. The area of lowest impact or lowest measured concentration is the "reference" target for the site. This approach can be necessitated when a suitable reference location cannot be found. This discussion appears on page 3 of the guidance. The guidance also discusses the guideline to select sites that match the Superfund site in all aspects except contamination. Characteristics to be considered include physical characteristics, climatic characteristics, and biological characteristics (pages 3 through 5 of the guidance).

Similar language appears in EPA's *ECO Update*, "Field Studies for Ecological Risk Assessment" (EPA 1994a), which again states that the reference site should be as close as possible to the Superfund site so it will accurately reflect conditions at the site. It also acknowledges that in some cases no single reference site adequately approximates the Superfund site (in which case multiple reference sites may be needed), and that in some instances there may be no suitable reference sites. (See "Reference Site" discussion on page 5 of the *ECO Update* [EPA 1994a].)

For all reference areas, the influence of past operations was considered. An evaluation of the past air deposition from facility stacks was made (DOE/RL-2005-49). Deposition beyond the proximity of the facilities would likely be decayed for those contaminants released in significant quantities or be diluted below measurable levels. These assumptions were assessed by a comparative analysis of the reference site soils, as they are spaced over a distance of about 32 km (20 mi) by 40 km (25 mi). The reference sites are all within about 1.6 to 8 km (1 to 5 mi) from the nearest operational area.

Upland reference areas were chosen within the Lower Columbia Basin to minimize the effects of changing climatic conditions, sources of soil (e.g., river and air deposited), and nearby agricultural activities. The upland sites range geographically from Yakima Ridge on the Arid Lands Ecology Reserve in the southwest, to near Gravel pit 9 about 4.8 km (3 mi) north of the 300 Area, and to the lower slopes of Saddle Mountain, about 6.4 km (4 mi) north of the Columbia River.

Examination of borrow pits that have not been used for several decades shows that these areas tend to naturally revegetate with native species such as sagebrush, snow buckwheat, yarrow, and Sandberg's bluegrass. Consequently, five of the reference locations were chosen from recovering borrow pits to reflect the current habitat at the remediated waste sites. Many of the remediated waste sites have been backfilled with material from these borrow pits, and so the soils and habitat will be most similar for these areas.

The other five reference locations were chosen because they are in minimally disturbed shrub-steppe habitat. The soils at these nonbackfilled waste sites, which are mostly in the old Hanford and Richland townsites, tend to be composed of finer grained soils, similar to those that currently support the undisturbed shrub-steppe habitats.

Other areas that were also considered for undisturbed reference locations include the Columbia National Wildlife Refuge, Yakima Firing Center, proposed Black Rock Dam location, and Grant County near Ephrata. In general, these sites were dismissed because of their distance from the Hanford Site and corresponding conditions that increasingly differ from the Hanford Site (see EPA direction listed above), with no real advantage over the sites proposed.

Other individual reasons for not selecting these sites are as follows:

- The Columbia National Wildlife Refuge was used as a reference location for a U.S. Fish and Wildlife Service study of dichlorodiphenyltrichloroethane/dichlorodiphenyldichloroethylene (DDT/DDE DDE) at the remediated military waste sites on the North Slope and Arid Lands Ecology Reserve headquarters (Roy et al. 1998). While the levels of DDT/DDE at the Columbia National Wildlife Refuge reference area were less than the worst of the military waste sites, they were comparable with approximately half of the other waste sites. With other locations closer to the study areas, there was no perceived benefit to selecting a site farther away and with recognized levels of some contaminants.

- The Yakima Firing Center, at a higher elevation, posed a slightly different climatic situation, and also had access and mapping difficulties because it is an active, secure military training facility and safety concerns with the possibility of unexploded ordnance.

- The proposed Black Rock Dam area did not have any areas of sagebrush or rabbitbrush large enough to have a defensible plot, has a much steeper terrain, and has been used more recently for cattle grazing.

- Grant County near Ephrata, while it has large areas of sagebrush, was at such a distance from the Hanford Site that the EPA directive to locate the reference site as close as possible to the Superfund site was not being followed.

In 2007, two off-site upland reference areas were selected by the Central Plateau risk assessment project: one at Crab Creek (north of Saddle Mountain) and one at Eaton Ranch (adjacent to the Yakima Firing Center). Two additional near-shore reference areas have been selected by the Inter-Areas shoreline assessment and also sampled in 2007. The results from all these sites will be incorporated as they become available.

4.1.4.2.2 General Considerations for Near-Shore/Riparian Reference Site Selection. The near-shore and riparian reference areas were chosen by considering the region's river system. The Columbia River has a large, fast, and widely varying flow, and is not dammed in the Hanford Reach. The flow regime does not allow finer grained sedimentation that is more frequently found in areas of the Columbia River behind dams. The Hanford Reach (and upriver) is also less influenced by agricultural activities and their corresponding contamination than most other rivers in the region. However, mines have operated up the Columbia River in Canada. While these mines left significant residue in the Columbia River, the residue decreases with increasing distance from the mines to Grand Coulee Dam (e.g., Majewski et al. 2003, Era and Serdar 2001). Presumably, these levels continue to decrease beyond the Grand Coulee Dam.

As discussed in EPA guidance (EPA/540-F-94-012) and provided that pollutant loading from other sources does not occur upstream, an upstream location may provide an appropriate reference site for a Superfund site with contaminated surface water. For these reasons, the Columbia River, upriver for the Hanford Site and downriver as far as possible from previous mining, and in a nondammed area, was determined to provide the best location for reference sites. The only area to meet these criteria was the Columbia River upriver from the Hanford Site operations areas and below the Priest Rapids Dam.

The two other large rivers considered for reference locations were the Yakima and Snake Rivers. The Snake has a flow that is heavily dammed and has a muddy bottom, unlike the Columbia River in the Hanford Reach. The Snake River drains a large amount of agricultural lands and supports a lot of heavy boat traffic, with the corresponding hydrocarbon and chemical pollution from these activities. The Yakima River also has significant nonpoint source pollution from the agricultural development along its length, and is a much smaller river than the Columbia River, with different ecological conditions because of the size. It was concluded that neither of these rivers are defensible choices as reference locations.

4.2 OTHER DATA USED IN THE RIVER CORRIDOR BASELINE RISK ASSESSMENT

This section presents an overview of the existing Hanford Site data applied in the human health and/or ecological risk assessments. Sources of existing analytical data include cleanup verification sample data for upland soils, groundwater monitoring well data, existing surface water and sediment data, results from PNNL the Surface Environmental Surveillance Program (SESP), and results compiled in an effort led by the CRC of the RCBRA that pertain specifically to the region of that project that includes the Hanford Site. These data were provided electronically from various Hanford Site data repositories, including the HEIS database, ENRE database, and other sources (e.g., PNNL). The original electronic files for these data sources are provided in the online project data repository at http://rcbra100-300.gisdt.org/.

The project-specific analytical data sources mentioned above were developed independently by multiple contractors; however, data used in these often originated from common Hanford Site repositories (e.g., HEIS), leading to a high degree of result overlap for some media. During development of the RCBRA database, every effort was made to reduce duplication of reported results among sources. Only one result per sample ID/analytical method/analyte combination was permitted in the final database. In the event of a duplicated result, the result from the preferred data source in a hierarchy of sources was selected, and the duplicate results were deemed "rcbra not useable" and flagged as being a duplicate result of a less-preferred data source.

In addition, some sample site names (location information) were normalized for consistency of reporting. For near-shore aquatic media, Hanford river mile (HRM) was approximated by using the sample-specific Easting global positioning satellite (GPS) coordinate and matching it with known HRMs easting coordinates. Normalizations of these types aid in data presentation and interpretation.

4.2.1 Existing Soil Data (CVP/RSVP)

Cleanup verification samples were collected at the Hanford Site to document completion of remedial actions at CERCLA waste sites. These data, initially documented in waste site " CVPs or RSVPs for specific waste sites or groups of waste sites are used to evaluate attainment of RAOs prescribed by the Tri-Parties. These samples are representative of contaminant concentrations remaining in soil following the excavation and removal of waste. Cleanup verification samples for CVP sites are collected from statistically determined locations on the excavation floor and sidewalls. Verification samples for Remaining Sites are collected from focused and statistically determined locations within the site where contamination is either evident or expected.

Cleanup verification data from both CVP and RSVP soil sites were used in this assessment to calculate exposure concentrations under various human exposure scenarios. CVP/RSVP data were previously evaluated in the screening-level ecological risk assessment (Appendix C of

BHI-01757); while they are used for human health risk evaluations, they are not evaluated further in the ecological risk assessment.

When overlap was encountered between the CVP/RSVP results and results from other sources, the CVP/RSVP data source was identified as the preferred source and duplicate results were declared "rcbra not useable."

4.2.2 Groundwater Monitoring Well Data

Groundwater well monitoring at the Hanford Site is performed by PNNL and managed by Fluor Hanford, Inc. Monitoring results are published each fiscal year in PNNL's Hanford Site Groundwater Monitoring Report (e.g., PNNL-15670). The annual groundwater monitoring reports discuss the general groundwater flow and chemistry on the Hanford Site, including the location and movement of groundwater contaminant plumes.

The human health risk assessment (Section 5.0) uses the analytical data obtained from groundwater monitoring wells to assess potential risks to receptors under various exposure scenarios. Groundwater data from 1999 to present are presented in the exploratory data analysis and trend analysis (Section 4.4). However, because groundwater conditions fluctuate dramatically over time, only well data from collected expressly for the 100 Area and 300 Area Component of the RCBRA are assessed in the human health risk assessment.

No overlap was encountered for analytical results for groundwater.

4.2.3 Surface Water and Sediment Data

Surface water and sediment have historically been characterized at the Hanford Site shoreline and within the Columbia River. Most surface water and sediment data were collected by PNNL for special characterization purposes. These data were maintained in the HEIS database or in PNNL documentation (reports and databases). Surface water and sediment data used in the risk analysis include surface waters from variable depths of the Columbia River; historic seep, spring, and aquifer tube samples; and sediments associated with the near-shore Columbia River, its islands, and sloughs.

Some overlap in sediment data were encountered. Results from less-preferred sources were flagged as "rcbra not useable."

4.2.4 Surveillance Program Data

The SESP is operated by PNNL. A variety of environmental media are routinely monitored. These include air, surface water, sediments, soil, natural vegetation, agricultural products, fish, and wildlife. Radionuclides and nonradiological chemicals including metals, organic compounds, pesticides, and PCBs are measured in various media. Ambient external radiation levels in the environment are also routinely monitored. Information obtained from these surveillance efforts are provided to federal, state, county, and city agencies; regional Indian tribes; other stakeholders; and the general public. The collected data are used to document

Hanford Site compliance with environmental regulations to provide information to the public about environmental conditions on the Hanford Site and adjoining properties, and to satisfy monitoring requirements of some contractors engaged in site cleanup activities.

Data previously published by the SESP in the Hanford Site annual monitoring reports that are included in the nature and extent characterization include tissue concentrations of radionuclides and nonradionuclides in upland and riparian vegetation and fruit, milfoil, mule deer, cottontail rabbit, game birds, bass, carp, sculpin, sucker, whitefish, clams, and crayfish.

4.2.5 Background and Comparison Data Sources

Background and comparison data sources are summarized in Table 4-2. To understand the nature and extent of contamination across media and locations, and to evaluate potential trends over time, data pertaining to the RCBRA investigation were compared to similar data from a variety of sources. Data sources were categorized as "area background," "Washington State background," or "other." Background data consisted of published values for natural background of soil metals in the state of Washington (Ecology 1994) and established Hanford Site background values for metals and radionuclides in soil (DOE/RL-92-24, DOE/RL-95-55, DOE/RL-96-12). Other data consisted of data collected by PNNL's SESP as part of an ongoing monitoring program that is inclusive of several sample media and locations and data relevant to the Hanford Site and immediate surroundings that were complied for the CRC of the RCBRA (WCH-91).

4.2.6 History of Soil Background Values Development

The Hanford Site-wide soil and groundwater background efforts were initiated in the early 1990s because the many RCRA and CERCLA projects at the Hanford Site were spending significant amounts of resources individually, attempting to characterize background levels for radioactive and/or nonradioactive analytes. Individually, none of the individual background efforts were statistically valid or robust. Also, in many places, it could not be demonstrated that samples even existed that could be regarded as representing bonafide (uncontaminated) "background."

In the early 1990s, there were multiple working definitions of soil background because the term was being defined differently for various projects, with inconsistent and conflicting results. It was also noticed that the background levels for many analytes were potentially above the state levels, but these values required a solid technical basis to supercede the state values. Consequently, one of the related efforts was to assist Ecology in redefining their definition of background in the WAC. (At the time, the WAC definition of soil background was "...the mean value of the background population...", which meant that 50% of all natural background could be misinterpreted as contaminated.)

A sitewide approach for characterization of soil background was used as an alternative to the determination of background for each waste management unit. This approach was based on the initial evaluations of available soil background data, geology, and development of a conceptual model to ensure the representativeness, comparability, and completeness of the data collection activities (WHC-MR-0246).

The basic premise of the Hanford Site-wide soil background approach was the conceptual model that the soils and sediments in the region were all related geologically in terms of their origin, physical composition, and chemical composition of the <2 mm size fraction (which is what the laboratories analyze) because the sand-size and smaller fractions in these sediments are dominated by clastic basaltic material. Consistency was shown in the type of materials that dominate the finer grained size fractions among these sedimentary facies, one-third to two-thirds of which consist of clastic basaltic material, together with variable proportions of quartz, feldspar, and other subordinate minerals for essentially all of the facies of the Hanford formation sediments and soils. Although the sediments of the Hanford formation appear diverse lithologically in outcrop or in excavated exposures from one location to another, there is a continuum in the proportions of the materials that comprise these sediments. Thus, the characteristics that control their physical and chemical composition have been shown to comprise a single compositional population (Jim Hoover, e-mail communication dated May 10, 2007 [CCN 134185]).

These efforts were approved and vetted throughout the entire process by DOE, Ecology, EPA, and WDOH, that included the DQO process, SAPs, and final documents. The DQO process recommended by the EPA was used as guidance for all activities associated with the determination of soil background composition (DOE/RL-92-24, Vol. 1, Rev. 4). The principal users of the background data for CERCLA and RCRA decisions include the DOE, other conservators of the Hanford Site, subcontractors, and the federal and state regulatory agencies (DOE/RL-92-24, Vol. 1, Rev. 4).

The background data for nonradioactive analytes represent UCLs of the statistically valid population comprised of data from 22 localities on the Hanford Site. Radiological background data were initially obtained from over 300 samples and 1,420 results, but ultimately based on 149 samples from 39 localities.

4.2.7 Tabulation of Soil Reference Site and Background Concentrations

Concentrations reported in an online project data repository for Washington State background, area background, and reference site samples are tabulated for inorganic and radionuclides in Table 4-5. This summary provides the range of mean concentrations reported for upland and riparian reference sites and the range of concentrations reported for background and reference sites. An overlay plots of these concentrations is provided as Figure 4-2. There are 13 inorganic chemicals reported for the Washington State background data, and the maximum value reported for 11 of these 13 analytes is provided by the Washington State background data. The exceptions are mercury and zinc, and the maximum concentration is reported from the area background data. There are 36 inorganic chemicals and radionuclides in common between the reference site samples and the area background data; for all but plutonium-239/240, the maximum value was reported for the area background. This latter observation is expected because the reference site samples are multi-increment soil samples that represent the mean concentration for each investigation area. A more relevant comparison is the median area background concentration to the upland reference site concentrations, which are similar. For example the range of mean arsenic concentrations reported for upland reference sites is from 1.8 to 4.1 mg/kg compared to the median area background arsenic concentration of 3.9 mg/kg.

4.3 CONTAMINANTS OF POTENTIAL CONCERN

As described in the SAP (DOE/RL-2005-42), suite analyses were performed for samples collected for this project. To structure the nature and extent analyses towards those constituents most likely to pose risk to human health and the environment, analytical results for all media were evaluated against specific criteria to identify focused COPCs. This section describes the protocol used to identify focused COPCs for the nature and extent analyses. A COPC is a detected analyte that is associated with Hanford Site operations and has the potential for toxicity at environmentally relevant concentrations. Analytical results were also compared to background and reference site data to evaluate the nature and extent of contamination (presented in Section 4.4). Comparisons were made among reference sites as well as between reference sites and potentially affected areas. These comparisons did not eliminate any COPCs from further evaluation in the human health and ecological risk assessments. This approach for data analysis and assessment was developed during the regulator/trustee workshop conducted for this project from July 2006 to May 2007, and the notes from these workshops are provided as Appendix E.

4.3.1 Evaluation of Data Quality

Understanding the quality of data, as well as its utility and uncertainties, is imperative to performing a defensible human health and ecological risk assessment. Data collected and assessed must meet the needs and satisfy requirements of the risk assessment as stated in the *Sampling and Analysis Plan for the 100 Area and 300 Area Component of the RCBRA* (DOE/RL-2005-42, Rev. 1). Because this risk assessment report considers both RCBRA project-specific and historical data, these data types are evaluated separately as described in the subsections below.

4.3.1.1 RCBRA-Specific Data Quality. Analytical QA requirements prescribed in the QAPP of the SAP (DOE/RL-2005-42, Rev. 1, Section 2) pertain specifically to the data collected for the investigation areas identified for the RCBRA risk assessment effort. Results from other investigative and confirmatory sampling events, such as the cleanup and remaining site verification documentation, the 100-B/C Pilot Project (DOE/RL-2005-40), the 100-NR-2 investigation (PNNL 2005), and historical monitoring data, were collected under various project-specific criteria, and therefore were not evaluated against the quality criteria specified in the SAP (DOE/RL-2005-42). The QAPP specified the analytical performance requirements for soil, sediment, water, and biota collected under direction of the SAP. For each media type the analytical methods, required detection limits, precision, and accuracy were specified.

Analytical results for soil, sediment, water, and biota collected for the RCBRA investigation were evaluated against the quality criteria specified in the QAPP (DOE/RL-2005-42, Section 2). As a measure of data quality, analytical results identified as nondetects in the RCBRA data set (i.e., results for soil, sediment, water, and biota qualified by the laboratory, reviewer, or validator as "U," and subsequently assigned detect status of "FALSE" as described in Section 4.3.2) were compared to the laboratory required detection limits prescribed in the QAPP. Nondetect results reported at values higher than the prescribed detection limit were identified for additional consideration. The adequacy of these results was then determined by comparing the reported nondetect value to the applicable media-based lookup value (such as an ecological benchmark or cleanup value). Nondetect results reported at values less than the media-based lookup values were determined to be useable nondetect results. Those results where the nondetect result exceeded the media-based lookup value were acknowledged as uncertainties in the risk analysis.

4.3.1.2 Quality of Data from Non-RCBRA Sources. Non-RCBRA data sources included CVPs and RSVPs, project-specific investigations conducted by other contractors (e.g., 100-B/C Pilot Project [DOE/RL-2005-40], 100-NR-2 investigation [PNNL 2005]), and historical groundwater and environmental monitoring reports. Data collection, analysis, and quality requirements for each of these sources were specified in their project-specific planning documentation, which may have differed from the requirements specified in the RCBRA SAP (DOE/RL-2005-42, Rev. 1). Evaluation of analytical results against project-specific quality planning documentation was not performed for non-RCBRA data sources. These data were presumed to meet the minimum quality criteria for analytical performance and reporting as specified in their project-specific planning documentation. Results from non-RCBRA sources were not compared to the quality criteria specified in Section 2.0 of the SAP (DOE/RL-2005-42, Rev. 1). Their appropriateness for use in the RCBRA risk assessment was determined by evaluating individual results to the quality usability presented in this section.

4.3.2 Data Usability

This section discusses the criteria and assignment of usability codes for analytical data evaluated in the risk assessment.

4.3.2.1 Usability Criteria. Usability of analytical data was assessed using several criteria. Five key criteria for data usability included the reporting of analyte (by name or Chemical Abstracts Service [CAS] ID), result, units, media type, and definitive location information. Usable data were also required to be relevant to the risk assessment effort, e.g., useable results must pertain to specific media or measurements. Measurements or results reported that were not directly relevant to the objectives of the risk assessment were deemed "RCBRA not useable" in some instances. Where data were deemed "RCBRA not useable," they were assigned a usability code and reason. Usability codes and their descriptions are presented in Table 4-6.

Useable Data

Useable data included detected, nondetected, and qualified data meeting the usability criteria described above. Useable data were used to perform exploratory data analyses, exposure calculations, and risk analyses described in later sections of this report.

Unusable Data

Data deemed "RCBRA not useable" were assigned the appropriate usability codes and flagged as such in the database (Table 4-6). These data were excluded from analysis in exploratory data analyses and subsequent risk analyses.

4.3.3 Identification of Detected Constituents

This section presents the methods and results of an assessment of the detection status of each constituent.

4.3.3.1 Detect Status. Detection status for each analyte was determined on a sample-by-sample basis. Analytical data are subject to qualification by the analytical processing laboratory, a data reviewer, or a data validator. Qualification of data consists of assigning a character string of codes in combination to identify characteristics of the associated results. The laboratory qualifiers are reported by the analytical laboratory to indicate attributes such as analyte detection, sample dilutions, laboratory control limit exceedances, detection of analyte in the quality control (QC) blank, result estimation, etc. Different categories of constituents may have different permitted combinations of valid qualifiers; however, "B" and "U" qualifiers (indicating analytical detection in the QC blank, and reported quantity is below the detection limit, respectively), are mutually exclusive qualifiers for all categories. If no qualifier code is reported with the analytical result, the value reported is believed to be reliable without qualification.

Review qualifiers are sometimes assigned to data where the quality of the record has been questioned by the reviewer. Reasons for review qualification include follow-up required (F), exceedance of laboratory holding time (H), rejection of result (R), result determined to be nondetect (U), or special circumstances exist (Z). Reviews are typically followed by validation at the request of the project.

Validation qualifiers are assigned by an individual who validates results at the request of the project management for which the sample was collected. Validation qualifier codes have the same meaning as laboratory qualifier codes, with the exception of "R," which indicates that the sample results was rejected.

Values for laboratory, review, and validation qualifiers are reported in the RCBRA database. Detect status was included as a derived field for all analytical results and is based on a simple algorithm. The algorithm states that if the universal detection qualifier of "U" (indicating the result was reported below the analytical detection limit) is encountered in any one of the three qualifier fields, the detect status is determined to be "FALSE" (i.e., a nondetect result). Results that are not qualified or are qualified with a combination of qualifiers other than "U" were treated as detected results and assigned a detect status of "TRUE."

4.3.4 Comparison of RCBRA Results to QAPP Detection Limits

Analytical QA requirements were prescribed in the QAPP (DOE/RL-2005-42, Rev. 1, Section 2). The QAPP specified the analytical performance requirements for soil, sediment, water, and biota. For each media type the analytical methods, required detection limits, precision, and accuracy were specified.

Analytical results for soil, sediment, water, and biota collected for the RCBRA investigation were evaluated against the quality criteria specified in the SAP. Results from other investigations, such as the 100-B/C Pilot Project (DOE/RL-2005-40), 100-NR-2 investigation (PNNL 2005), and historical monitoring data, were collected under project-specific specifications and therefore were not evaluated against RCBRA-specific quality criteria.

Results identified as nondetects in the RCBRA data set (i.e., results for soil, sediment, water, and biota qualified by the laboratory, reviewer, or validator as "U," and subsequently assigned detect status of "FALSE" as previously described in Section 4.3.3) were compared to the laboratory required PQL prescribed in the QAPP. There are approximately 101,410 reported values in the RCBRA dataset. Roughly 72% of these reported values were classified as nondetects with 91% of these nondetects less than the PQL. The remaining 9% of nondetect results reported at values higher than the PQL were identified for additional consideration. The adequacy of these results was then determined by comparing the reported nondetect value to the applicable media-based lookup value (such as an ecological benchmark or cleanup value). No benchmarks were available for 31% of the nondetect results greater than the PQL. Fourteen percent of the nondetect results greater than the PQL were also found to be greater than the benchmark.

In summary, nondetect results reported at values less than the media-based lookup values were determined to be useable nondetect results. Those results where the nondetect result exceeded the media-based lookup value are acknowledged as uncertainties in the risk analysis.

4.3.5 Identification of Potentially Site-Related Constituents

Principal contaminants associated with 100 Area and 300 Area operations were summarized in Section 2.1.1 of this report. For example, principal contaminants at the liquid waste sites include tritium, carbon-14, cobalt-60, nickel-63, strontium-90, cesium-137, europium-152, europium-154, europium-155, plutonium-239/240, uranium, chromium, and nitrate. At the solid waste burial grounds, principal radioactive contaminants are similar to those described for the liquid waste sites. Nonradioactive contaminants at the solid waste burial grounds included boron, cadmium, lead, nickel, lithium-aluminum alloy, mercury, palladium, uranium, and zirconium. However, the number of analytes with one or more positive detections in the CVP/RSVP data, the RCBRA soil data, and the last 5 years (2002-2006) of groundwater data greatly exceed the number of these principal contaminants. In part, this may reflect the presence of naturally occurring metals and radionuclides and ubiquitous environmental chemicals such as certain pesticides, PCBs, etc. Some of these detected analytes may also be related to stack emissions, burn pits, dumping areas, landfills, septic tanks, sewers, and unplanned releases, as well as being minor components of liquid waste site and burial ground disposals.

Constituents detected at least once in abiotic media results from the RCBRA, 100-B/C Pilot Project, or 100-NR-2 Shoreline Assessment are reported in Table 4-7. There are 125 inorganic, organic, and radionuclide constituents listed in Table 4-7. Analytes positively detected in one or more of the RCBRA multi-increment soil data, CVP/RSVP samples, or the groundwater samples from wells within the 100 Area and 300 Area operable units are shown in Tables 4-8 through 4-10, respectively.

4.3.6 Identification of Toxicologically Relevant COPCs

Toxicological relevance of potential site-related COPCs was evaluated to help refine COPCs. Among radionuclides, primary radionuclides[1] having a half-life exceeding 3 years were retained as COPCs for the risk assessments. Radionuclides with shorter half-lives associated with historical Hanford Site operations would not be toxicologically relevant due to decay over the period of time since operations ceased. Among the radionuclides in Tables 4-18 through 4-20, those with short half-lives that are excluded from the quantitative risk calculations include the following:

- Actinium-228; 6-hour half-life (accounted for in the decay chain of radium-228)
- Beryllium-7; 53-day half-life
- Cesium-134; 2.1-year half-life
- Lead-212; 11-hour half-life (accounted for in the decay chain of thorium-228)
- Lead-214; 27-minute half-life (accounted for in the decay chain of radium-226)
- Manganese-54; 312-day half-life
- Radium-224; 3.7-day half-life (accounted for in the decay chain of thorium-228)
- Ruthenium-106; 1.0-year half-life
- Thorium-234; 24-day half-life (accounted for in the decay chain of uranium-238).

One additional radionuclide, thorium-228 (half-life of 1.9 years), also has a half-life of less than 3 years. Because activity of an operational release of radium-228 would quickly come into equilibrium with thorium-228, thorium-228 is retained as a COPC for this assessment.

As stated in Section 5.9.4 of EPA (1989), essential nutrients that are present at relatively low concentrations and are toxic only at high doses need not be considered in a quantitative risk assessment. The elements sodium, magnesium, calcium, and potassium are among those cited in EPA (1989) as examples of such nutrients. Iron, an essential element of particular importance for its role in the oxygen-carrying proteins hemoglobin and myoglobin, is similarly cited in EPA (1989; Section 5.9.4). However, since the publication of the 1989 guidance, a provisional oral reference dose for iron of 0.3 mg/kg-day has been published by EPA's National Center for

[1] Radionuclides with short half-lives (less than 30 days) that are within the decay chain of a primary radionuclide are accounted for within the dose conversion factor or slope factor of the parent nuclide; see Section 5.5.

Environmental Assessment (EPA/540/R-95/128). As a point of comparison, the recommended dietary allowance of iron varies from 8 to 27 mg/day (Institute of Medicine 2001), or approximately 0.1 to 0.6 mg/kg-day when expressed as a body weight-averaged intake, depending on variables such as age and pregnancy. The highest measured iron concentration in waste site soils, approximately 30,000 mg/kg, would result in an iron intake of just 6 mg/day at a soil ingestion rate of 200 mg/day (EPA's "conservative estimate of the mean" for children; see Section 5.4.2). Therefore, iron will be grouped with the other essential nutrients described above and will not be included in the quantitative risk assessments.

Silicon primarily occurs in nature as either silicon dioxide or a silicate anion; its abundance in the earth's crust, where it is a component of many types of rocks, is second only to oxygen. Silica (aka, silicon dioxide) is also a component of plants, including edible varieties, and is used as a food additive to prevent caking. There is ample practical evidence that silica is toxicologically inert, except in situations where fine silica dusts may be inhaled, leading to silicosis. Therefore, silica and silicon will not be considered in the quantitative risk assessments. In summary, chemicals excluded from the quantitative risk calculations include the following:

- Calcium
- Iron
- Magnesium
- Silica and silicon
- Sodium
- Potassium.

4.3.7 Background and Reference Site Comparison

Comparisons of waste site or operational area samples to background and reference site data are provided for information purposes only. The risk assessments will evaluate all COPCs identified based on the criteria presented above. In addition, comparisons were made among reference sites as well as between reference sites and background. These background and reference site comparisons did not eliminate any analytes from further evaluation in the human health and ecological risk assessments. Comparisons to background and reference site data aid in understanding whether risks are related to Hanford Site waste sites or to other sources. This information will be used to help interpret the results of the risk assessments based on all COPCs.

The background and reference site comparison decision logic is presented in Figure 4-3. Constituents identified in Tables 4-11 through 4-20 provide the lists of COPCs greater than background or reference site concentrations across aboitic media for the RCBRA, CVP/RSVP, 100-B/C Pilot Project, and 100-NR-2 data sets.

Background and reference site comparisons were conducted following the decision logic presented in Figure 4-3, which depicts the basic set of questions for group comparison test selection, namely how many groups are being compared (1) and are the data normal (2 and 3). When the data are normal and two groups are being compared, a third question about equality of variance is listed (4). The comparison method is determined by the answers to these questions.

4.3.7.1 Background Comparisons for Soils and Groundwater. Although published summary statistics for groundwater background are documented (DOE/RL-96-61), the original background groundwater results from which these values were calculated were not obtained. Thus, statistical testing for groundwater data was not possible. Detected analytes in RCBRA groundwater well data are listed in Table 4-10. Consitituent concentrations in RCBRA groundwater that were greater than background or reference site concentrations are listed in Table 4-11.

Soil concentrations were compared to background and reference concentrations using background comparisons (distribution shift tests) (Table 4-12). The RCBRA investigation area soil data were compared to four reference or background sets, including (1) the combined set of RCBRA reference data, (2) the RCBRA reference data for the associated site type (backfill, native soil, or riparian), (3) Hanford Site background soil, and (4) Washington State background soil (Tables 4-12 and 4-13). The CVP/RSVP soil data, and soil and sediment data pertaining to the 100-B/C Pilot Project, and the 100-NR-2 investigation data were compared to the area background soil and Washington State background soil (Tables 4-12, and 4-14 through 4-20). The process outlined in Figure 4-3 was applied only when both the site and reference set have detection rates at least as large as 50%. When this criterion was not met, or for those analytes with no reference set for comparison, the analyte was identified as being greater than background or reference site concentrations. The uncertainty associated with these comparisons was evaluated with additional statistical tests for infrequently detected analytes.

To address uncertainties associated with background comparisons for RCBRA reference site data for infrequently detected analytes, some other statistical tests were used. When Pearson's chi-square test concluded that the site detection rate was not significantly different from the reference detection rate, or the site rate was significantly lower than the reference detection rate, the slippage test (Gilbert and Simpson 1990) was applied to determine whether there was a significant number of site results larger than the maximum detected result at the reference site. If the slippage test concluded that the site did not differ in large concentrations and if the detection rate at the site was less than or equal to that of the reference set, the site was considered no different from reference based on tests for infrequently detected analytes. Comparisons for infrequently detected analytes indicate that an additional 19% of the retained analytes in RCBRA site data were no different from reference, and 4% of retained analytes in CVP/RSVP site data were not different from background.

At the RCBRA soil operational and waste sites, 106 analytes were retained as different from reference and background based on distribution shift tests. The retained analytes were those concluded as different in comparisons to three or more of the four reference and background datasets. Of those 106 analytes, 20 were identified by uncertainty analysis as infrequently detected analytes that were not different from reference and background (see the list in Table 4-12). At CVP/RSVP sampled sites, 104 analytes were retained as different from background based on distribution shift tests. These analytes were those concluded as different in comparisons to one or more of the two background datasets. Of those 104 analytes, 28 had no background data for comparison and 4 were identified by uncertainty analysis as infrequently detected analytes that were not different from background (Table 4-14). The 100-B/C Pilot Project soil results from the combined set of operational areas were compared to Hanford Site background soil and Washington State background soil. From 100-B/C Pilot Project soil results, 53 analytes were retained as different from background based on distribution shift tests (Table 4-15). Of those 53 analytes, 18 had no background data for comparison and 4 were identified by uncertainty analysis as infrequently detected analytes that were not different from background (Table 4-15). The 100-NR-2 investigation data soil results from the combined set of operational areas were compared to Hanford Site background soil and Washington background soil. From 100-NR-2 soil results, 21 analytes were retained as different from background based on distribution shift tests (Table 4-16). Of those 21 analytes, 8 had no background data for comparison and 1 was identified by uncertainty analysis as infrequently detected analytes that were not different from background (Table 4-16).

The list of COPCs presented in Tables 4-11 through 4-16 represent the combined list of COPCs identified for soil and groundwater. Detailed results showing test conclusions by analyte at each site compared separately to the available reference and background datasets are available in Appendix F, Section F-2.0.

Comparisons between the reference and background data sets for soil were performed using the Kruskal-Wallis test. The results are listed in Table 4-12.

4.3.7.2 Background and Reference Area Comparisons for Sediment and Pore Water. Sediment concentrations from RCBRA operational sites, the 100-B/C Pilot Project data, and the 100-NR-2 investigation data are compared to RCBRA reference site concentrations using distribution shift tests. Pore water at RCBRA operational sites are compared to RCBRA reference site concentrations using distribution shift tests. The process outlined in Figure 4-3 is applicable only when the detection rates both at the site and in the reference set have detection rates at least as large as 50%. The uncertainty associated with these comparisons was evaluated with additional evaluations for infrequently detected analytes.

All RCBRA pore water sites are near-shore aquatic locations. Pore water samples were analyzed for each RCBRA operational and reference site from samples collected in early 2006 and a second sample collected for a subset of locations in late 2006. The combined set of pore water samples at RCBRA operational sites was compared to the combined set of pore water samples at RCBRA reference sites. A total of 32 analytes were retained as different from RCBRA reference pore water based on distribution shift tests (Table 4-17). Of those 32 analytes, 1 was retained because there are no reference data for comparison and 13 were identified by uncertainty analysis as infrequently detected analytes that were not different from reference. Focused COPCs for pore water are listed in Table 4-17.

All RCBRA sediment sites are near-shore aquatic locations. A single sediment sample was collected at each RCBRA investigation area operational site and each RCBRA reference site. The combined set of sediment samples at RCBRA operational sites was compared to the combined set of sediment samples at RCBRA reference sites. A total of 39 analytes were retained as different from RCBRA reference sediments based on distribution shift tests. Of those 39 analytes, one was retained because there are no reference data for comparison and 10 were identified by uncertainty analysis as infrequently detected analytes that were not different from reference. The COPCs identified for RCBRA sediment are listed in Table 4-18. The combined set of sediment samples from the 100-B/C Pilot Project were compared to the combined set of sediment samples at RCBRA reference sites. From 100-B/C Pilot Project sediment results, 19 analytes were identified as different from RCBRA reference sediments based on distribution shift tests (Table 4-19). Of those 19 analytes, 1 constituent had no reference data for comparison and 6 were identified by uncertainty analysis as infrequently detected analytes that were not different from reference (listed in Table 4-19). The combined set of 100-NR-2 investigation data sediment results were compared to the combined set of sediment samples at RCBRA reference sites. From 100-NR-2 sediment results, eight analytes were retained as different from RCBRA reference sediments based on distribution shift tests. Of those eight analytes, one was identified by uncertainty analysis as infrequently detected analytes that were not different from reference site concentrations (listed in Table 4-20).

4.3.8 Six Radionuclides (K-40, Ra-226, Ra-228, Th-228, Th-230, and Th-232)

During the latter stages of workshop presentations and meetings to discuss the initial report results, it was decided that the remediated waste site risk assessment results were being obscured by six radionuclides without any known Hanford Site sources. These radionuclides are potassium-40, radium-226, radium-228, thorium-229, thorium-230, and thorium-232. These naturally-occurring radionuclides are retained as COPCs for the risk assessment, but results for these six radionuclides will be reported separately from other COPCs.

4.4 NATURE AND EXTENT OF CONTAMINATION

This section describes the results of graphical analyses used to evaluate the nature and extent of contamination for the pooled set of samples collected for the 100 Area and 300 Area Component of the RCBRA SAP and other data sources discussed in Section 4.2. The list contaminants evaluated in this section include the three key plume contaminants identified in the SAP (chromium, strontium-90, and uranium).

The nature and extent of contamination was evaluated by assessing COPC detect status across all media, plotting contaminant concentrations by environment (upland, riparian, and near-shore) and category (operational and reference locations), evaluating COPC detection trends in paired biotic and abiotic media, evaluating COPC concentrations by HRM, and evaluating trends in COPC concentrations over time for specific media and locations. Because little was known about the nature and extent of contaminants in the near-shore aquatic zone, intensive investigation and a detailed narrative is provided the near-shore aquatic zone (Section 4.4.2). The discussion of nature and extent of contamination in the riparian and upland areas is focused on general trends between terrestrial environment (i.e., upland/riparian) and category (operational/reference) and for plume contaminants (i.e., chromium, strontium-90, and uranium).

4.4.1 Evaluation of Contaminant Trends by Media Type

Plots that show spatial and temporal trends for detected COPCs in all media are compiled in Appendix F (Section F-3.0, "Contaminant Trends by Media"). Detected and nondetected sample results are distinguished on these plots and different kinds of media and sample locations are also identified. Generally, few detected COPCs show consistently higher concentrations at Hanford Site operational sample locations compared to background or reference site data sources. Some exceptions are found among CVP/RSVP soil samples, RCBRA soil samples of remediated "remaining" sites, and across the near-shore aquatic environment. Contaminant trends for biotic and abiotic media in the near-shore aquatic environment are described in the following section.

4.4.2 Evaluation of Contaminant Trends Across All Near-Shore Aquatic Media for Key Groundwater Plume Contaminants

This section describes the observations and general trends of key groundwater plume contaminants in aquatic media. Aquatic media evaluated in this risk assessment included sediment, pore water, surface water, aquifer tube water, aquatic macroinvertebrates, clams, and fish. Discussions are presented by key groundwater plume contaminant (chromium, strontium-90, and uranium) with respect to trend observations over time, between media, and amongst data sources. Results for COPCs detected at least once in RCBRA, the 100-B/C Pilot, or 100-NR-2 data sources were analyzed across all media by analyte and HRM; these results are presented in Appendix F (Section F-4.0, "Contaminant Trends Across all Near Shore Aquatic Media").

Known emergent groundwater contaminant plume areas were evaluated as part of the RCBRA investigation. The near-shore aquatic study design was developed to investigate the potential for ecological effects for three key contaminants in the 100 Area and 300 Area. These key contaminants are chromium, strontium-90, and uranium. The primary source plumes for these contaminants are located in the 100-K and 100-D Areas (chromium), the 100-N Area (strontium-90), and the 300 Area (uranium).

Historical data were pooled with samples collected during the RCBRA effort to identify potential spatial and temporal trends in the presence and bioavailability of these contaminants in the near-shore aquatic environment. Hexavalent chromium, uranium, and strontium-90 were evaluated across all aquatic media (abiotic and biotic) along the shoreline of the Columbia River, from the Vernita Bridge area (~ HRM 0) to the 300 Area (~ HRM 43). Results are discussed by contaminant plume type in the subsections below.

Chromium. Chromium as a contaminant in Hanford Site groundwater is primarily in the hexavalent form; it is noted that in some cases total chromium is measured and reported, and in other cases hexavalent chromium is measured and reported. The primary source plumes for hexavalent chromium are located in the 100-K and 100-D Areas. Hexavalent chromium was detected only in aquifer tube and pore water samples. The greatest number and highest detections of hexavalent chromium corresponded with aquifer tube samples from areas near HRM 10, which corresponds with the 100-D Area. Frequent aquifer tube detections at lesser concentrations were encountered near HRM 7.7 and HRM 15 (100-K and 100-H Areas, respectively). Additional detections were encountered near the 100-B/C Area. Only nondetect values were reported for the Vernita Bridge area and 300 Area. Chromium concentration trends (both hexavalent and total) are evaluated by HRM, time trend, environment category, and media in Figures 4-4 through 4-28. The number of results and frequency of detection for total and hexavalent chromium by media for the near-shore aquatic zone are presented in Table 4-21.

Because hexavalent chromium was not detected in media other than water, no additional media-concentration comparisons could be made for this analyte. General observations of hexavalent chromium concentrations in water included higher concentrations in seep and aquifer tube water relative to pore water or surface water (Figure 4-11). Hexavalent chromium was most frequently detected in seeps, followed by aquifer tubes, pore water, and surface water.

Total chromium concentrations in water, sediment, and tissue were generally higher than reference concentrations (Figures 4-4 through 4-28). The highest concentrations of chromium (total) in biota were encountered in clams (Figure 4-28). Abiotic media concentrations were generally higher or similar to paired concentrations in biota (Figures 4-24 through 4-32).

Strontium-90. Strontium-90 in groundwater underlying the Hanford Site intersects the Columbia River at the 100-N Area. Near-shore aquatic media are potentially affected by this emergent groundwater plume. Abiotic and biotic aquatic media were analyzed for strontium-90 to approximate its nature and extent along the Columbia River near-shore environment. Strontium-90 concentrations were evaluated in aquifer tubes, surface water, seeps, pore water, sediment, fish, clams, aquatic macroinvertebrates, crayfish, and mussels. The number of results and frequency of detection for strontium-90 by media for the near-shore aquatic zone are presented in Table 4-22. The highest frequency of detection of strontium-90 in water media was observed in surface water (frequency of detection = 79.2%). Operational area concentrations of strontium-90 were higher than reference concentrations. Figures 4-29 through 4-46 depict trends in strontium-90 concentrations by HRM, over time, by category (operational and reference), and by media. Trends are described by media type below.

- **Aquifer tubes**. Detected concentrations of strontium-90 in aquifer tube samples ranged from 0.456 pCi/L at HRM 5.9 (between the 100-B/C and 100-K Areas) to 2,800 pCi/L at HRM 8.9 (100-N Area). The median detected concentration of strontium-90 in aquifer tubes at all sites was 14.7 pCi/L.

- **Surface water**. Strontium-90 was consistently detected in surface water across all locations (frequency of detection = 79.2 %). The maximum detected concentration of strontium-90 in surface water was 65.6 pCi/L at HRM 8.9 (100-N Area). The median detected concentration of strontium-90 in surface water across all sites was 0.077 pCi/L.

- **Pore water**. Strontium-90 was detected in only three pore water samples. All three detects were near the 100-N Area. Two detects at HRM 8.9 were 0.73 pCi/L and 3.92 pCi/L. A single detect at HRM 9 was reported at 6.23 pCi/L.

- **Sediment**. Strontium-90 was detected in 40% of all sediment samples. Concentrations ranged from 0.002 pCi/g at the 100-K Area and Ringold (HRMs 6.3 and 27.4, respectively) to 46.7 pCi/g in the 100-N Area (HRM 8.9). The median detected concentration of strontium-90 in sediment was 0.008 pCi/g. With the exception of one sample from Aquatic Site 11, an aquatic reference site, all strontium-90 concentrations greater than 1 pCi/g were reported from HRM 8.9, the 100-N Area. A value of 5.5 pCi/g strontium-90 in sediment was reported for Aquatic Site 11, at HRM 0.6, which is located slightly downstream of the Vernita Bridge, on the north shore of the river.

- **Aquatic macroinvertebrates**. Detected concentrations of strontium-90 in aquatic macroinvertebrates ranged from 0.0425 pCi/g to 0.489 pCi/g. The highest detected concentration in aquatic macroinvertebrates was at HRM 11 (downstream of the 100-D Area). The median detected concentration of strontium-90 in aquatic macroinvertebrates was 0.1265 pCi/g across all aquatic sites. Strontium-90 concentrations were consistent between biotic tissues and abiotic media. No trend in strontium-90 concentrations was observed between aquatic invertebrate concentrations and abiotic aquatic media (Figures 4-33 and 4-40).

- **Clams**. Detected concentrations of strontium-90 in clams ranged from 0.003 pCi/g near HRM 42.2 (300 Area) to 383 pCi/g at HRM 8.9 (100-N Area). The median detected concentration of strontium-90 in clam samples across all areas was 0.297 pCi/g. Clams showed the highest concentrations of strontium-90 of all aquatic biota (Figure 4-46). Strontium-90 concentrations were frequently higher than paired sediment concentrations (Figure 4-41) but similar to pore water concentrations (Figure 4-34).

- **Fish**. Detected concentrations of strontium-90 in fish tissue ranged from 0.015 pCi/g at HRM 42.4 (300 Area) to 3.19 pCi/g reported from Wahluke stretch of the Hanford Reach (HRM 14.3). The median detected concentration of strontium-90 in fish tissue across all sites was 0.018 pCi/g. Strontium-90 concentrations were consistent between biotic tissues and abiotic media. No trend in strontium-90 concentrations was observed between fish tissue concentrations and sediment (Figure 4-42). Fish tissue concentrations were generally lower than pore water concentrations (Figure 4-35).

Uranium. Uranium is a known contaminant that resulted from extraction processes in the 300 Area. Abiotic and biotic aquatic media were analyzed for uranium to approximate its nature and extent of contamination and bioavailability along the Columbia River near-shore environment. Total uranium was calculated from concentrations of isotopic uranium in biotic and abiotic media. Uranium was evaluated in surface water, aquifer tube water, seeps, and pore water; sediment; and aquatic macroinvertebrates including clams, crayfish, and fish. The number of results and frequency of detection for total and isotopic uranium by media for the near-shore aquatic zone are presented in Table 4-23. Inorganic (total calculated uranium) and isotopic uranium, including uranium-233/234, uranium-235, and uranium-238, were detected in roughly half of aquatic media. The highest concentrations of uranium (total and isotopic) in abiotic and biotic media were consistently reported from the 300 Area.

Analytical results for calculated total uranium and uranium isotopes are discussed below by analyte on a media-specific basis. Figures 4-47 through 4-117 depict trends in inorganic and isotopic uranium concentrations by HRM, over time, by environment category, and by media.

- **Surface water.** Uranium was consistently detected in surface water. Total uranium was measured in 98% of surface water samples across all locations. Concentrations of calculated total uranium ranged from 0.0002 mg/kg in the 100-H Area to 0.116 mg/kg in the 300 Area. Uranium-233/234 was consistently detected in surface water throughout the Hanford Reach (99% detection across all locations). Detected concentrations ranged from 0.08 pCi/L at HRM 28.7 (Hanford Townsite) to 50.1 pCi/L at HRM 42.4 (300 Area). The median detected concentration across all sites was 0.23 pCi/L. Uranium-235 was detected in 20.3% of surface water samples across all locations. Uranium-235 was detected throughout operational areas of the Hanford Reach, with concentrations ranging from 0.005 pCi/L at HRM 0 (Vernita Bridge) to 2.7 pCi/L at HRM 42.4 (300 Area). The median concentration of uranium-235 in surface water across all sites was 0.019 pCi/L. Uranium-238 was detected in all surface water samples from the operational areas only. Uranium-238 was detected throughout the Hanford Reach, with concentrations ranging from 0.07 pCi/L at the 100-F Area to 45.5 pCi/L in the 300 Area. The median concentration of uranium-238 in surface water across all samples was 0.182 pCi/L.

- **Pore water.** Total uranium concentrations were calculated for 30 pore water samples. Concentrations ranged from 0.00047 μg/L at the 100-D Area to 0.141 μg/L total uranium in the 300 Area. Uranium-233/234 was detected in 71.4% of pore water samples at concentrations ranging from 0.167 pCi/L in the 100-D Area to 51.4 pCi/L in the 300 Area. Uranium-235 was only detected in aquifer tube samples from the 100-D and 100-K Areas and 300 Areas. Concentrations of uranium-235 ranged from 0.02 pCi/L in the 100-D Area to 5.76 pCi/L in the 300 Area. Uranium-238 was detected in 61.2% of pore water samples. Concentrations of uranium-238 in pore water ranged from 0.158 pCi/L in the 100-D Area to 46.4 pCi/L in the 300 Area.

- **Seep.** Concentrations of uranium in seeps were higher in the 300 Area than in other areas of the Hanford Site. Concentrations of total calculated uranium ranged from 0.0007 mg/L in the 100-D Area to the 29.8 mg/kg in the 300 Area. Uranium-233/234 was detected in 100% of seep samples. Uranium-233/234 concentrations ranged from 0.131 pCi/L in the 100-D Area to 111 pCi/L in the 300 Area. Uranium-235 was detected in 89.5% of seep samples. Concentrations of uranium-235 ranged from 0.0135 pCi/L in the 100-H Area to 6.25 pCi/L in the 300 Area. Uranium-238 was detected in 100% of seep samples. Concentrations of uranium-238 ranged from 0.123 pCi/L in the 100-D Area to 99.3 pCi/L in the 300 Area.

- **Sediment.** Uranium was consistently detected in sediment samples throughout the Hanford Reach. Concentrations of calculated total uranium ranged from 0.152 to 29.85 mg/kg in the 300 Area. Detected concentrations of total uranium were less than 6 mg/kg at all other locations. Uranium-233/234 was detected in 99.5% of sediment samples at concentrations ranging from 0.108 pCi/g in the 100-D Area to 11.3 pCi/g in the 300 Area. Uranium-235 was detected in 53.4% of sediment samples. Concentrations ranged from 0.009 pCi/g to

0.64 pCi/g in the 100-F Area and Ringold area, respectively. Uranium-238 was detected in 97.5% of sediment samples. Uranium-238 concentrations ranged from 0.05 to 9.97 pCi/g in the 300 Area. All other detected concentrations of uranium-238 were less than 2.5 pCi/L.

- **Fish.** Total and isotopic uranium was infrequently detected in fish samples. Total uranium concentrations in fish ranged from 0.004 to 0.141 pCi/g in fish samples from the 300 Area. Maximum concentrations in fish tissue were greatest in the 300 Area. Total uranium concentrations were detected in 27.7% of fish samples. Uranium-233/234 was not detected in fish samples. Uranium-235 was detected in 8.5% of fish samples, at concentrations ranging from 0.0012 pCi/g to 0.03 pCi/g in the 300 Area. Uranium-235 was detected only in fish from the 100-N Area, 100-N to 100-D Area, and 300 Area. Uranium-238 was detected in 26.9% of fish samples. Concentrations of uranium-238 ranged from 0.0013 to 0.0561 pCi/g in the 300 Area.

- **Clams.** Total and isotopic uranium were infrequently detected in clam tissue. Total uranium concentrations in clam tissue ranged from 0.129 pCi/g to 0.987 pCi/g in the 300 Area. Total uranium was detected in 33.3% of samples from the 100-H, 100-K, and 300 Areas. Uranium-233/234 was detected in 40% of clam samples from the 100-H, 100-K, and 300 Areas. Concentrations of uranium-233/234 ranged from 0.05 to 0.347 pCi/g in the 300 Area. Uranium-235 was detected in 33.3% of clam samples. Concentrations ranged 0.00125 to 0.036 pCi/g in the 300 Area. Uranium-238 was detected in 40% of clam samples. Concentrations ranged from 0.043 to 0.326 pCi/g in the 300 Area. Uranium-238 was only reported in one sample each from the 100-H and 100-K Areas.

- **Aquatic macroinvertebrates.** Total and isotopic uranium were detected in 14.3% of all samples. All results were reported for an unknown location in the data set provided by the SESP. Results for total uranium ranged from 0.764 to 1.64 pCi/g. Uranium-233/234 ranged from 0.274 to 0.59 pCi/g. Uranium-235 was detected at concentrations ranging from 0.017 to 0.025 pCi/g. Uranium-238 was reported at concentrations ranging from 0.254 to 0.548 pCi/g.

4.4.3 Evaluation of Contaminant Trends for RCBRA Data

Plots of all COPCs detected in RCBRA soil, sediment, and pore water samples at each sample site are presented in Appendix F-5.0, "Contaminant Trends between RCBRA Sites; Relationships of Biotic COPC Concentrations to Paired Soil, Sediment, Water Concentrations." Appendix F-5.0 also presents scatter plots to evaluate the relationship between abiotic and biotic samples for these media. The results of the linear regression for soil, sediment, and pore water were evaluated to determine statistically significant positive relationships between abiotic and biotic media. The significant regressions for soil COPCs versus plants, invertebrates, and small mammals are presented in Table 4-24. The significant regressions for sediment COPCs versus aquatic macroinvertebrates and clam are presented in Table 4-25. The significant regressions for pore water COPCs versus aquatic macroinvertebrates and clam are presented in Table 4-26.

4.4.4 Evaluation of Contaminant Trends Across Groundwater Samples

Contaminant trends in groundwater were evaluated by location over time for each of the three key COPC plume areas: chromium, strontium-90, and uranium. Results from multiple locations were grouped by approximated Hanford River Mile. Results of the groundwater trend analyses are described by plume below. Appendix F, Section F-3.0, "Contaminant Trends by Media Type."

Hexavalent Chromium. Time trends of hexavalent chromium are depicted in Figures 4-118 through 4-120. Concentrations of hexavalent chromium in groundwater were evaluated at three river mile locations: HRM 10.2, HRM 10.3, and HRM 10.4. All three locations correspond to the 100-D Area.

Concentrations of hexavalent chromium in groundwater varied by location over time at HRM 10.2. Three sampling locations near HRM 10.2 showed a general decline between 2001 and 2003 (Figure 4-118). No distinct time trend was observed for other sampling locations near HRM 10.2.

Hexavalent chromium in groundwater at HRM 10.3 showed a general decline in reported concentrations for two locations between 1999 and 2002 (Figure 4-119). No distinct time-trend was observed for other sampling locations associated with this HRM.

The highest concentrations of hexavalent chromium in groundwater were reported at HRM 10.4. Incidence of groundwater sampling at HRM 10.4 was more frequent than at other 100-D Area locations. Results were highly variable between years and locations. General declines in hexavalent chromium concentrations were observed for a few sampling locations, but a trend across all sites over time was not observed (Figure 4-120).

Strontium-90. Time trends of strontium-90 are depicted in Figures 4-121 through 4-123. Strontium-90 was evaluated in groundwater at three river mile locations: HRM 6.6 (100-K Area), HRM 8.9 (100-N Area), and HRM 9.1 (100-N Area).

Strontium-90 results from HRM 6.6 (near the 100-K Area) showed a sharp decline in concentrations between 1999 and 2001 for one sampling location, but consistent concentrations between 1999 and 2002 for another adjacent sampling location. No data were available for 2003 through 2005. Only two results were available for HRM in 2005. Results from 2005 were consistent with the results reported between 1999 and 2002 (Figure 4-121).

Strontium-90 results from HRM 8.9 groundwater (near the 100-N Area) showed a declining trend over time for two sampling locations, and consistent results for two other sampling locations at that HRM (Figure 4-122). Strontium-90 concentrations from samples collected in 2006 were lower than results reported in previous years.

Groundwater concentrations of strontium-90 from HRM 9.1 (near 100-N Area) were consistent from year-to-year across the two locations that were sampled multiple times. Results from two additional sampling locations at that HRM were consistent with previous results, and one sample from an additional location was reported between values reported in previous years.

Uranium. Time trends of uranium concentrations in groundwater are depicted in Figures 4-124 through 4-127. Total uranium concentrations in groundwater were evaluated for sampling locations associated with HRM 42.4, 42.6, 42.7, and 42.8. These river miles correspond to the uranium plume near the 300 Area.

Data for all locations spanned from 1998 to 2005. A general decline in uranium concentration at each location was observed for HRMs 42.4 and 42.6 (Figures 4-124 and 4-125). A slight decline in uranium concentrations was observed for two sampling locations at HRM 42.7 from 1998 to 2001, and 2001 to 2004, for each location, respectively. Uranium concentrations at one sampling location near HRM 42.8 showed a general decline between 1998 and 2000, with relatively consistent concentrations between 2000 and 2004.

4.5 COMPUTATION OF REPRESENTATIVE CONCENTRATIONS

4.5.1 Overview

This section presents the approach used to calculate representative concentrations for use in both the ecological and human health risk assessment. Representative concentrations are calculated using means as estimates of central tendency exposure (CTE) and 95% UCLs on the mean as estimates of reasonable maximum exposure (RME). The approach for calculating representative concentrations was developed during the regulator/trustee workshop conducted for this project from July 2006 to May 2007, and the notes from these workshops are provided as Appendix E.

There are three basic questions that need to be considered before calculating reference concentrations, UCLs, and means:

1. How many sample results are available for the exposure area?
2. What distributional form do these data most closely follow?
3. Are the data censored (are there nondetect sample results)?

Answers to these questions form the basis for the most appropriate UCL and mean calculation and substitution method for censored values for the dataset. The UCL and mean calculation, as well as, censored value substitution decision logic is outlined in Figure 4-128. These methods are described in the sections below, including a discussion of bounding methods for UCL calculations. These methods represent a combination of EPA guidance (EPA 2002a) and Ecology guidance and methods (see Ecology 1992b, Ecology 1994, and MTCAStat, www.ecy.wa.gov/PROGRAMS/tcp/tools/Mtca.exe).

4.5.2 Censored Values

A nondetect is an analytical sample result where the concentration is deemed to be lower than could be detected using the method employed by the analytical laboratory. A value is reported and a qualifier assigned indicating that the sample concentration was smaller than that value. The data are essentially censored at the reported value. Thus, nondetect results are referred to as censored data. Nondetects may correspond to concentrations that are virtually zero, or they may correspond to values that are considerably larger than zero but which are below the laboratory's ability to provide a reliable measurement. All approaches to working with nondetects use substitution values to estimate the sample results that might have been obtained with a more sensitive analytical method. Some of the most widely used methods are substitutions of the nondetects with the detection limit, half the detection limit, or zero. Beyond these simple substitutions, more complicated substitution methods apply a range of values or even a distributional form to nondetect sample results.

Two nondetect substitution methods are considered in the calculation of UCLs based on the decision logic depicted in Figure 4-128. Consistent with EPA guidance (EPA 2002a) and MTCAStat procedures (Ecology 1992b), a simple substitution method (half the detection limit) is used in most case for censored data. A special case is for censoring greater than 15% on normally distributed data, in which case the bounding method is used (1→2→3→4→6 in Figure 4-128). The bounding method is discussed further in Statistical Methodology appendix.

4.5.3 Upper Confidence Limits and Mean

In *Calculating Upper Confidence Limits for Exposure Point Concentrations at Hazardous Waste Sites* (EPA 2002a), EPA recommends using the average concentration to represent "a reasonable estimate of the concentration likely to be contacted over time" (EPA 1989) and "because of the uncertainty associated with estimating the true average concentration at a site" recommends that the 95 percent UCL be used. There are many UCL methodologies available for calculating UCLs. The particular UCL calculation used will depend on the distributional form of the data. This is also true for estimation of the mean. Thus, the first step in choosing a mean method or UCL method is to evaluate the distributional form of the data. The commonly used and highly recommended Shapiro-Wilk *W* test (Gilbert 1987, Ecology 1992b) is used to test the distributional form of the data. Figure 4-128 presents a flowchart for the logic to arrive at a given substitution method for censored values and a particular UCL and mean method. The description for those pathways is as follows: First determine the number of observations available (1 in Figure 4-128). If there are less than three observations with at least one detected value, then substitute half the detection limit for the nondetects and use the maximum value for the UCL. If there are three to four observations, then assume the data are lognormally distributed (2 in Figure 4-128). If there are five or more observations, then calculate the percent of censored data in the dataset (number of nondetects out of the total number of samples expressed as a percent) and proceed from the correct detection rate category by answering question 3 in Figure 4-128. The data are next tested to see if they follow a lognormal distribution (4 5 and 8 in Figure 4-128). The original data are log transformed, and the Shapiro-Wilk test is performed on the log-transformed data. If the p-value from the Shapiro-Wilk test is greater than 0.05, then lognormality is assumed (answer is "Yes"). However, if the Shapiro-Wilk p-value is less than 0.05, then lognormality is rejected (answer is "No") and normality is tested (6 7 and 9 in Figure 4-128). To determine if the data are normal, Shapiro-Wilk is performed on the original untransformed data. If the p-value is greater than 0.05, then the normal distribution is assumed (answer is "Yes"). If the Shapiro-Wilk p-value is less than 0.05, then normality is rejected (answer is "No") and the distributional form of the data is considered to be something other than lognormal or normal.

For lognormal data, the UCL is based on Land's method using the H-statistic (EPA 2002a, Exhibit 3; Gilbert 1987; Ecology 1992b) and the mean is based on the Minimum Variance Unbiased Estimate (MVUE) for the lognormal mean (Gilbert 1987, Section 13.1.1). For normal data, the arithmetic average is used to estimate the mean and the UCL is based on the well-known t-statistic. If the distribution is neither normal nor lognormal, a nonparametric estimate of the UCL is calculated based on a bootstrap method (EPA 2002a, Section 4.2) using the arithmetic average for the mean.

A bounding method for UCL calculations is proposed for when there is greater than 15% nondetects and the Shapiro-Wilk test indicates the data are normally distributed (Figure 4-128, answer "Yes" to 6). Bounding methods have been used to determine the limits on a UCL in a distribution free way (EPA 2002a). The goal is to gain a better understanding of the range of UCLs that are produced based on substituting a range of values for nondetects rather than a single constant value. Because there is always uncertainty associated with the substitution method used for nondetects, and that uncertainty can vary, bounding methods are used to evaluate that uncertainty. If the uncertainty from censoring is high, the range of values produced from a series of UCL calculations on a given set of data will be large. In contrast, if the uncertainty from censoring is low, the range will be small. In general, the uncertainty in the substitution method increases as the detection limit gets larger and the number of nondetects in the data set increases. A conservative approach is to use the upper UCL value produced from simulations using the bounding method. The bounding method does not appear to be practical from a numerical standpoint under either a lognormal distribution using Land's Method for UCL calculation scenario or under a bootstrapping UCL calculation scenario.

The flowchart given in Figure 4-128 was followed for all analytes except for the 32 analytes listed in Table 4-27. Per agreement with Ecology, representative concentrations were calculated for this list of radionuclides and PCBs regardless of whether there was at least one recorded detect. One-half of the PQL was substituted for nondetects and then the representative concentration flowchart was followed considering all concentrations as detected.

The representation concentrations results are provided in electronic format in Appendix F, Section F-6.0, "Representative Concentrations." The number of representative concentrations for each data source and statistical method are summarized in Table 4-28.

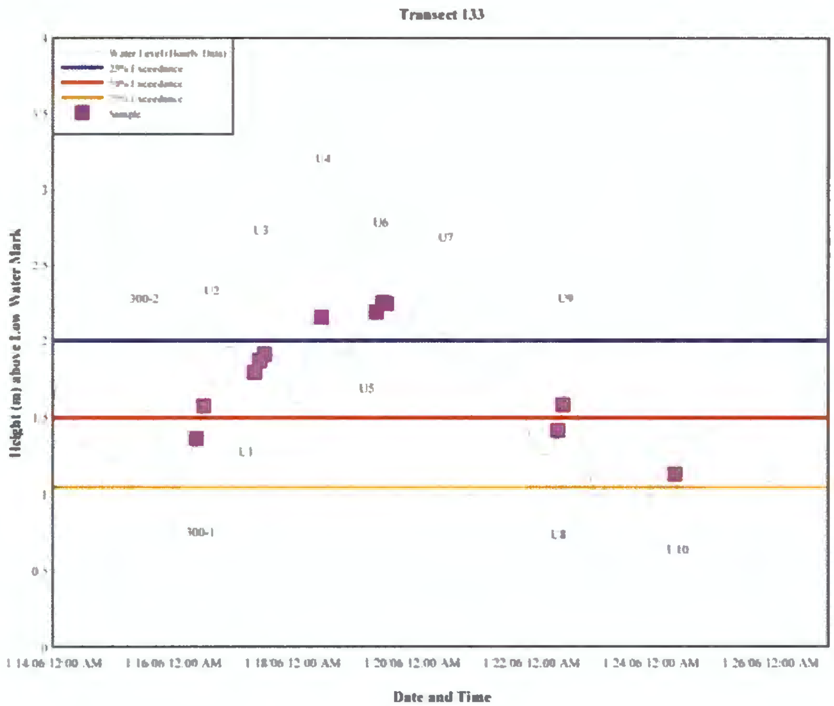
4.6 RESULTS OF EXTERNAL DOSIMETERS

The project deployed dosimeters as quantitative measure of the total external radiation field at the upland and riparian investigation areas. The dosimeters provide a measure of external exposure to human and ecological receptors from gamma-emitting radionuclides. Figure 4-129 provides a comparison of the dosimetry results for each site, for each environment, and for reference sites compared to waste sites or operational areas. The tabulation of dosimetry results are available from the online project data repository.

Figure 4-129 shows that the dosimetry results differ between the sites and that generally the set of five dosimeters at each site record similar results. When the dosimetery data are pooled for an environment (upland and riparian) and categories (operational and reference) then one can see that the external doses measured are similar for the same environment and not statistically different. External doses are also greater in the upland compared to riparian environments. As the highest dose rate was for an upland reference site (Yakima Ridge II), variation in dose rate measurements was not interpreted to represent any relevant measurement of Hanford Site-related radionuclide releases.

Figure 4-1. River Conditions during two Sampling Events at a Uranium Plume Sampling Station.

a)



b)

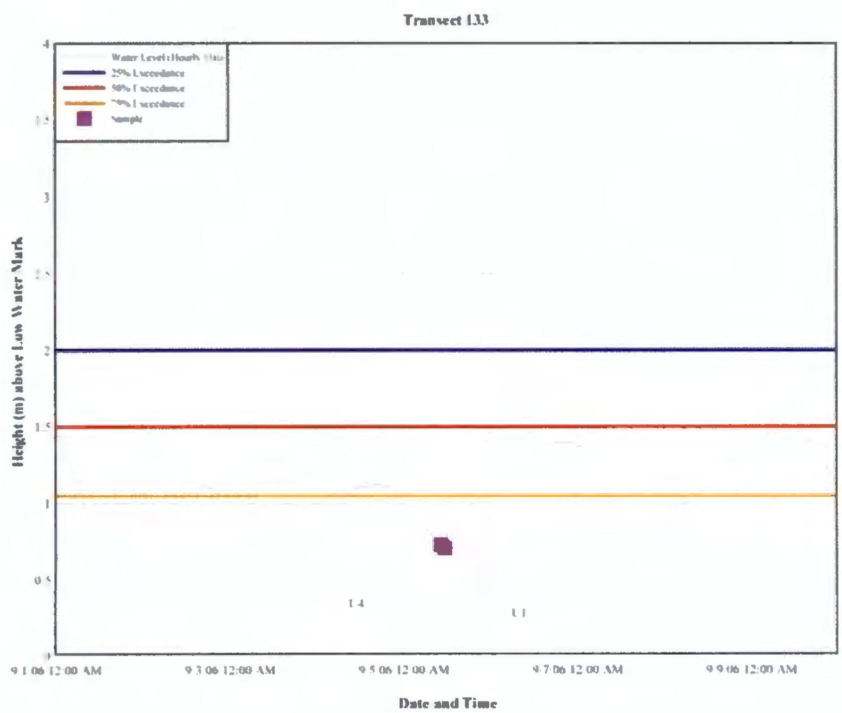


Figure 4-2. Overlay Plot of Reference Site, Washington State Background, and Area Background Concentrations of Inorganic Chemicals and Radionuclides for Soil.

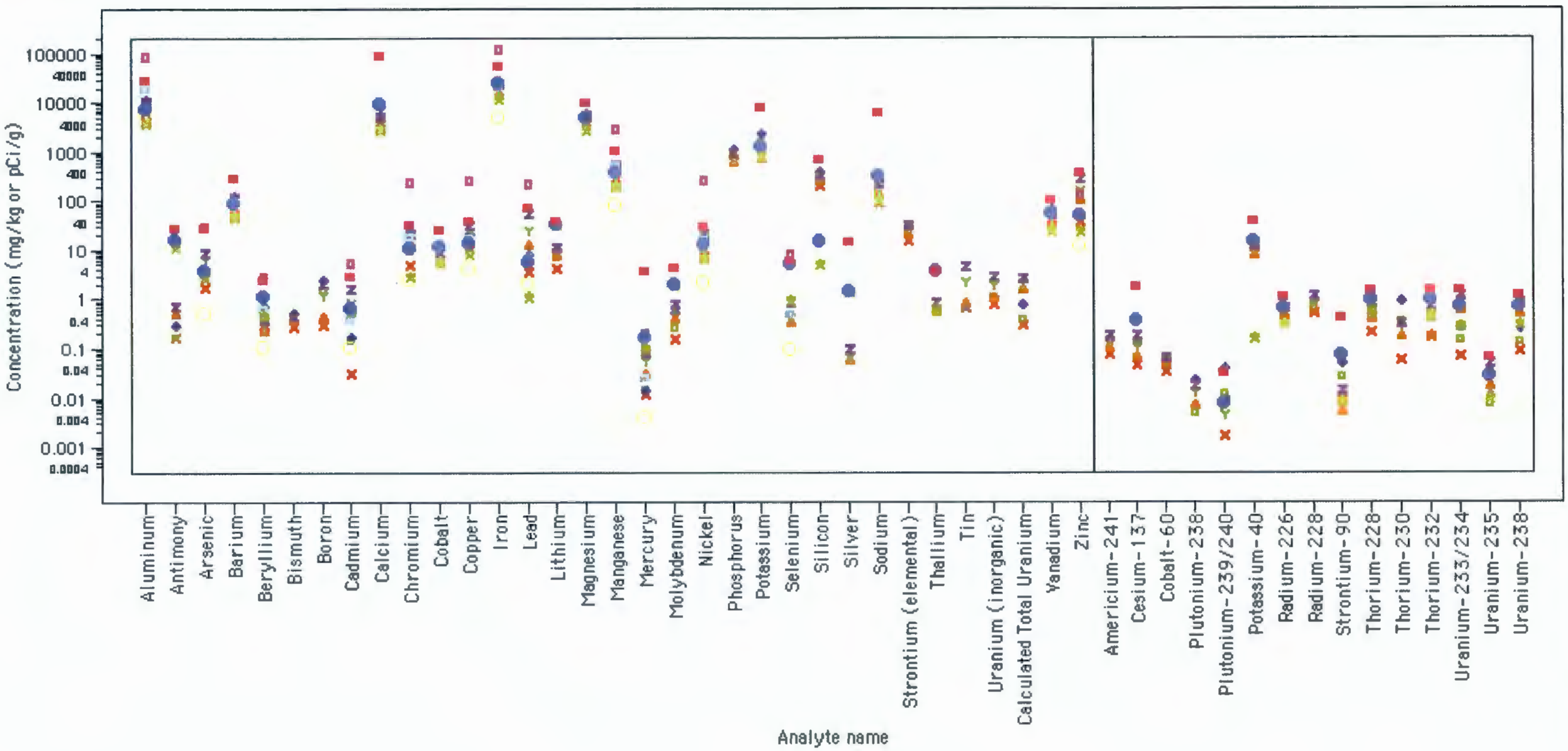


Figure 4-3. Group Comparisons Decision Logic.

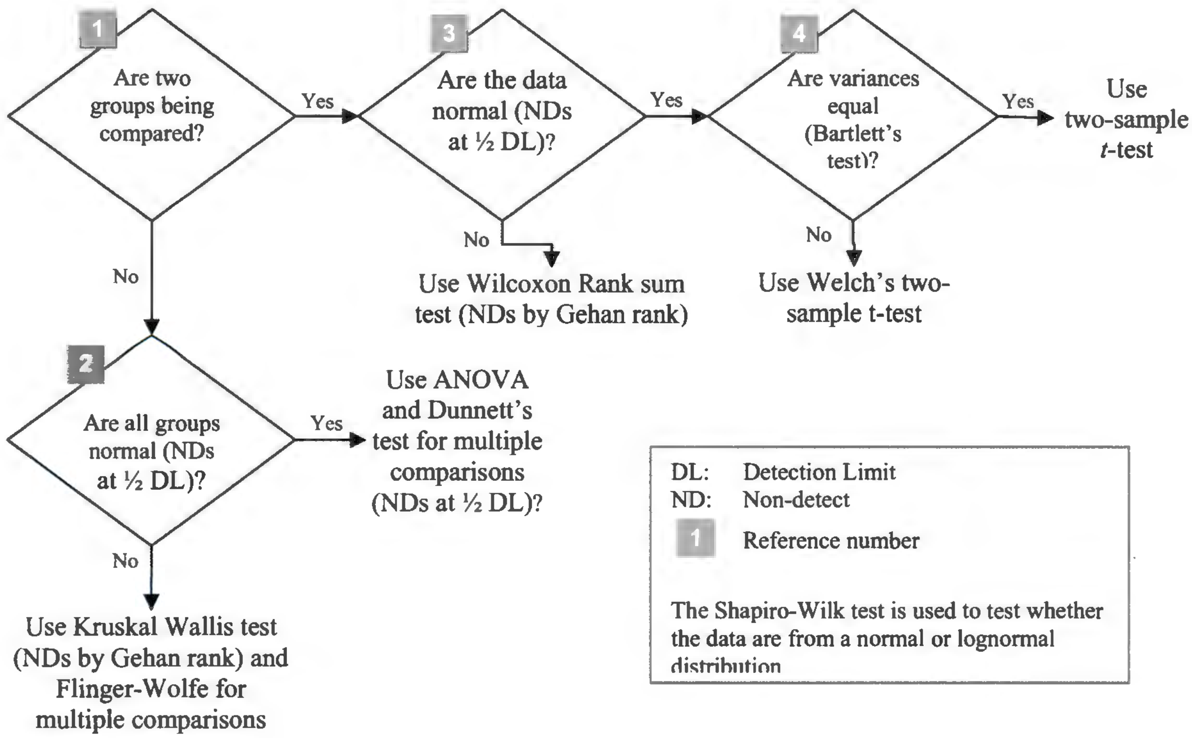


Figure 4-4. Chromium Concentrations in Water (ug/L) by Hanford River Mile.

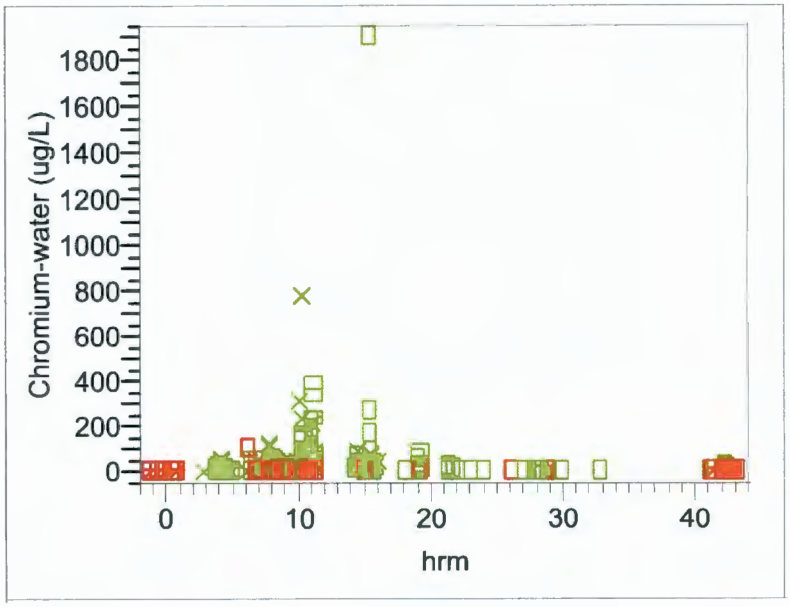


Figure 4-5. Chromium Concentrations in Water (ug/L) by Date.

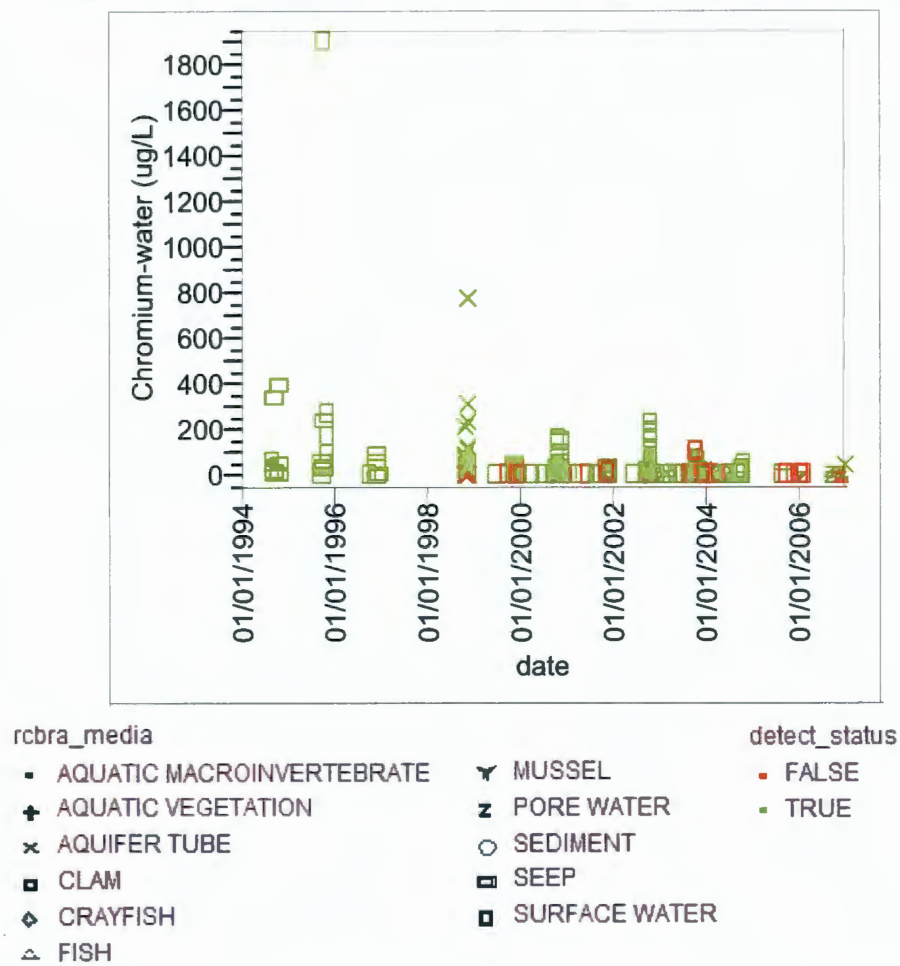


Figure 4-6. Box Plot of Chromium in Water (ug/L) by Category.

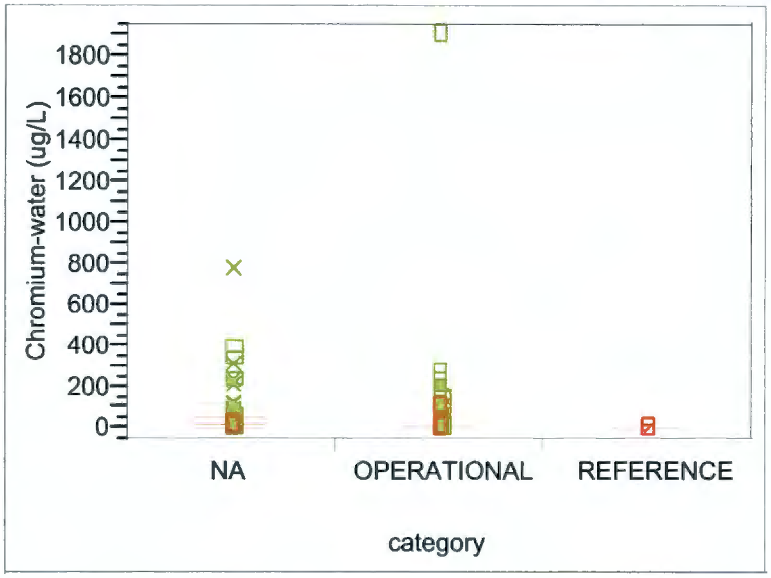


Figure 4-7. Box Plot of Chromium in Water (ug/L) by RCBRA Media.

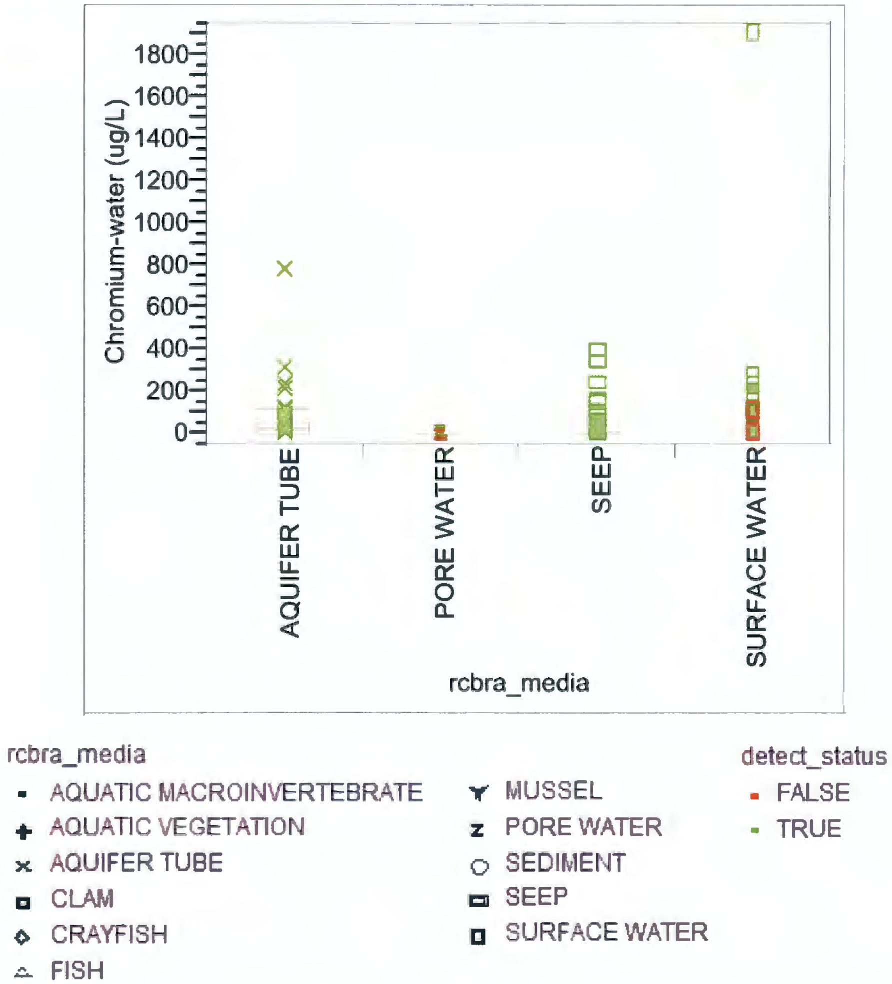


Figure 4-8. Concentrations of Hexavalent Chromium in Water (ug/L) by Hanford River Mile.

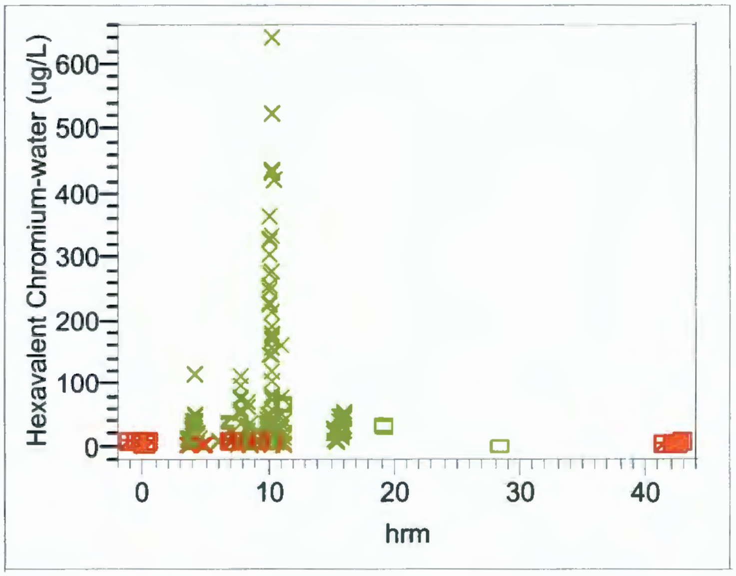


Figure 4-9. Concentrations of Hexavalent Chromium in Water (ug/L) by Date.

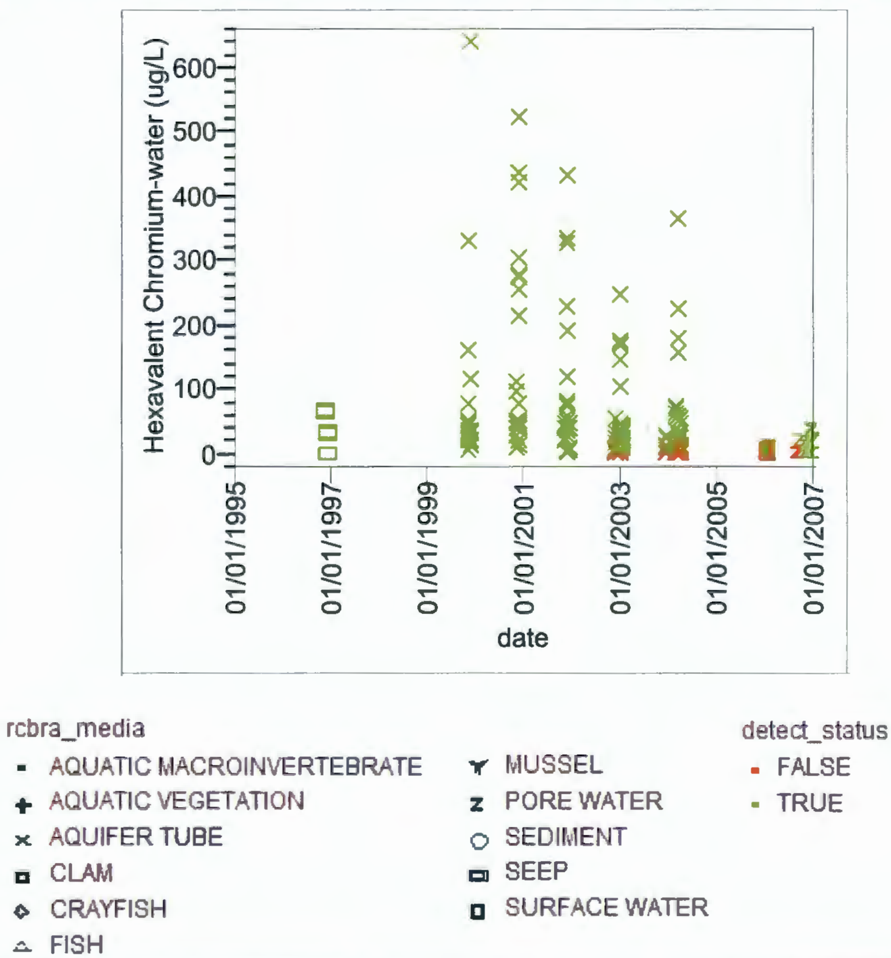


Figure 4-10. Box Plot of Hexavalent Chromium in Water (ug/L) by Category.

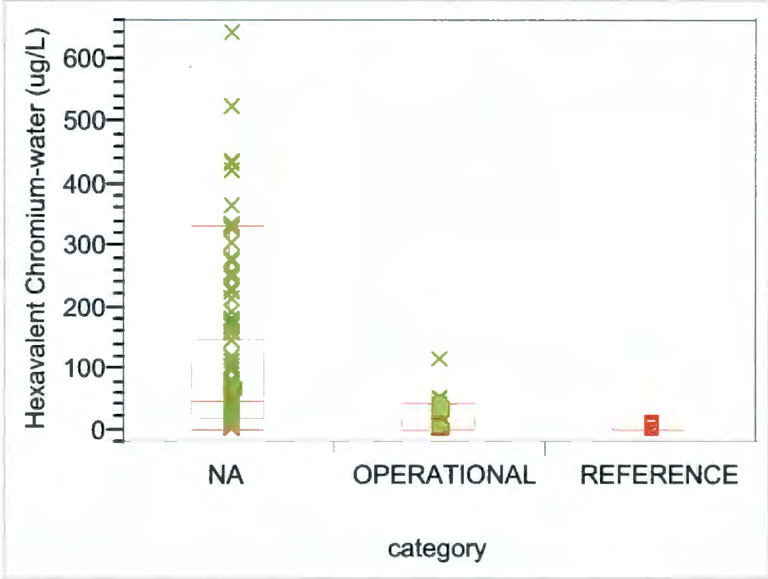


Figure 4-11. Box Plot of Hexavalent Chromium in Water (ug/L) by RCBRA Media.

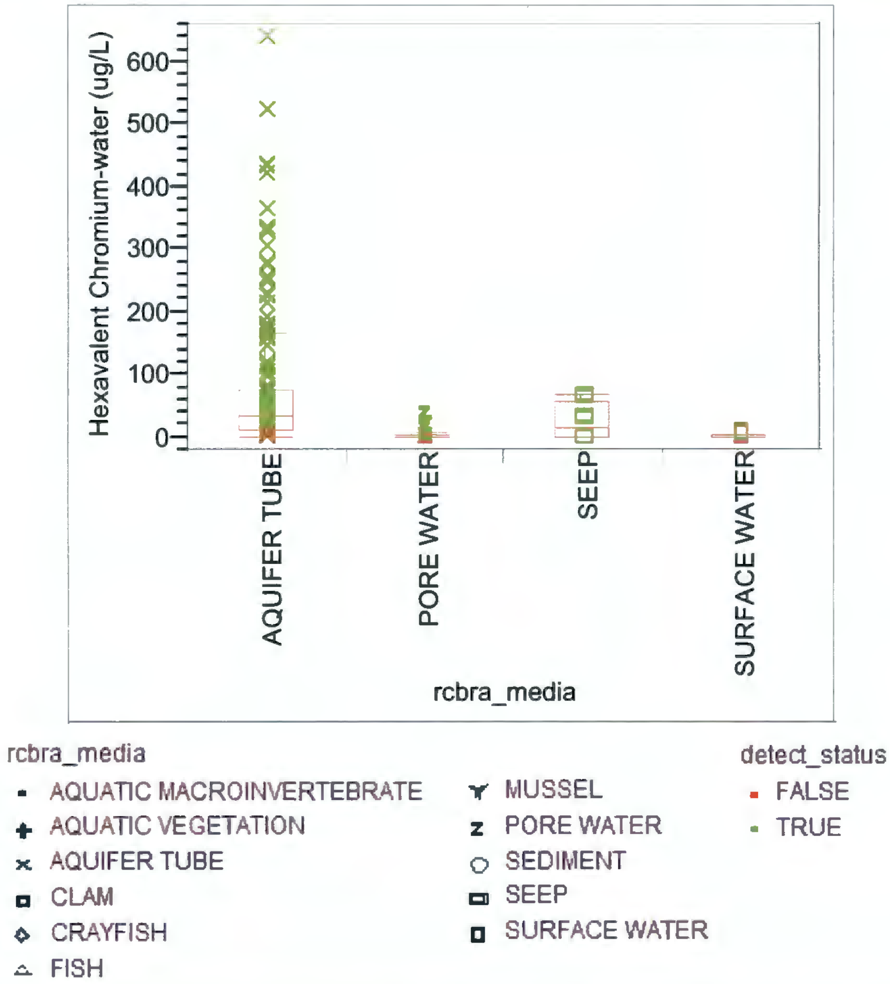


Figure 4-12. Overlay of Chromium Concentrations in Pore Water (ug/L) and Aquatic Macroinvertebrates (mg/kg) by Hanford River Mile.

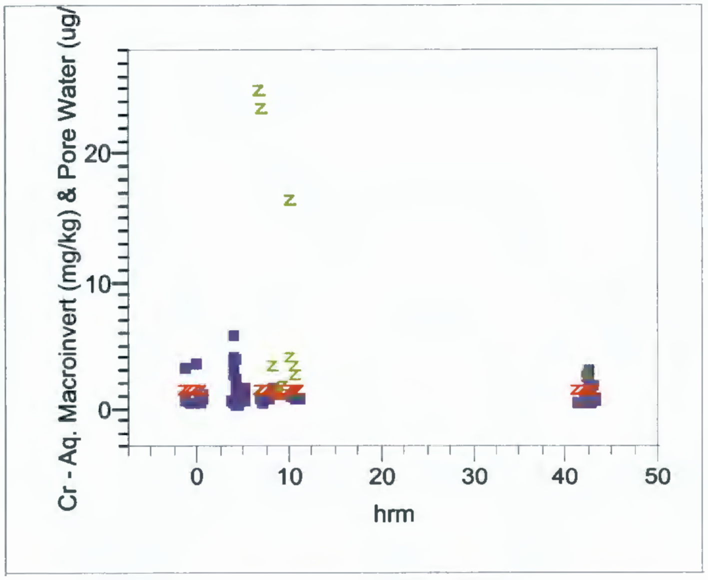


Figure 4-13. Overlay of Chromium Concentrations in Pore Water (ug/L) and Clams (mg/kg) by Hanford River Mile.

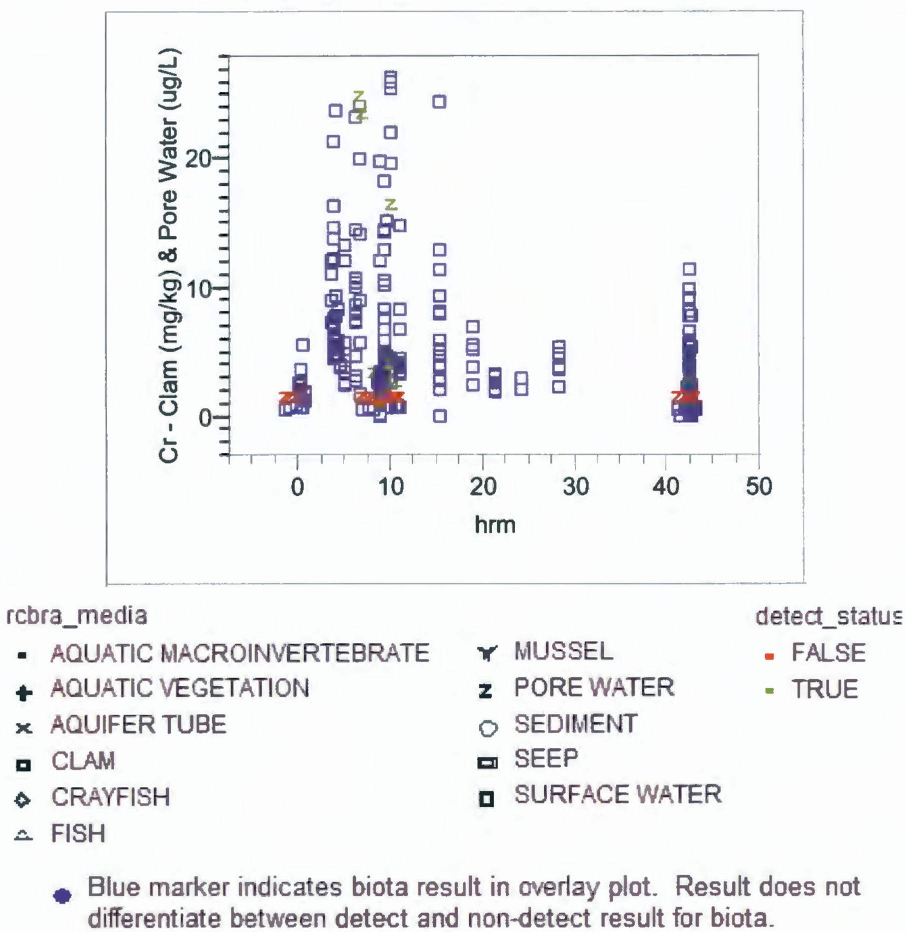


Figure 4-14. Overlay of Chromium Concentrations in Pore Water (ug/L) and Fish (mg/kg) by Hanford River Mile.

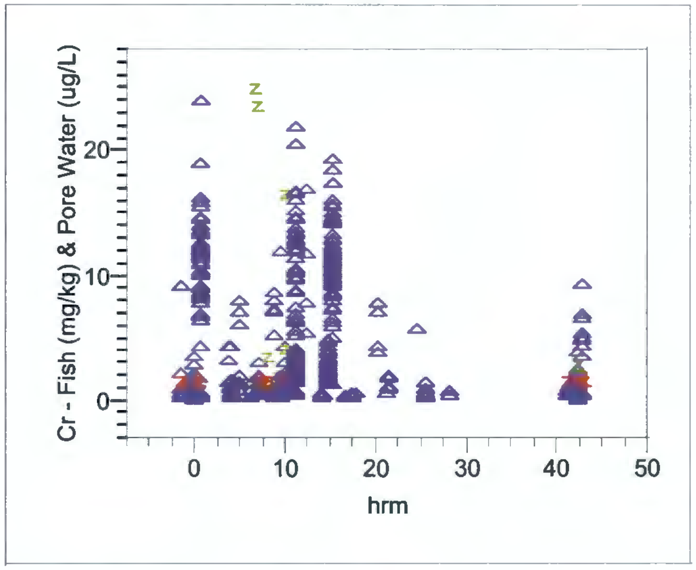


Figure 4-15. Overlay of Hexavalent Chromium Concentrations in Pore Water (ug/L) and Total Chromium Concentrations in Aquatic Macroinvertebrates (mg/kg) by Hanford River Mile.

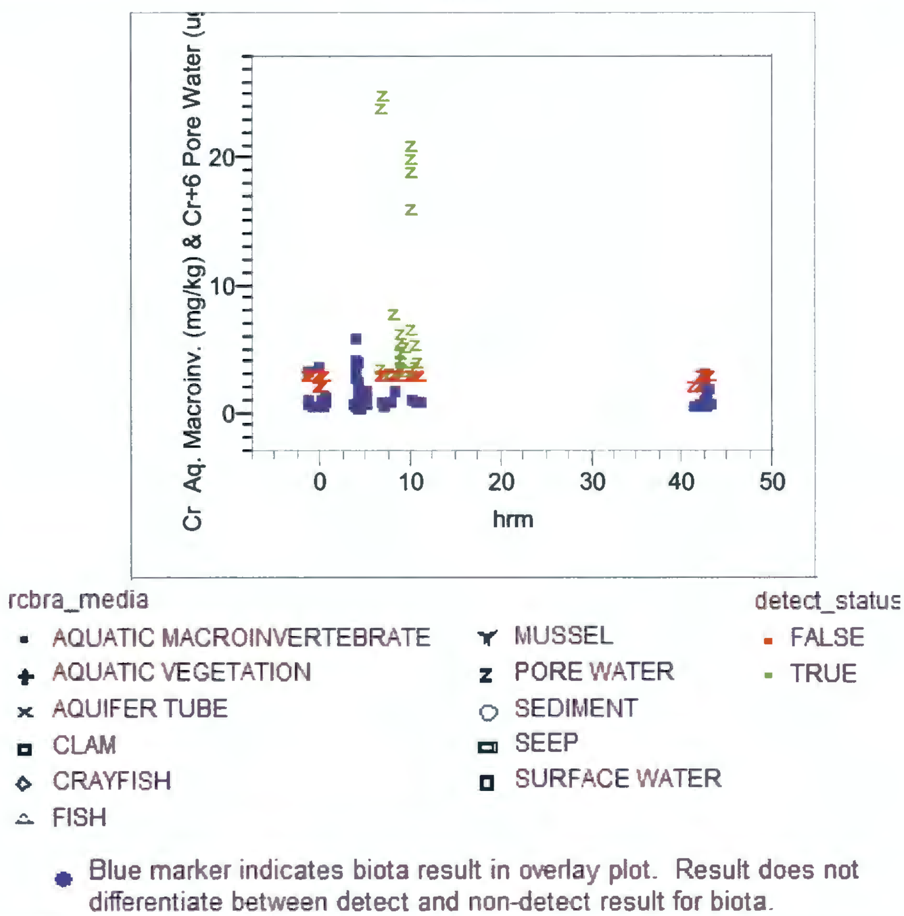


Figure 4-16. Overlay of Hexavalent Chromium Concentrations in Pore Water (ug/L) and Total Chromium Concentrations in Clams (mg/kg) by Hanford River Mile.

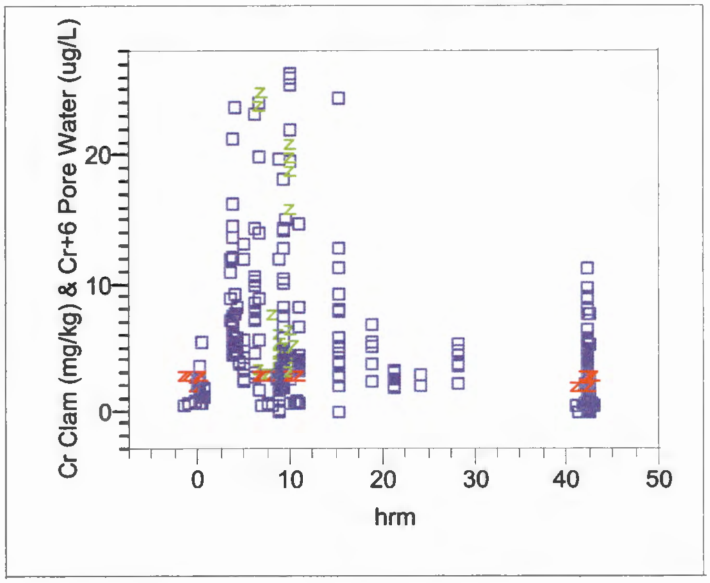
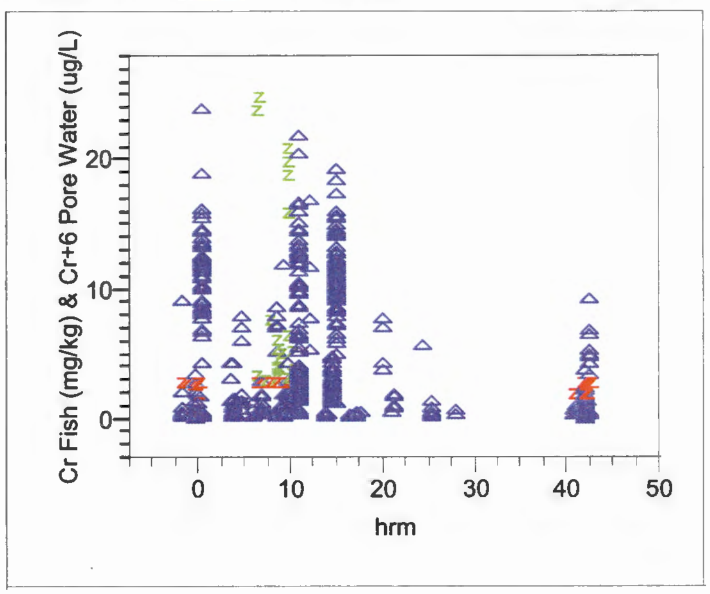


Figure 4-17. Overlay of Hexavalent Chromium Concentrations in Pore Water (ug/L) and Total Chromium Concentrations in Fish (mg/kg) by Hanford River Mile.



rcbra_media

- AQUATIC MACROINVERTEBRATE
- AQUATIC VEGETATION
- AQUIFER TUBE
- CLAM
- CRAYFISH
- FISH
- MUSSEL
- PORE WATER
- SEDIMENT
- SEEP
- SURFACE WATER

detect_status

- FALSE
- TRUE

Blue marker indicates biota result in overlay plot. Result does not differentiate between detect and non-detect result for biota.

Figure 4-18. Chromium Concentrations in Sediment (mg/kg) by Hanford River Mile.

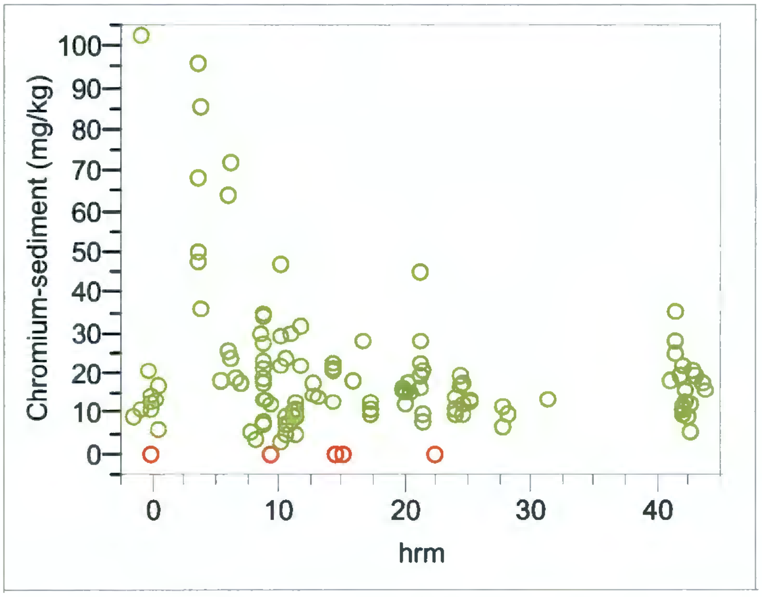


Figure 4-19. Chromium Concentrations in Sediment (mg/kg) by Date.

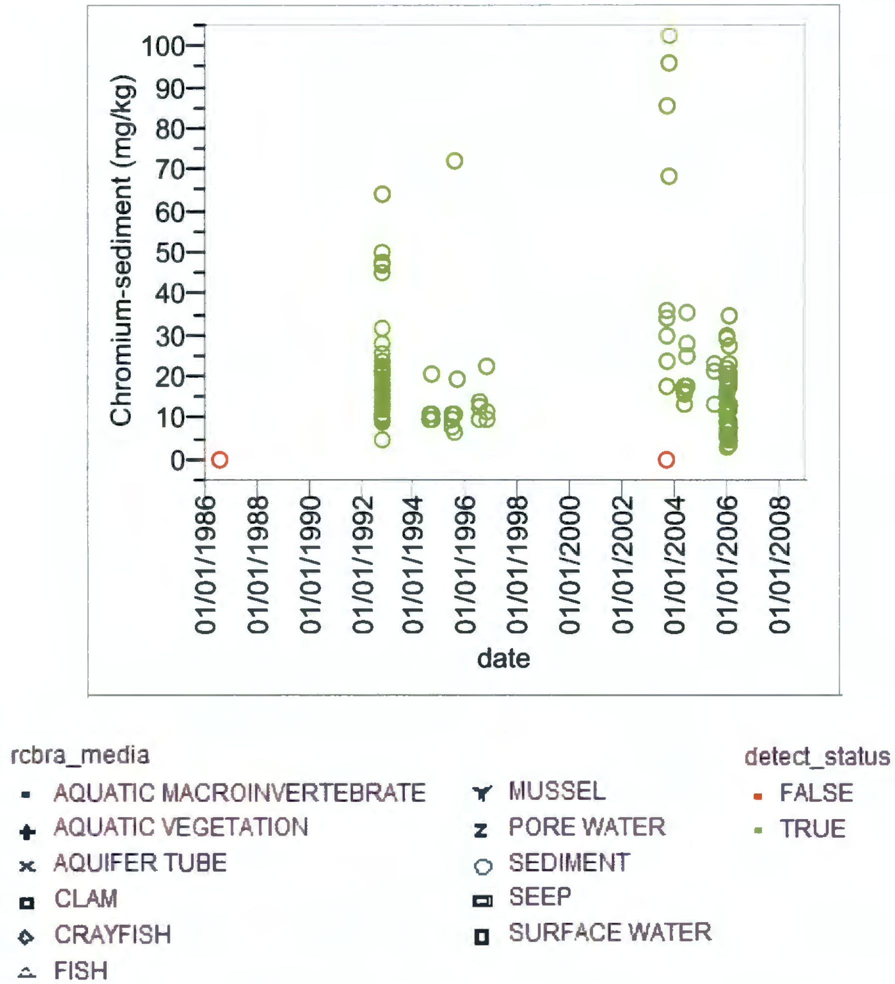


Figure 4-20. Box Plot of Chromium-Sediment (mg/kg) by Category.

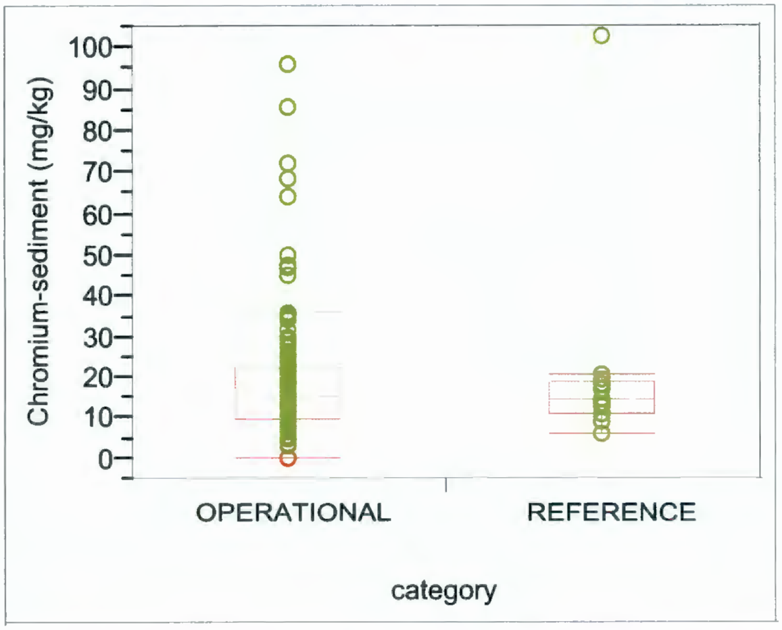


Figure 4-21. Box Plot of Chromium-Sediment (mg/kg) by RCBRA Media.

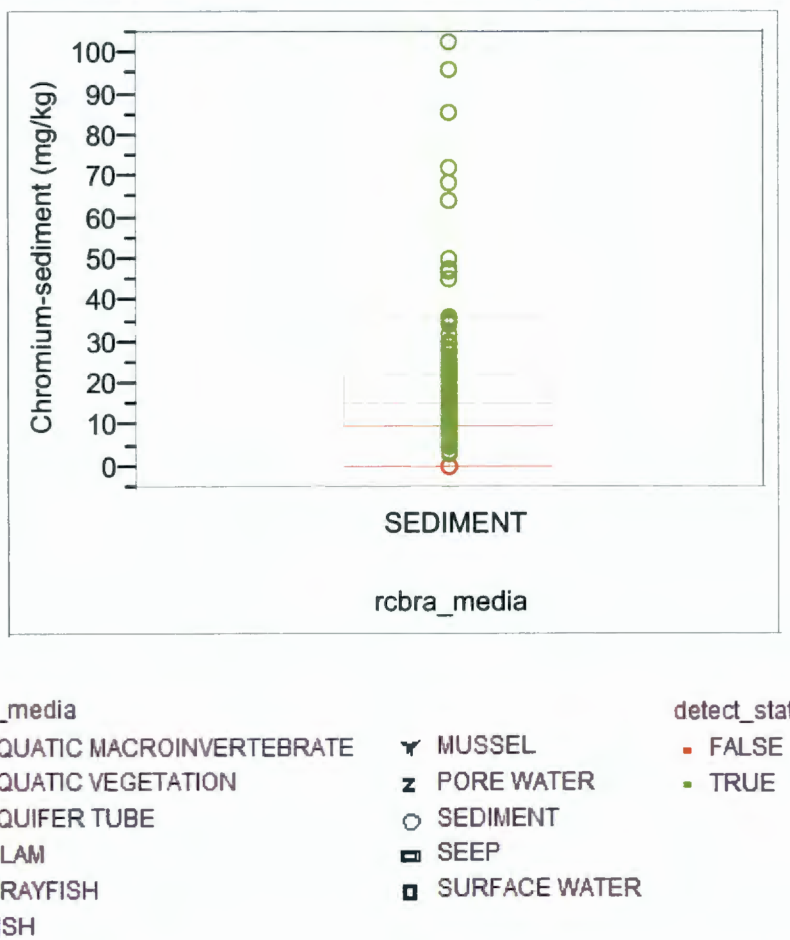


Figure 4-22. Overlay of Chromium Concentrations in Sediment and Aquatic Macroinvertebrates (mg/kg) by Hanford River Mile.

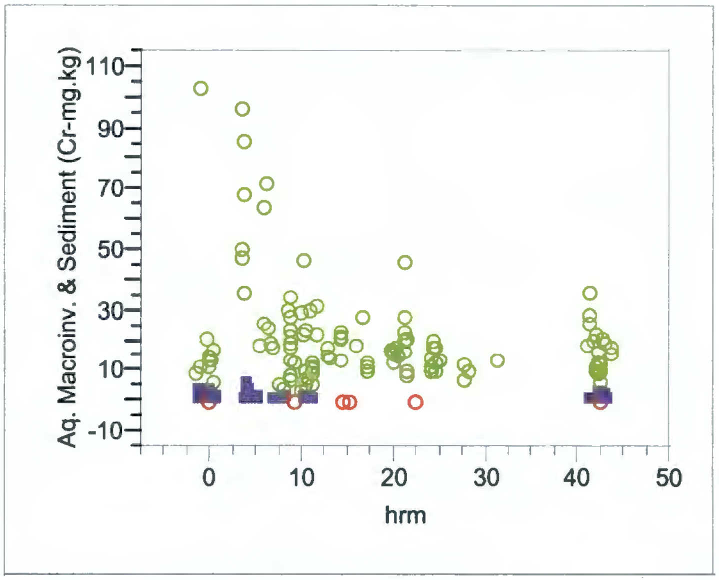


Figure 4-23. Overlay of Chromium Concentrations in Sediment and Clams (mg/kg) by Hanford River Mile.

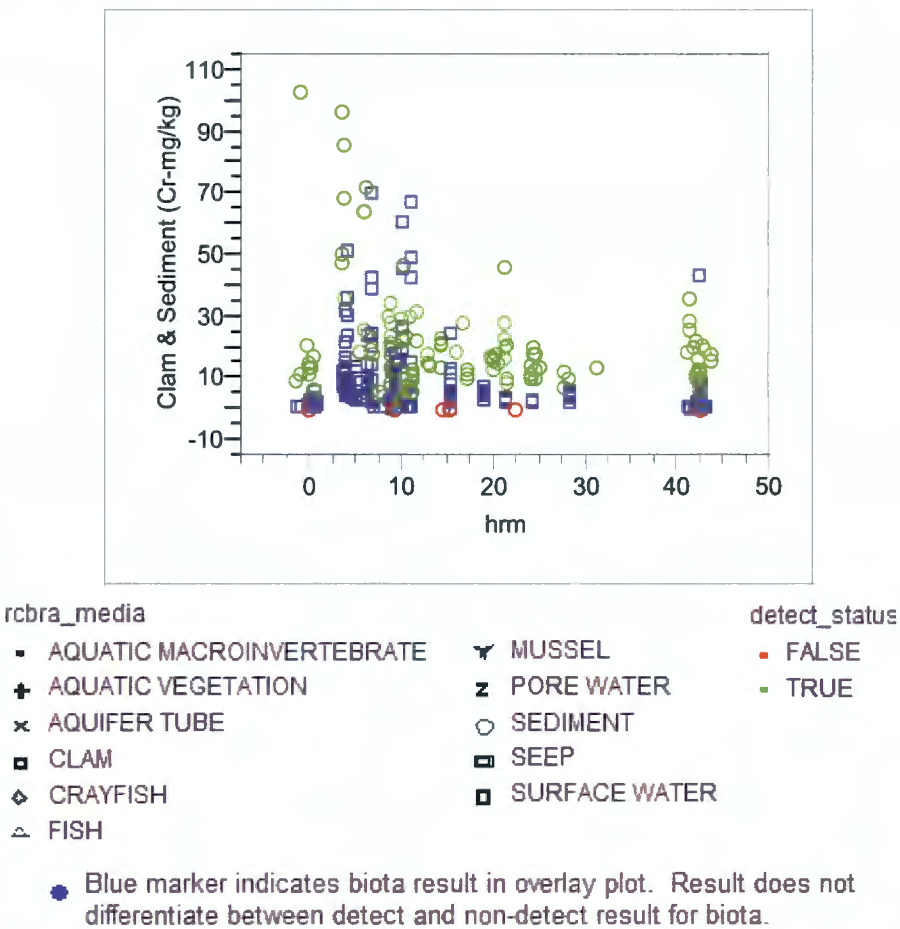


Figure 4-24. Overlay of Chromium Concentrations in Sediment and Fish (mg/kg) by Hanford River Mile.

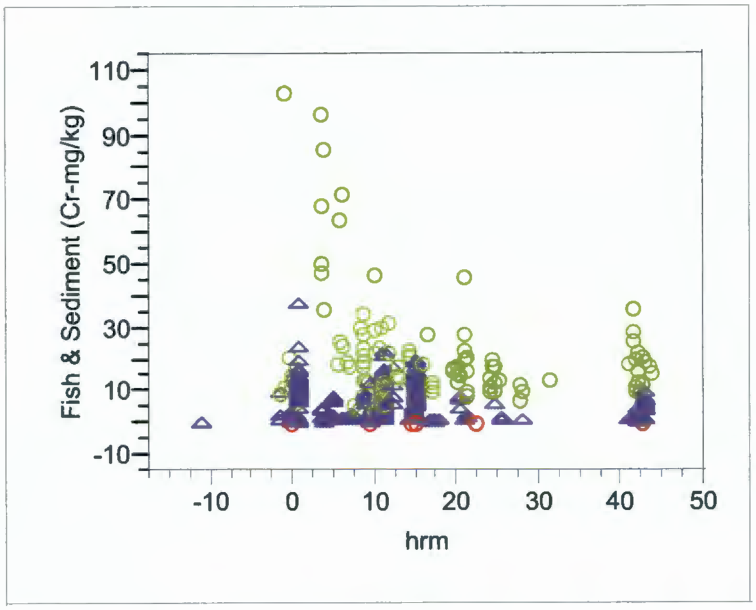
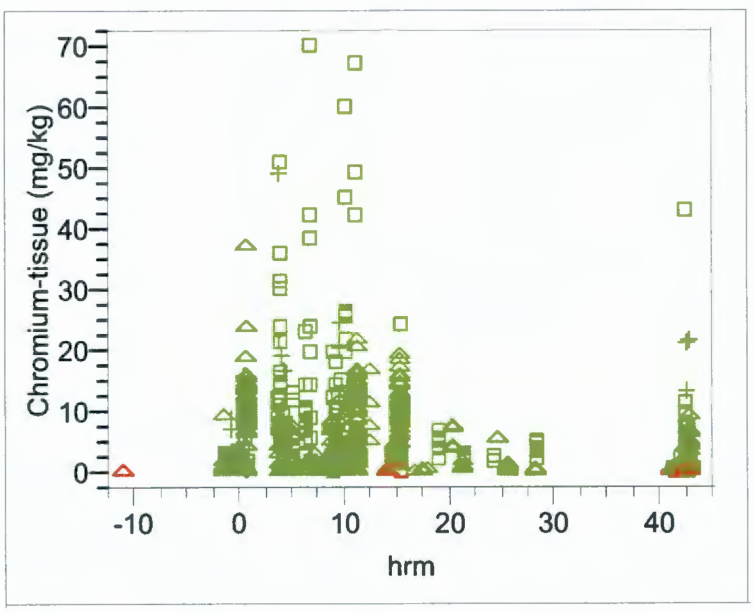


Figure 4-25. Chromium Concentrations in Tissue (mg/kg) by Hanford River Mile.



rcbra_media

- AQUATIC MACROINVERTEBRATE
- AQUATIC VEGETATION
- AQUIFER TUBE
- CLAM
- CRAYFISH
- FISH
- MUSSEL
- PORE WATER
- SEDIMENT
- SEEP
- SURFACE WATER

detect_status

- FALSE
- TRUE

Blue marker indicates biota result in overlay plot. Result does not differentiate between detect and non-detect result for biota.

Figure 4-26. Chromium Concentrations in Tissue (mg/kg) by Date.

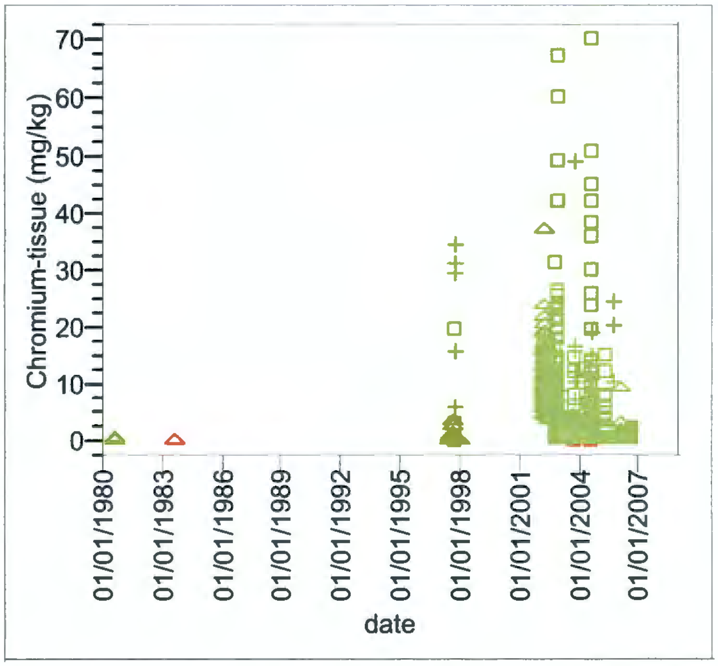


Figure 4-27. Box Plot of Chromium in Tissue (mg/kg) by Category.

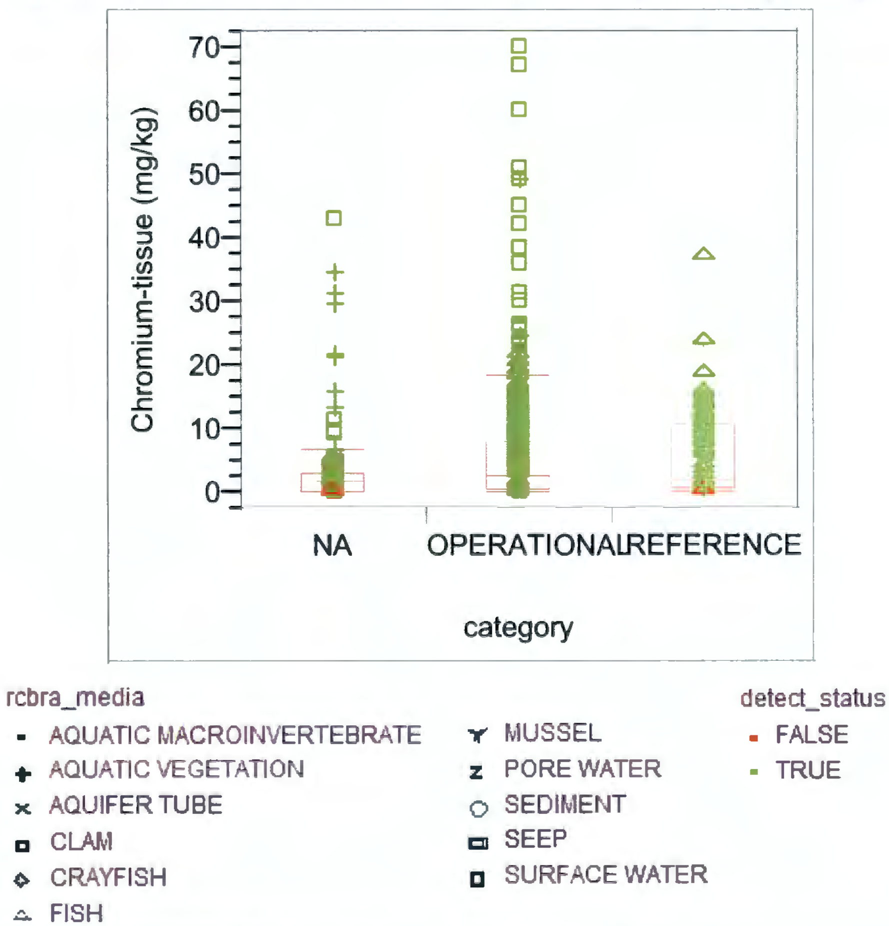


Figure 4-28. Box Plot of Chromium in Tissue (mg/kg) by RCBRA Media.

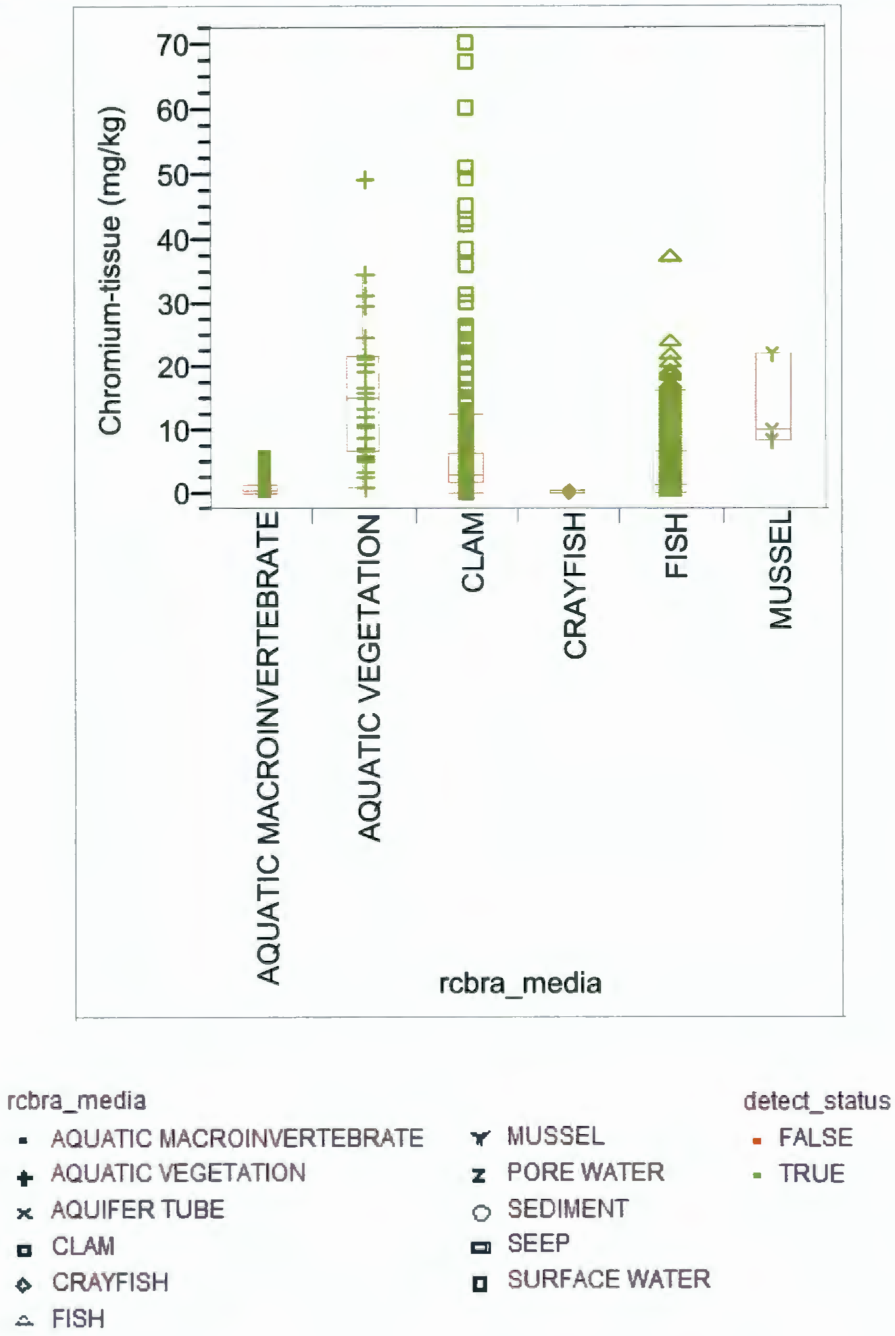


Figure 4-29. Concentrations of Strontium-90 in water (pCi/L) by Hanford River Mile.

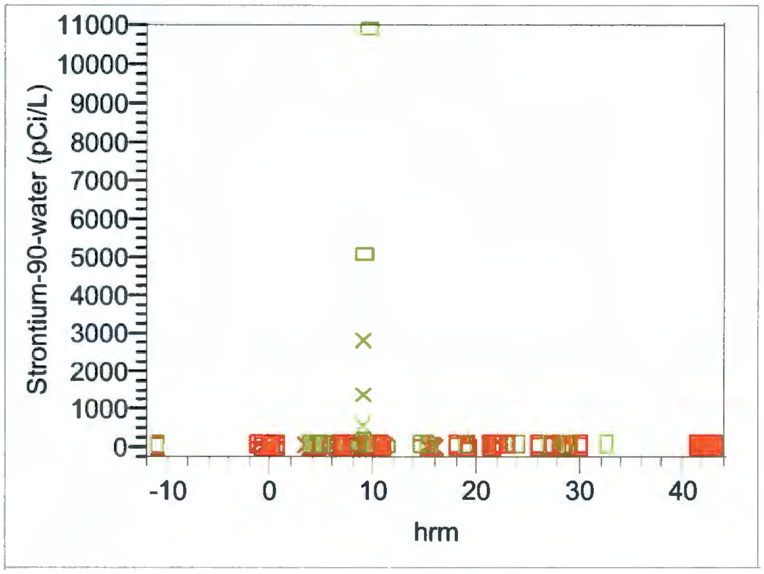


Figure 4-30. Concentrations of Strontium-90 in Water (pCi/L) by Date.

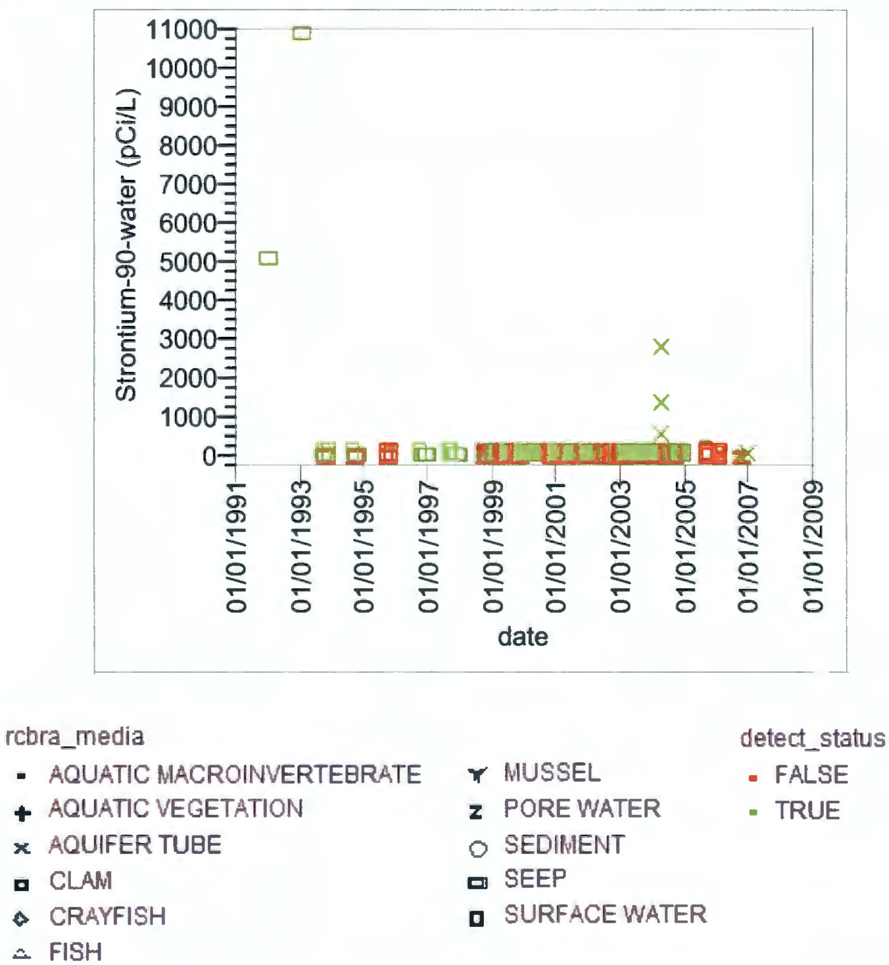


Figure 4-31. Box Plot of Strontium-90 in Water (pCi/L) by Category.

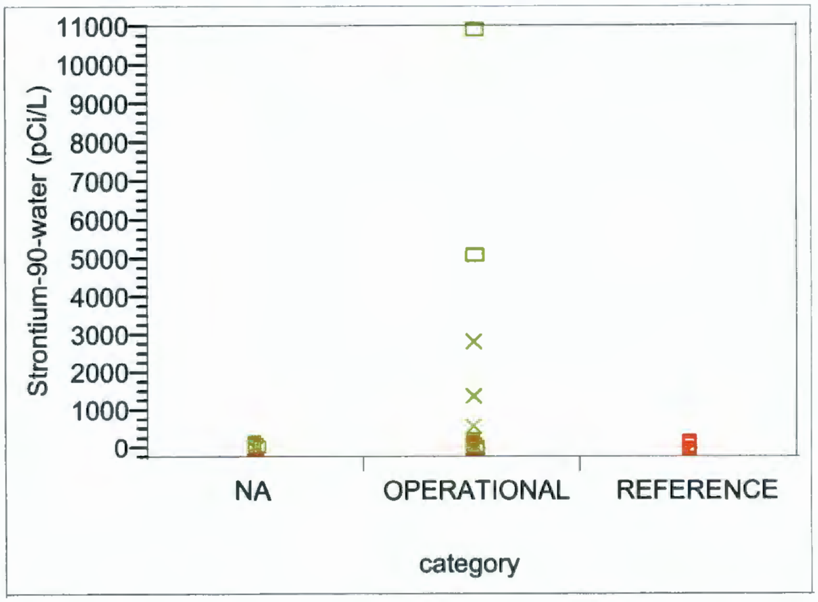


Figure 4-32. Box Plot of Strontium-90 in Water (pCi/L) by RCBRA Media.

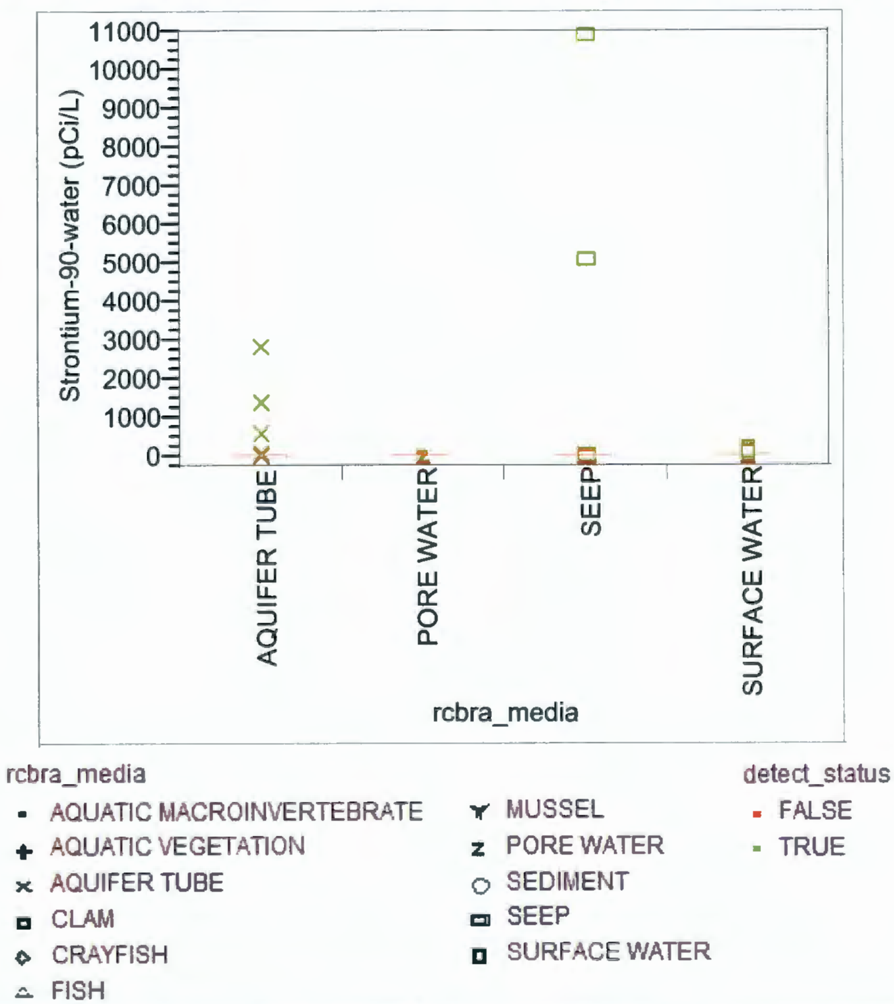


Figure 4-33. Overlay of Strontium-90 Concentrations in Pore Water (pCi/L) and Aquatic Macroinvertebrates (pCi/g).

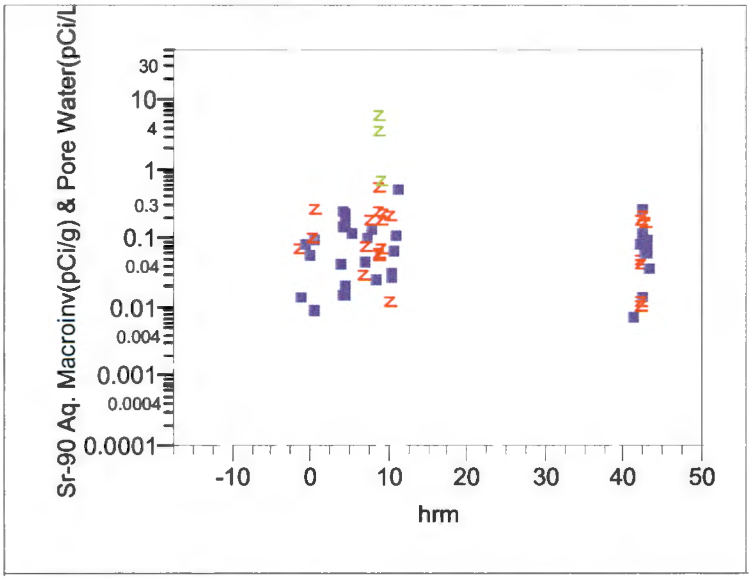


Figure 4-34. Overlay of Strontium-90 Concentrations in Pore Water (pCi/L) and Clams (pCi/g).

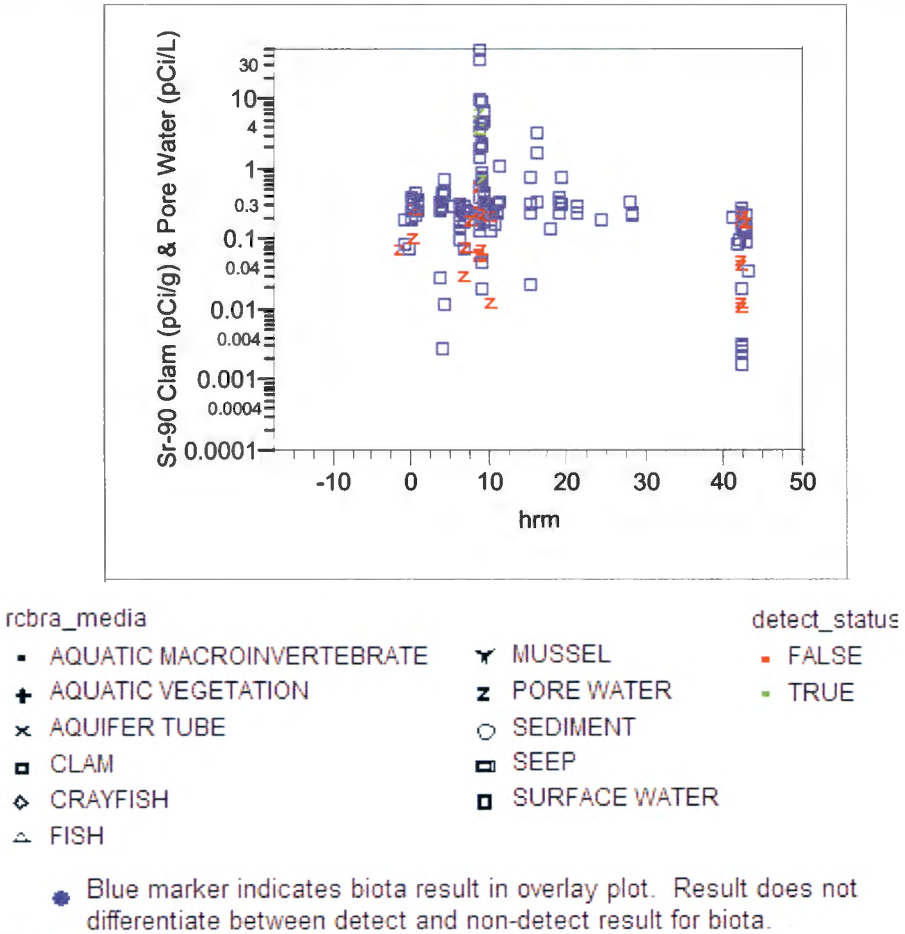


Figure 4-35. Overlay of Strontium-90 Concentrations in Pore Water (pCi/L) and Fish (pCi/g).

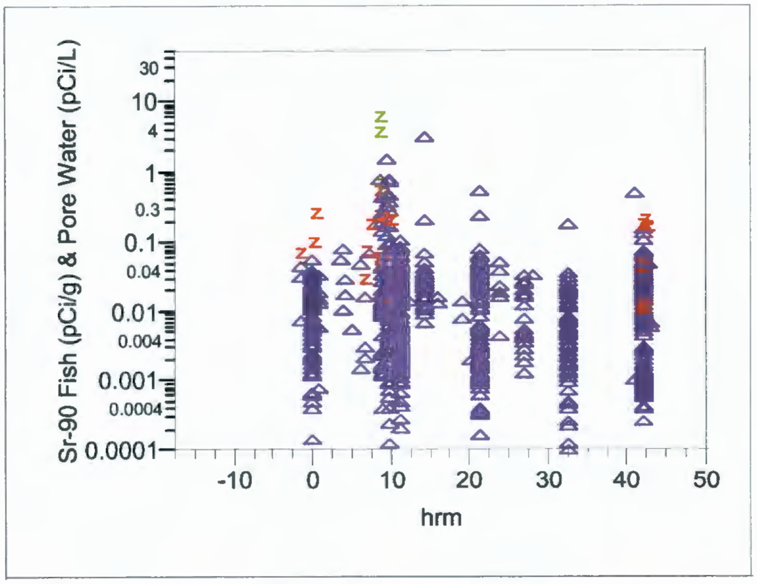


Figure 4-36. Concentrations of Strontium-90-Sediment (pCi/g) by Hanford River Mile.

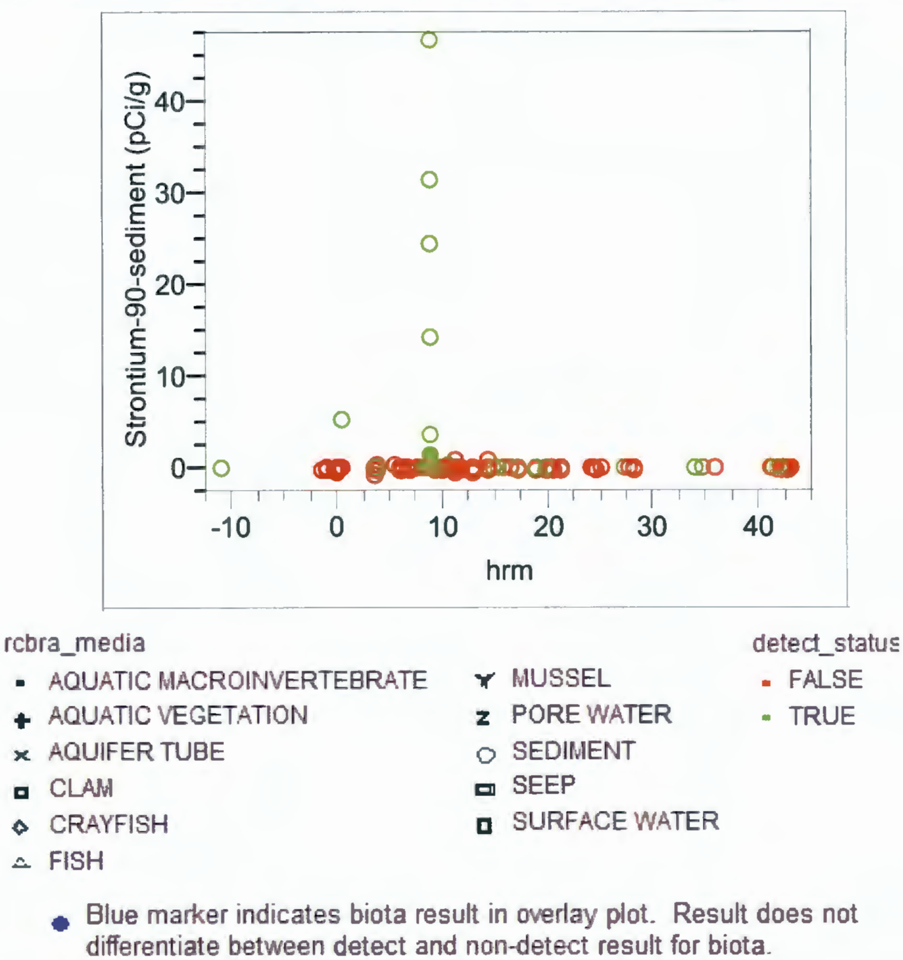


Figure 4-37. Concentrations of Strontium-90-Sediment (pCi/g) by Date.

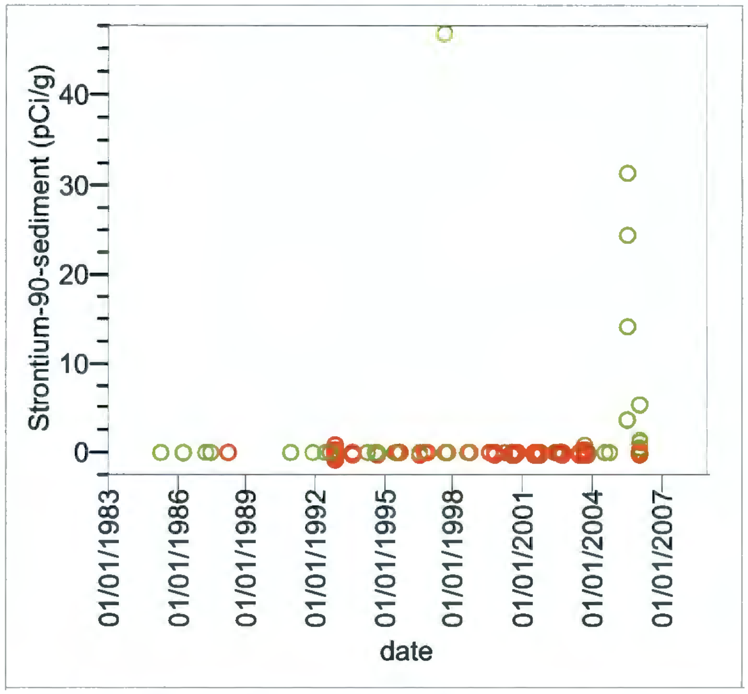


Figure 4-38. Box Plot of Strontium-90-Sediment (pCi/g) by Category.

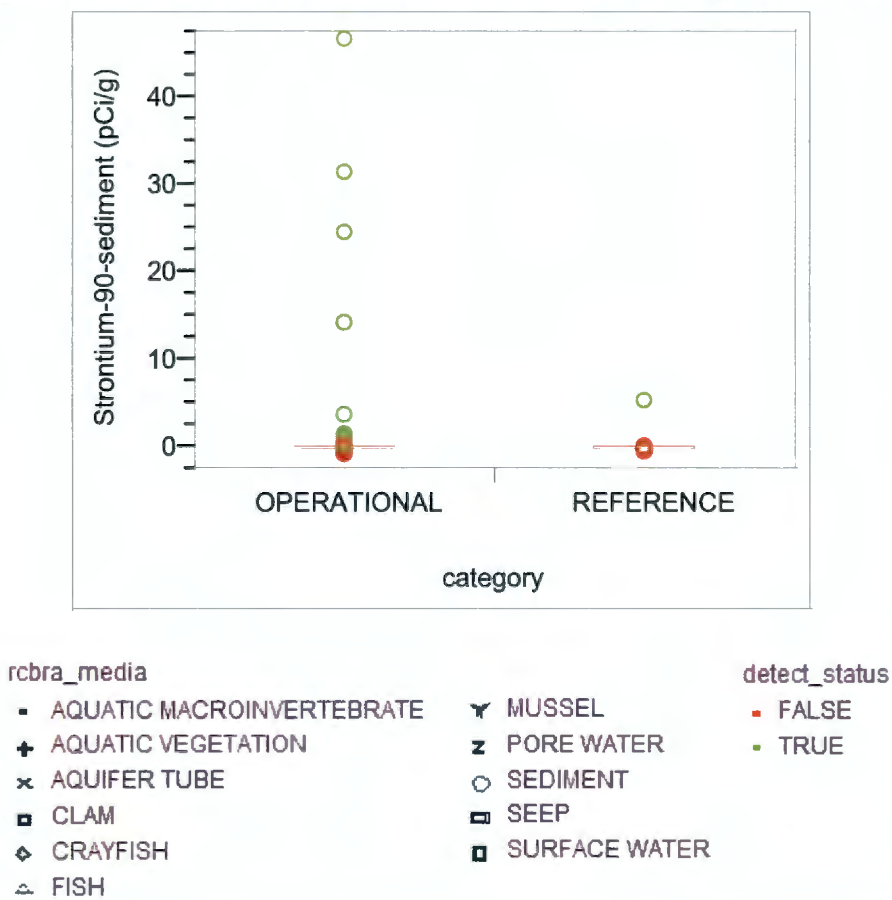


Figure 4-39. Box Plot of Strontium-90 Concentrations in Sediment (pCi/g) by RCBRA Media.

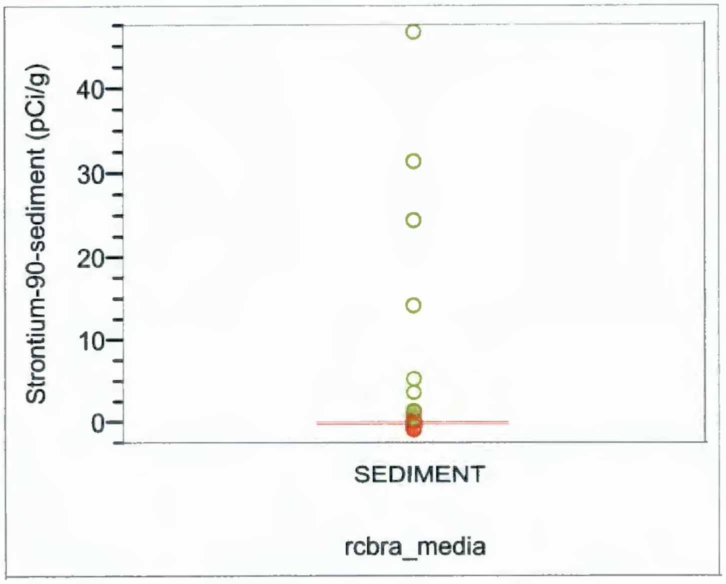


Figure 4-40. Overlay of Strontium-90 Concentrations in Sediment and Aquatic Macroinvertebrates (pCi/g).

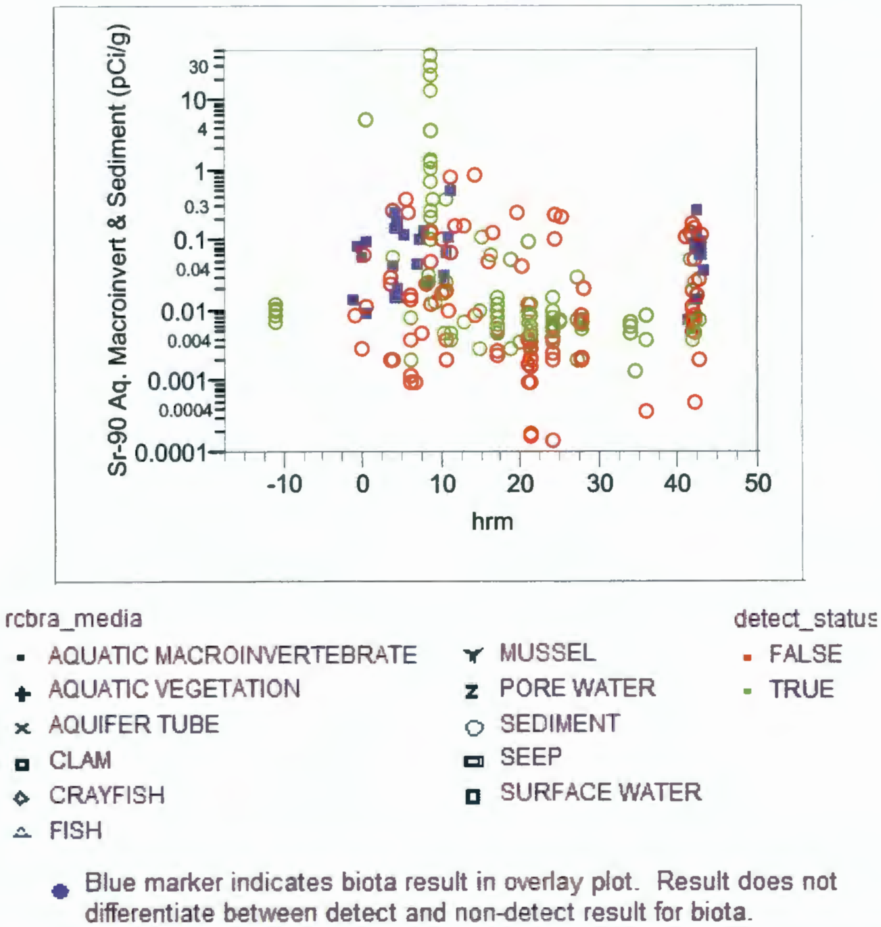


Figure 4-41. Overlay of Strontium-90 Concentrations in Sediment and Clams (pCi/g).

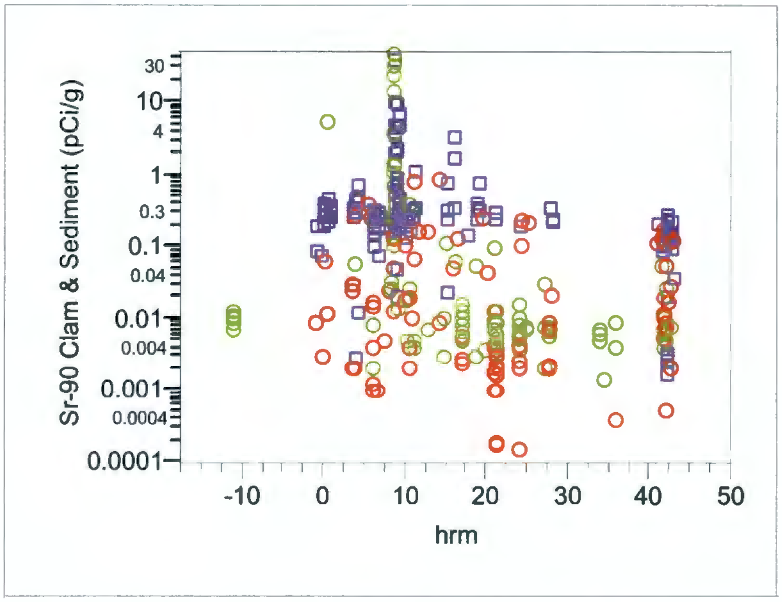
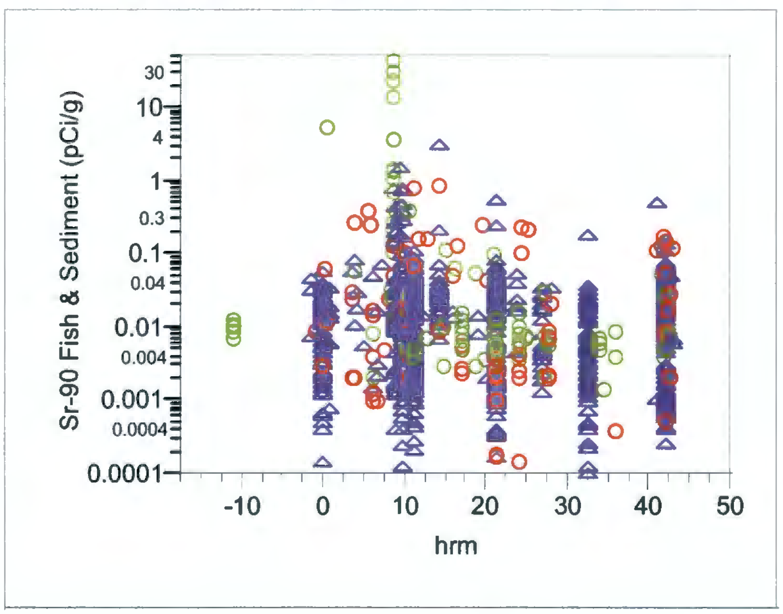


Figure 4-42. Overlay of Strontium-90 Concentrations in Sediment and Fish (pCi/g).



rcbra_media

- AQUATIC MACROINVERTEBRATE
- AQUATIC VEGETATION
- AQUIFER TUBE
- CLAM
- CRAYFISH
- FISH
- MUSSEL
- PORE WATER
- SEDIMENT
- SEEP
- SURFACE WATER

detect_status

- FALSE
- TRUE

Blue marker indicates biota result in overlay plot. Result does not differentiate between detect and non-detect result for biota.

Figure 4-43. Concentrations of Strontium-90 in Tissue (pCi/g) by Hanford River Mile.

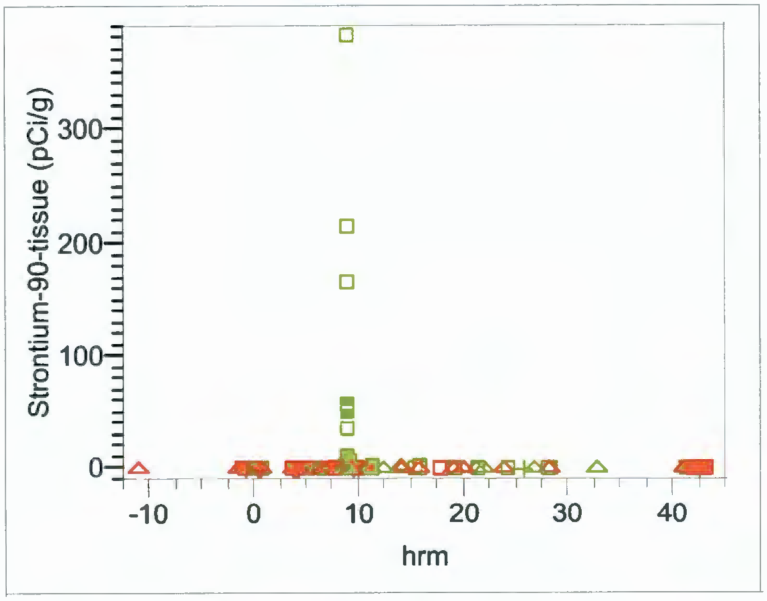


Figure 4-44. Concentrations of Strontium-90 in Tissue (pCi/g) by Date.

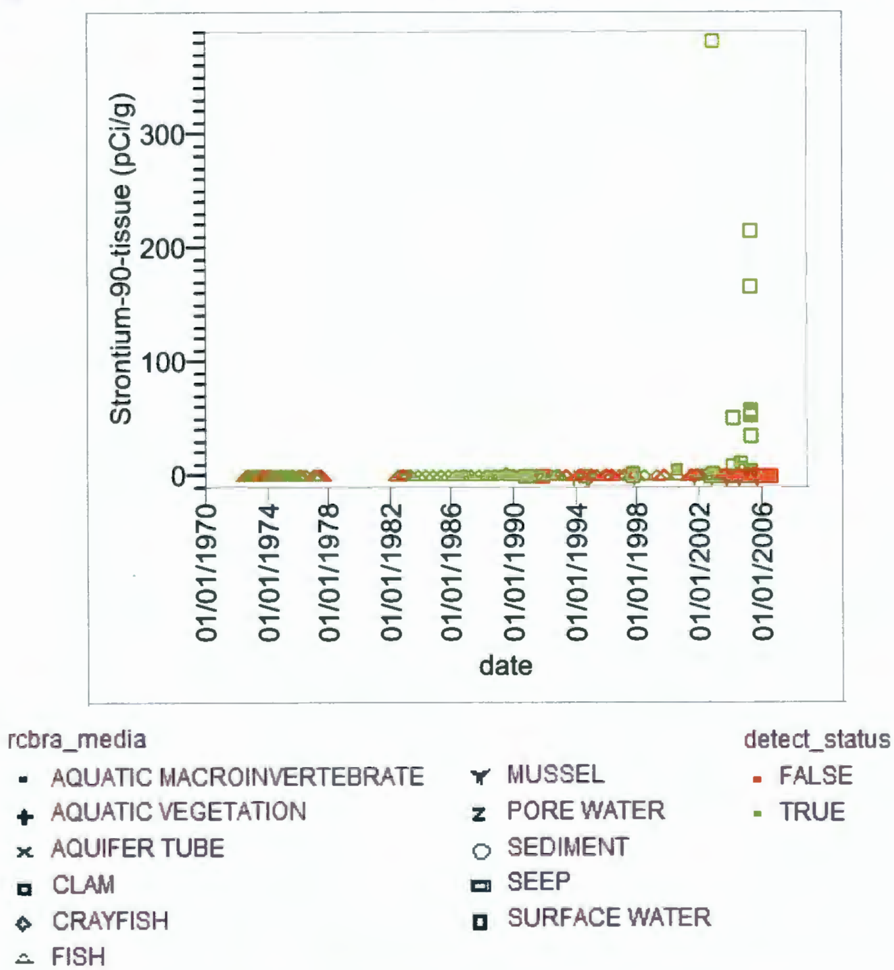


Figure 4-45. Box Plot of Strontium-90 in Tissue (pCi/g) by Category.

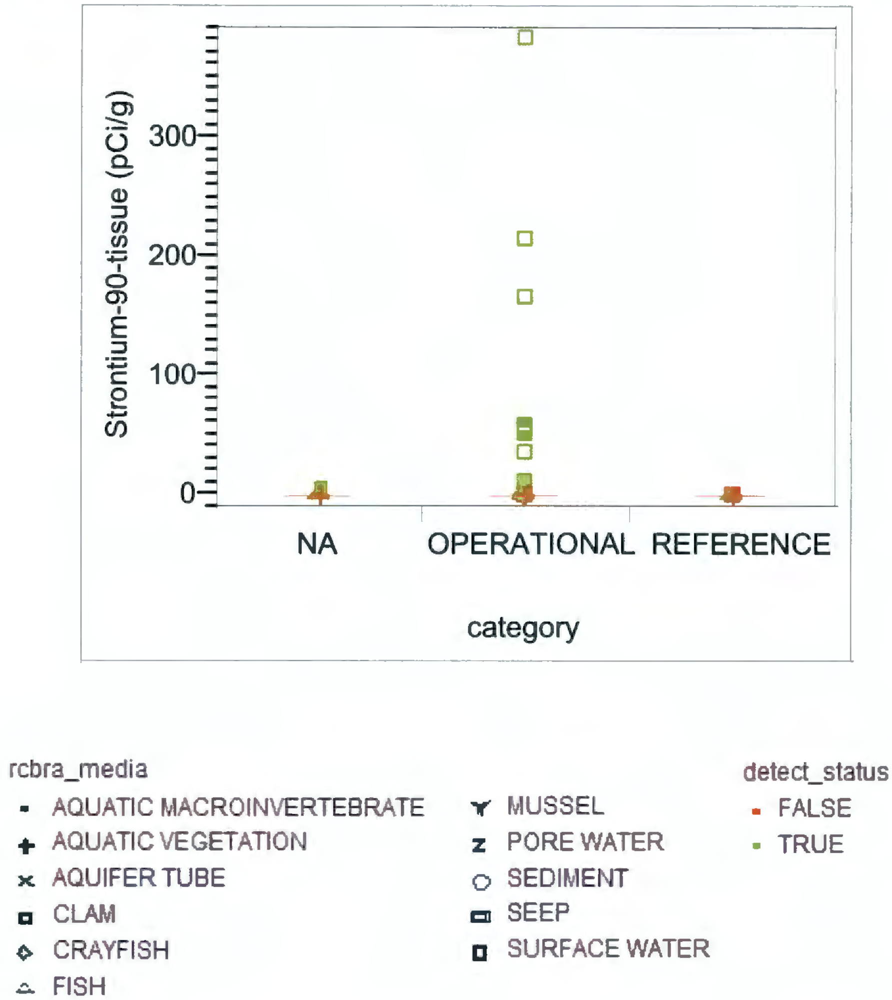


Figure 4-46. Box Plot of Strontium-90 in Tissue (pCi/g) by RCBRA Media.

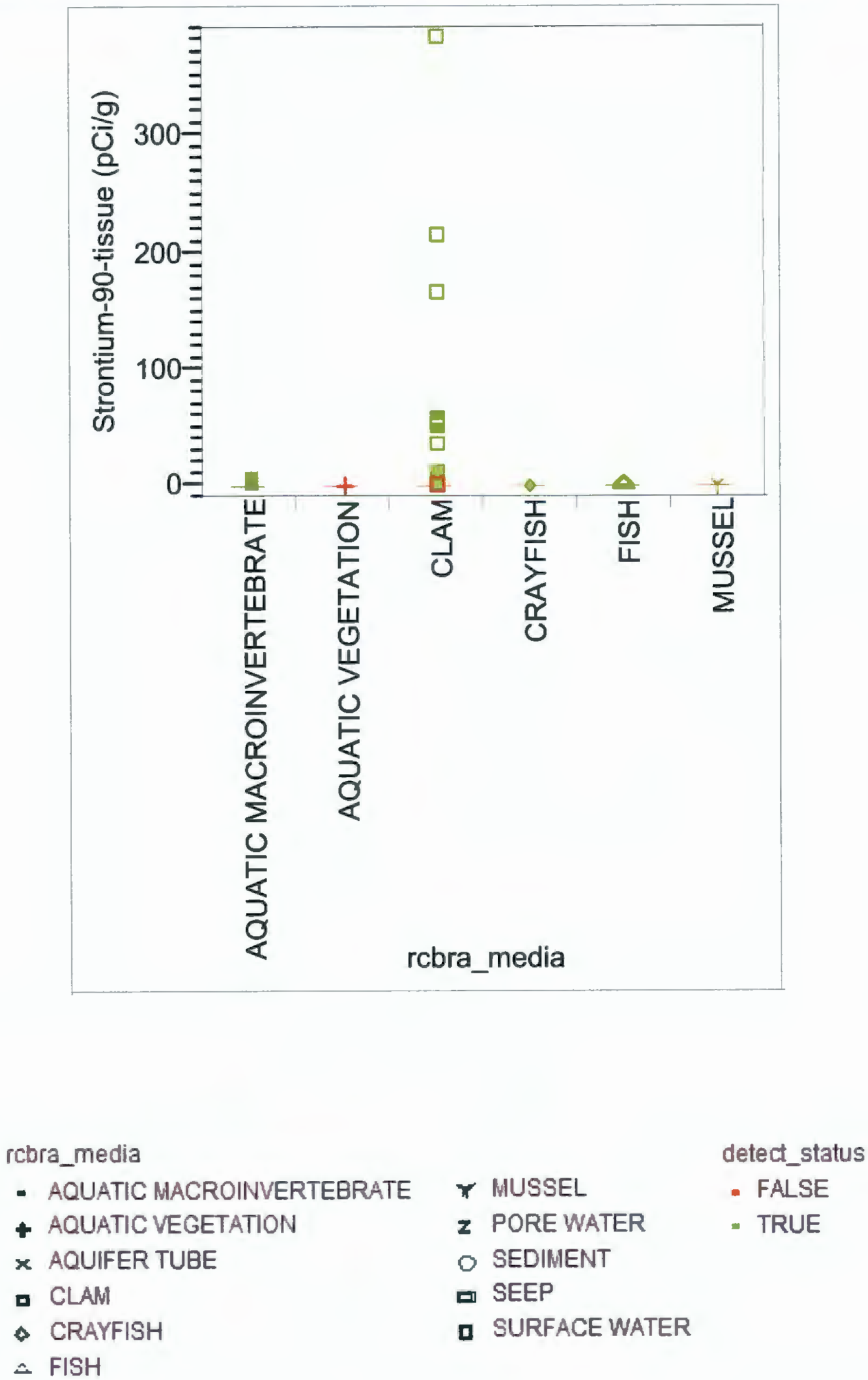


Figure 4-47. Concentrations of Calculated Total Uranium in Water (mg/L) by Hanford River Mile.

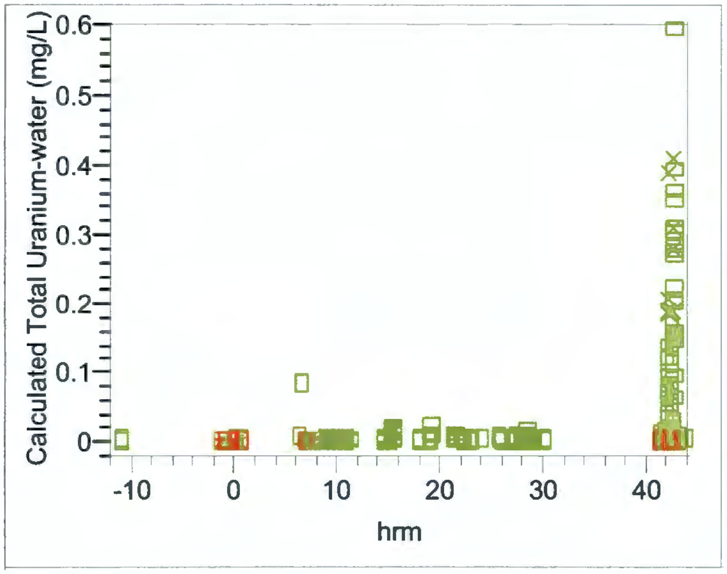


Figure 4-48. Concentrations of Calculated Total Uranium in Water (mg/L) by Date.

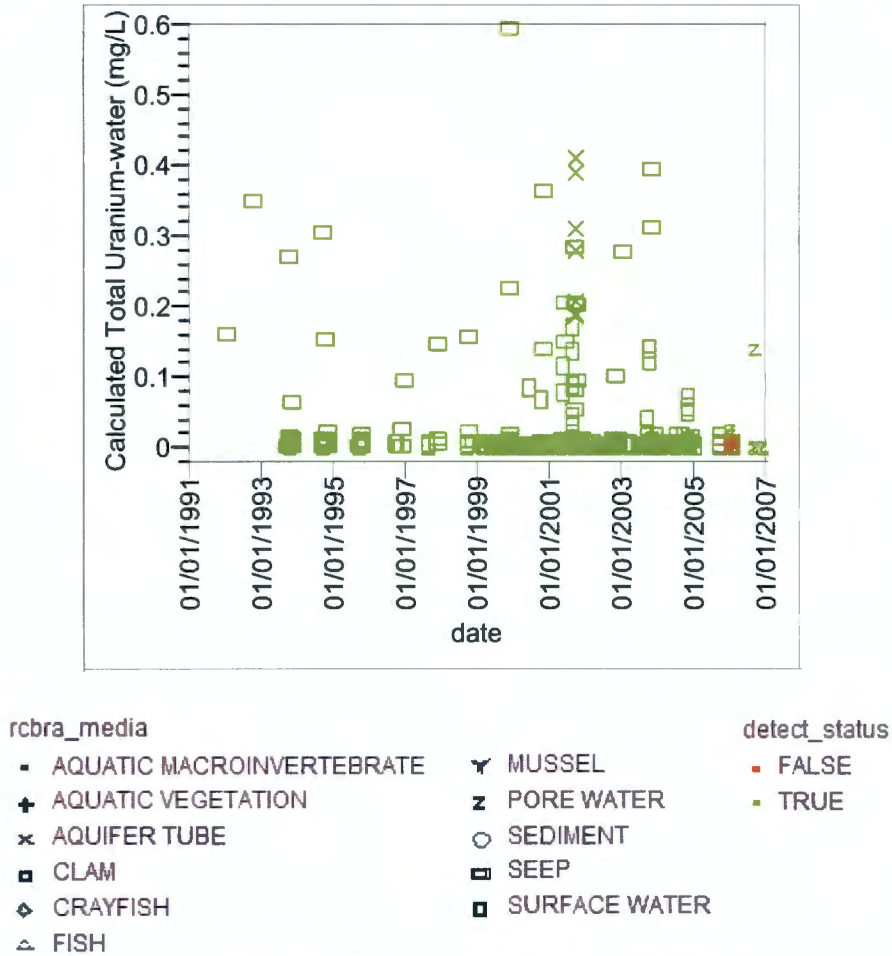


Figure 4-49. Box Plot of Calculated Total Uranium in Water (mg/L) by Category.

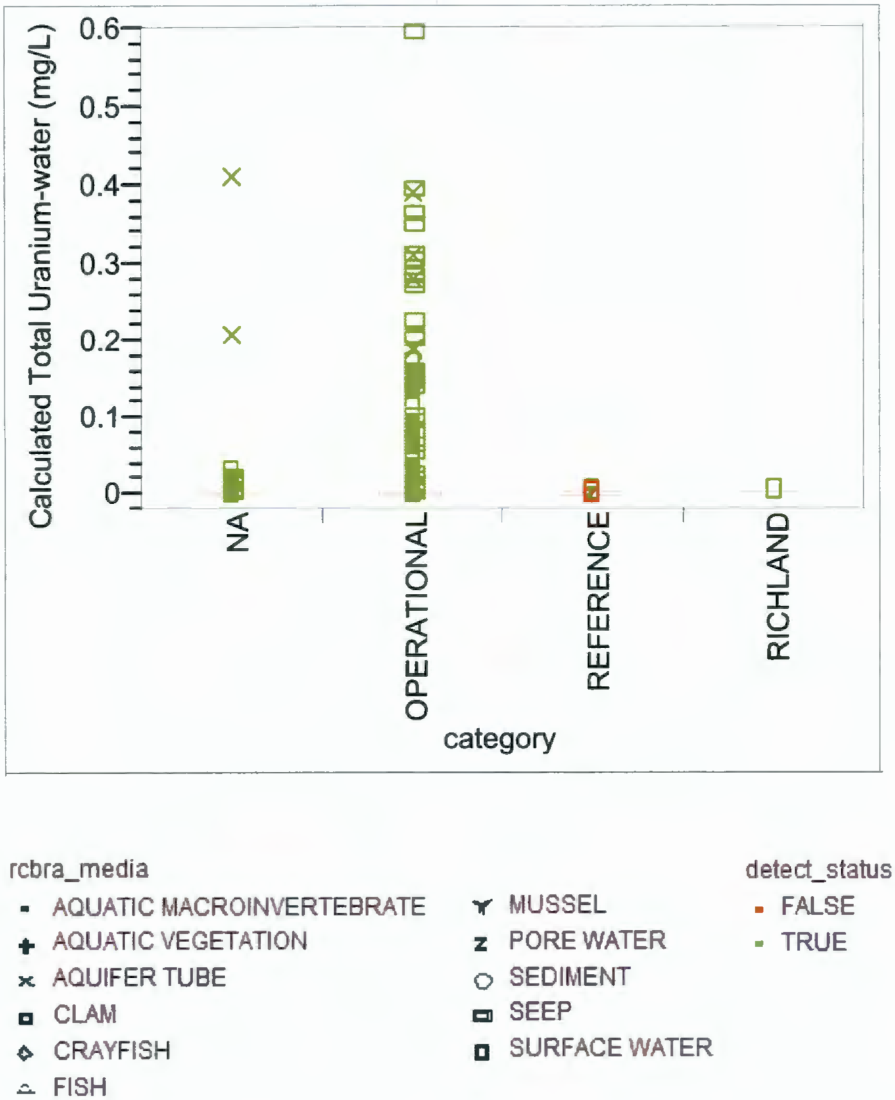


Figure 4-50. Box Plot of Calculated Total Uranium in Water (mg/L) by RCBRA Media.

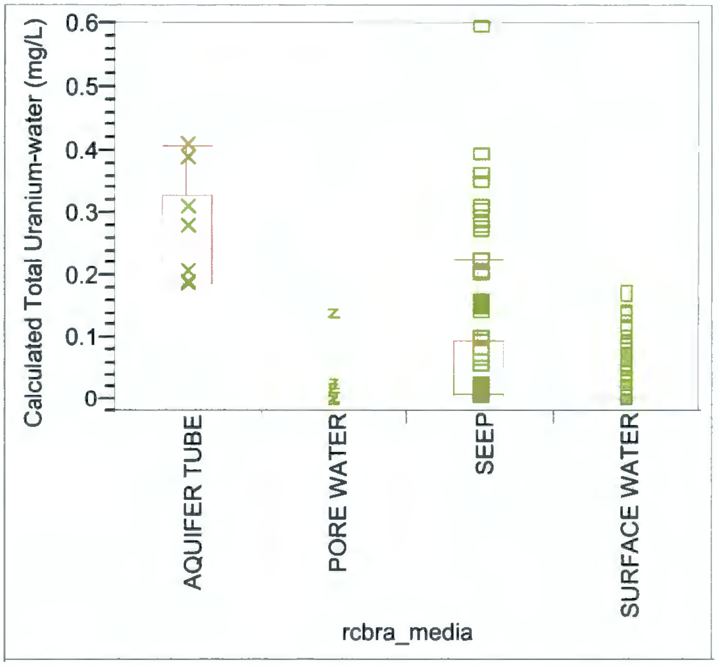


Figure 4-51. Concentrations of Calculated Total Uranium in Sediment (mg/kg) by Hanford River Mile.

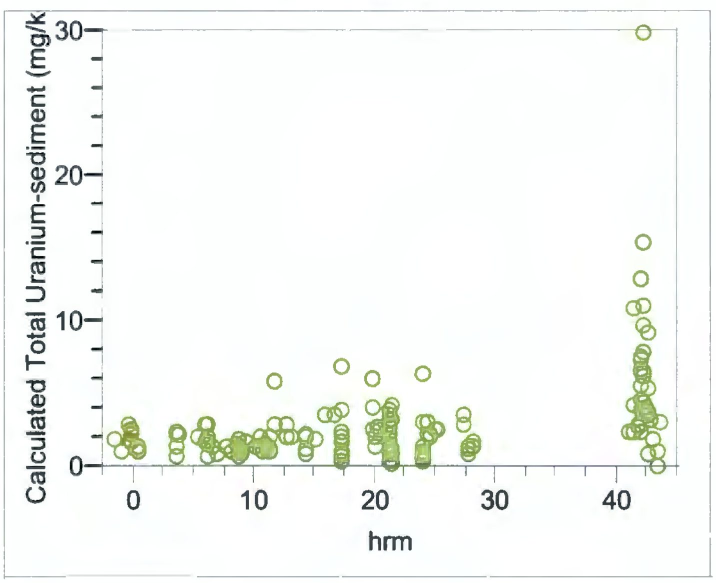


Figure 4-52. Concentrations of Calculated Total Uranium in Sediment (mg/kg) by Date.

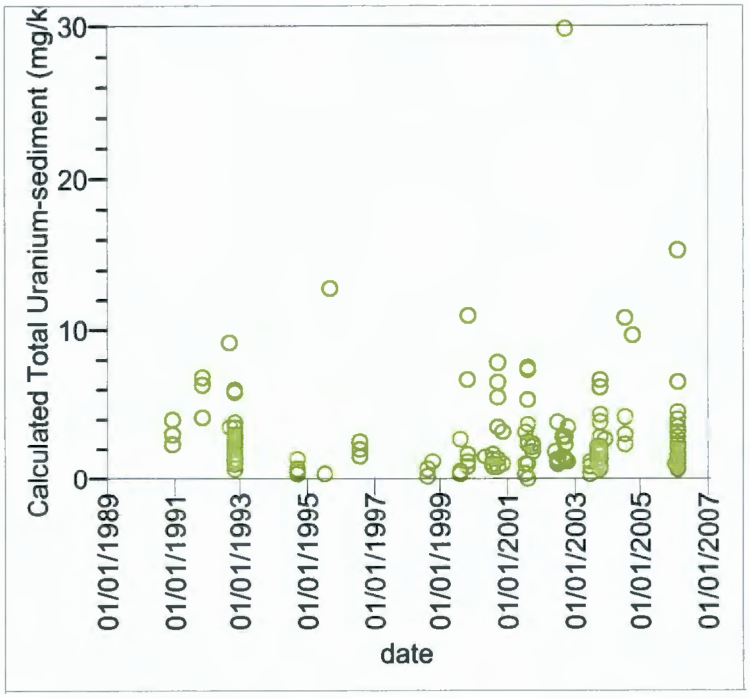


Figure 4-53. Box Plot of Calculated Total Uranium in Sediment (mg/kg) by Category

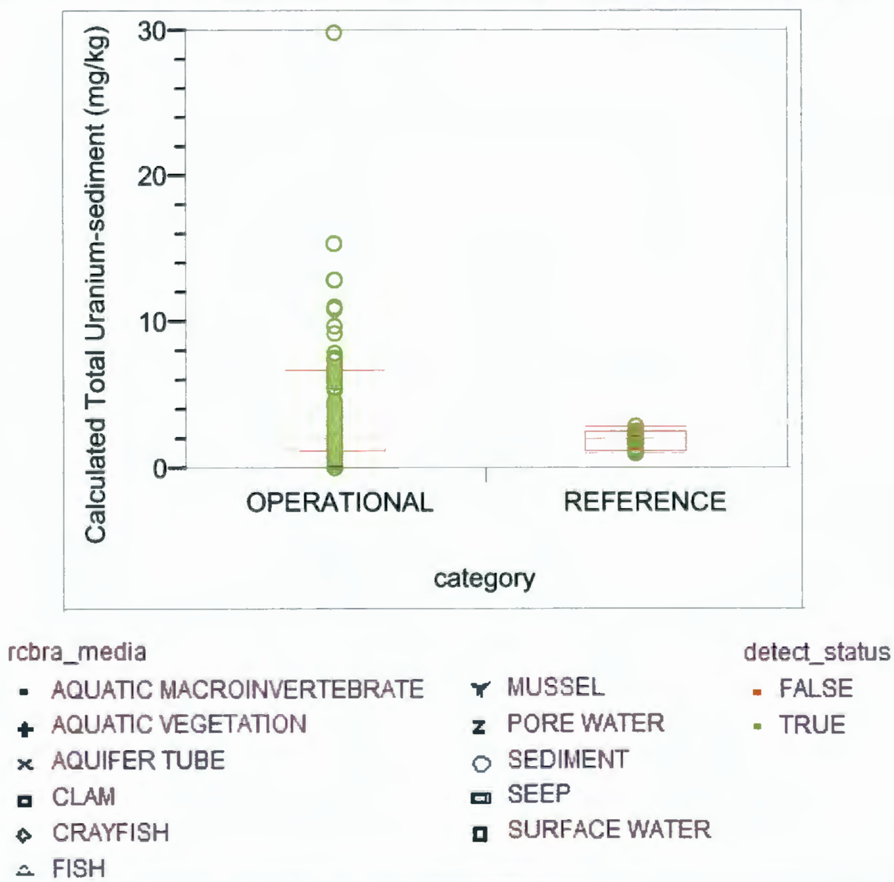


Figure 4-54. Box Plot of Calculated Total Uranium in Sediment (mg/kg).

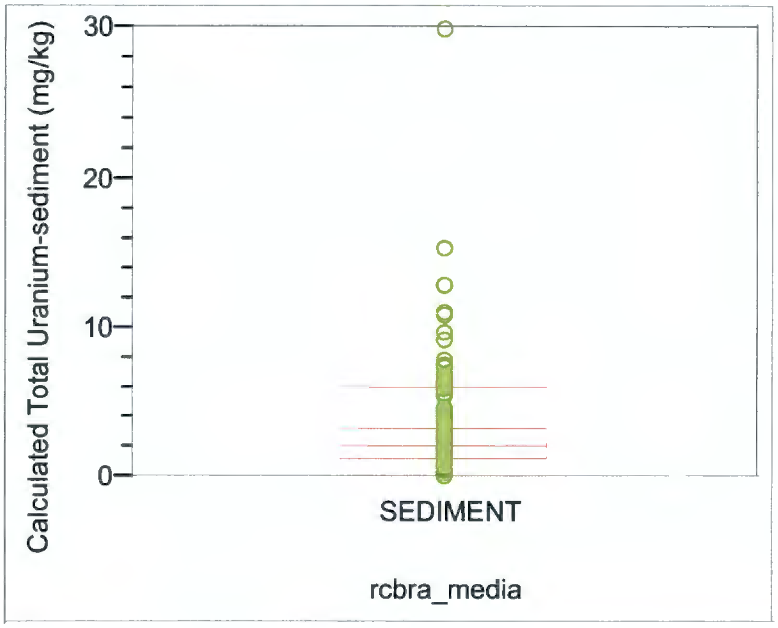


Figure 4-55. Concentrations of Calculated Total Uranium in Tissue (mg/kg) by Hanford River Mile.

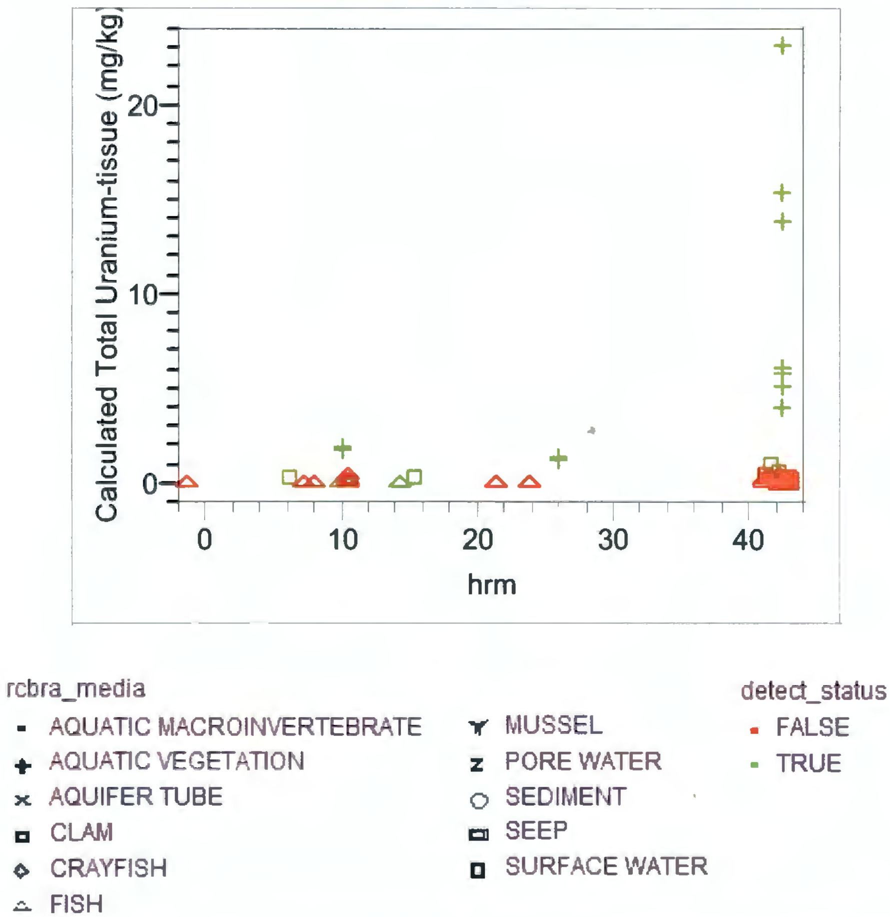


Figure 4-56. Concentrations of Calculated Total Uranium in Tissue (mg/kg) by Date.

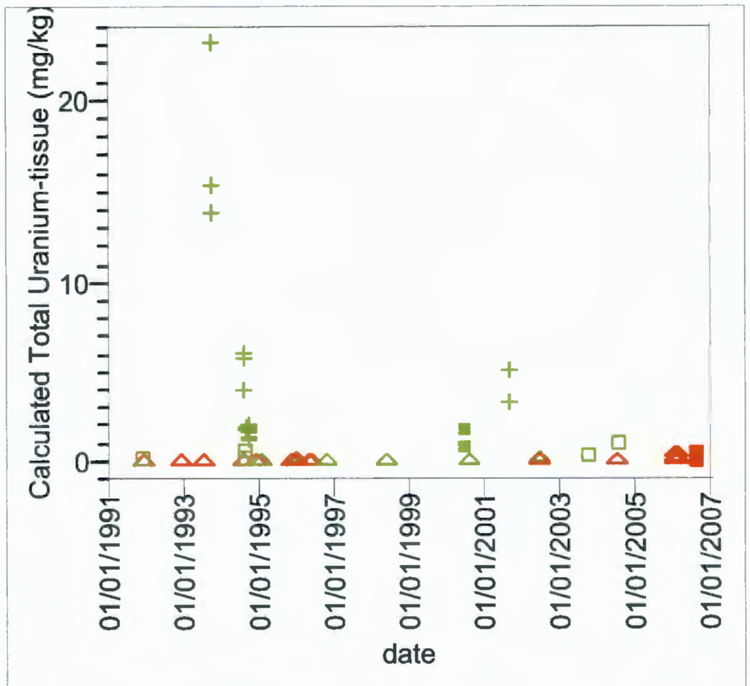


Figure 4-57. Box Plot of Calculated Total Uranium in Tissue (mg/kg) by Category.

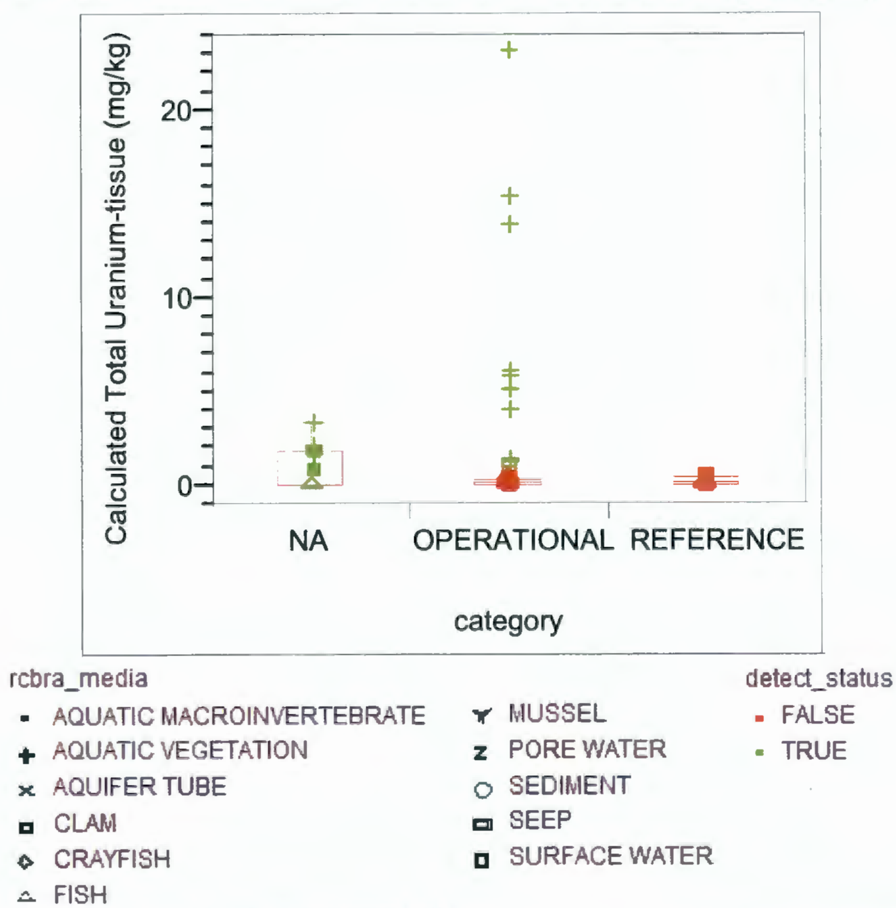


Figure 4-58. Box Plot of Calculated Total Uranium in Tissue (mg/kg) by RCBRA Media.

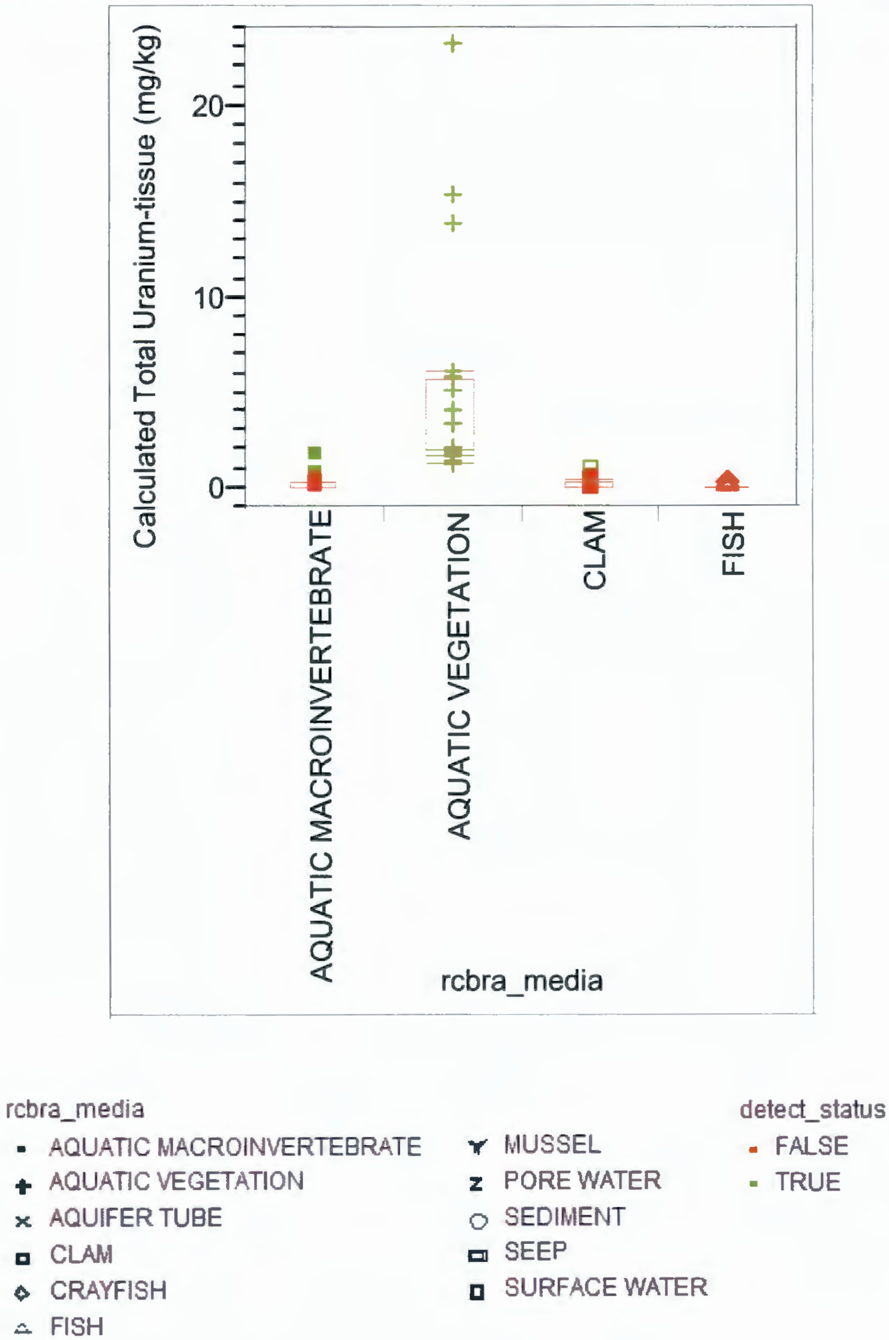


Figure 4-59. Concentrations of Uranium-233/234 in Water (pCi/L) by Hanford River Mile.

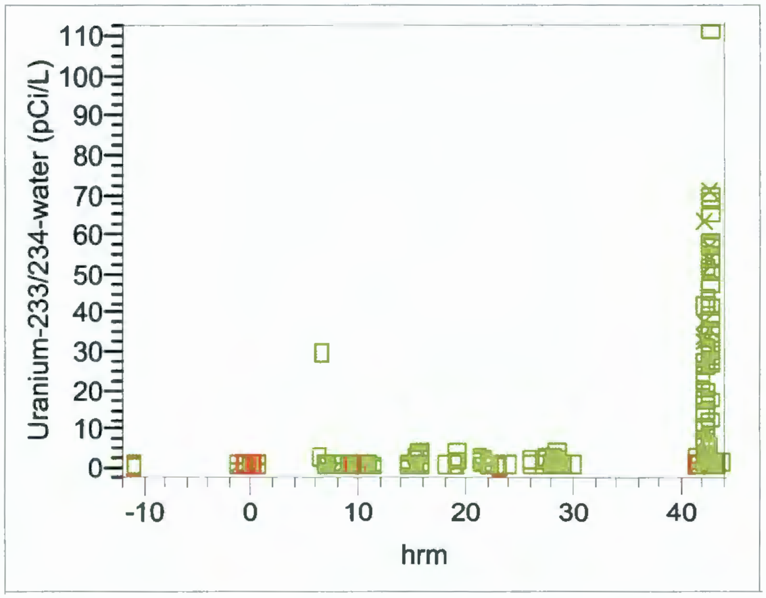


Figure 4-60. Concentrations of Uranium-233/234 in Water (pCi/L) by Date.

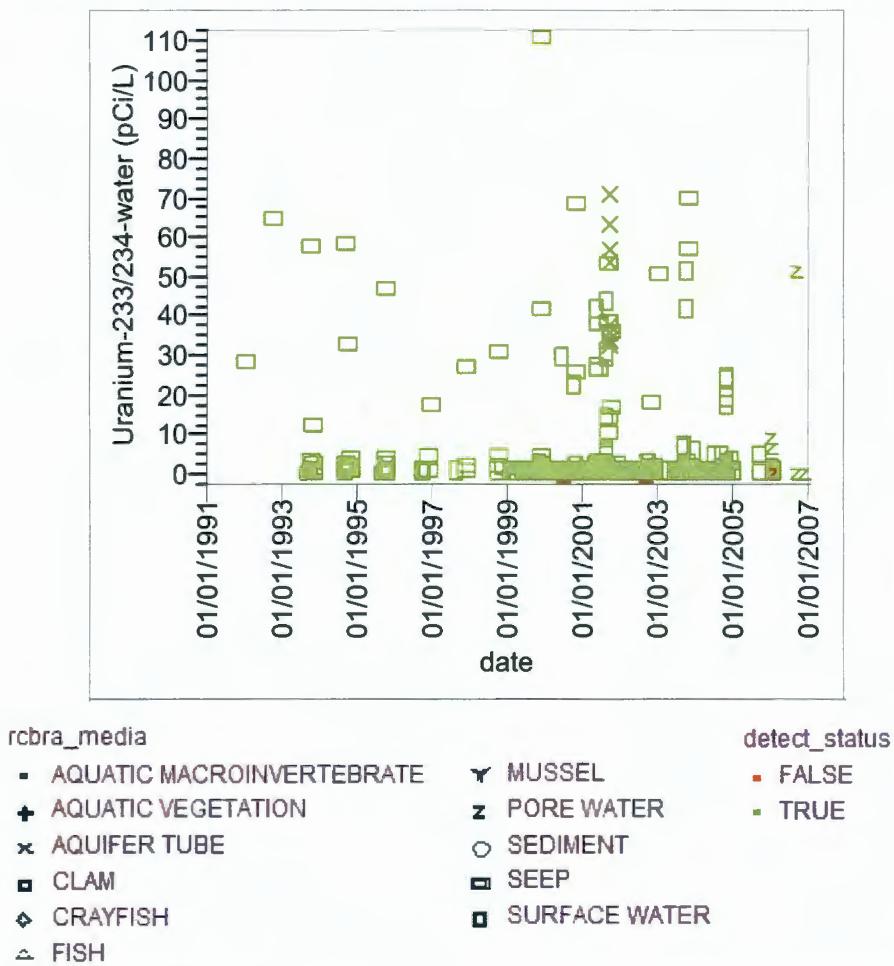


Figure 4-61. Box Plot of Uranium-233/234 in Water (pCi/L) by Category.

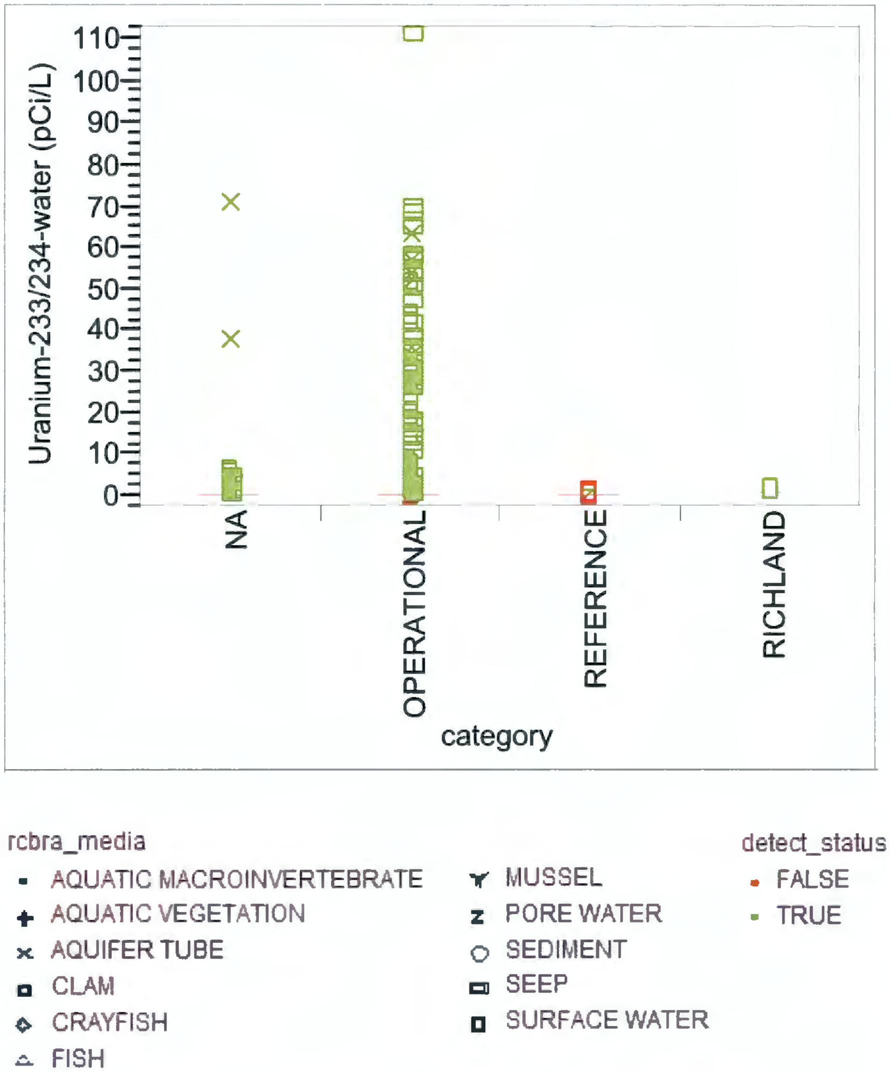


Figure 4-62. Box Plot of Uranium-233/234 in Water (pCi/L) by RCBRA Media.

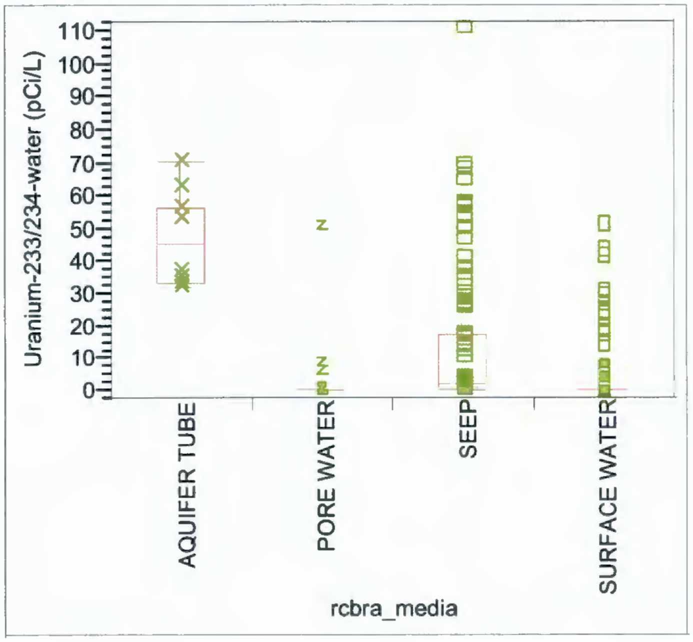


Figure 4-63. Concentrations of Uranium-233/234 in Tissue (pCi/g) by Hanford River Mile.

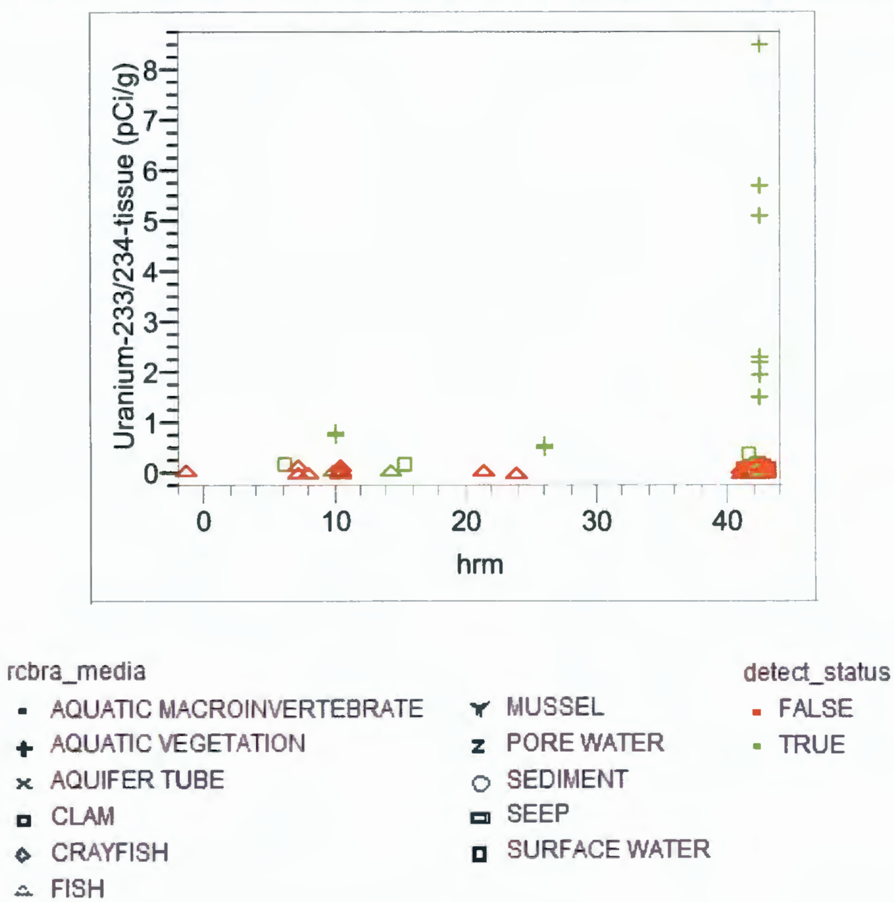


Figure 4-64. Concentrations of Uranium-233/234 in Tissue (pCi/g) by Date.

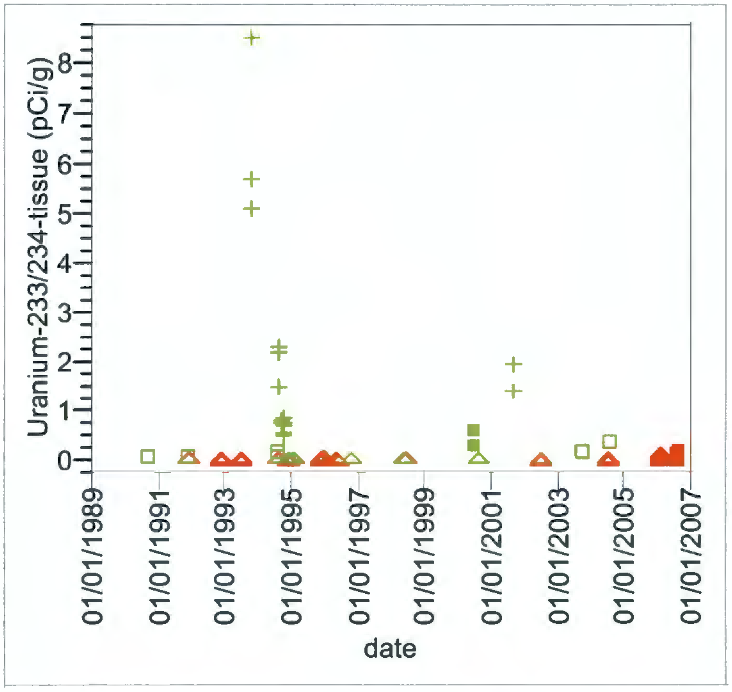


Figure 4-65. Box Plot of Uranium-233/234 in Tissue (pCi/g) by Category.

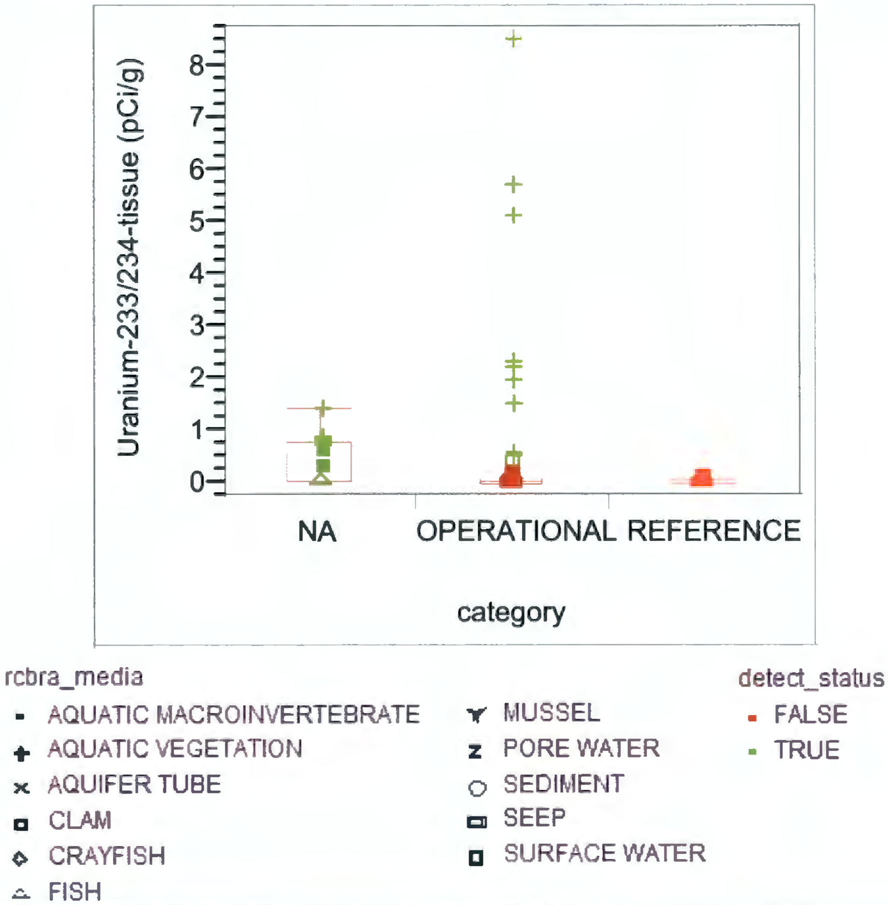


Figure 4-66. Box Plot of Uranium-233/234 in Tissue (pCi/g) by RCBRA Media.

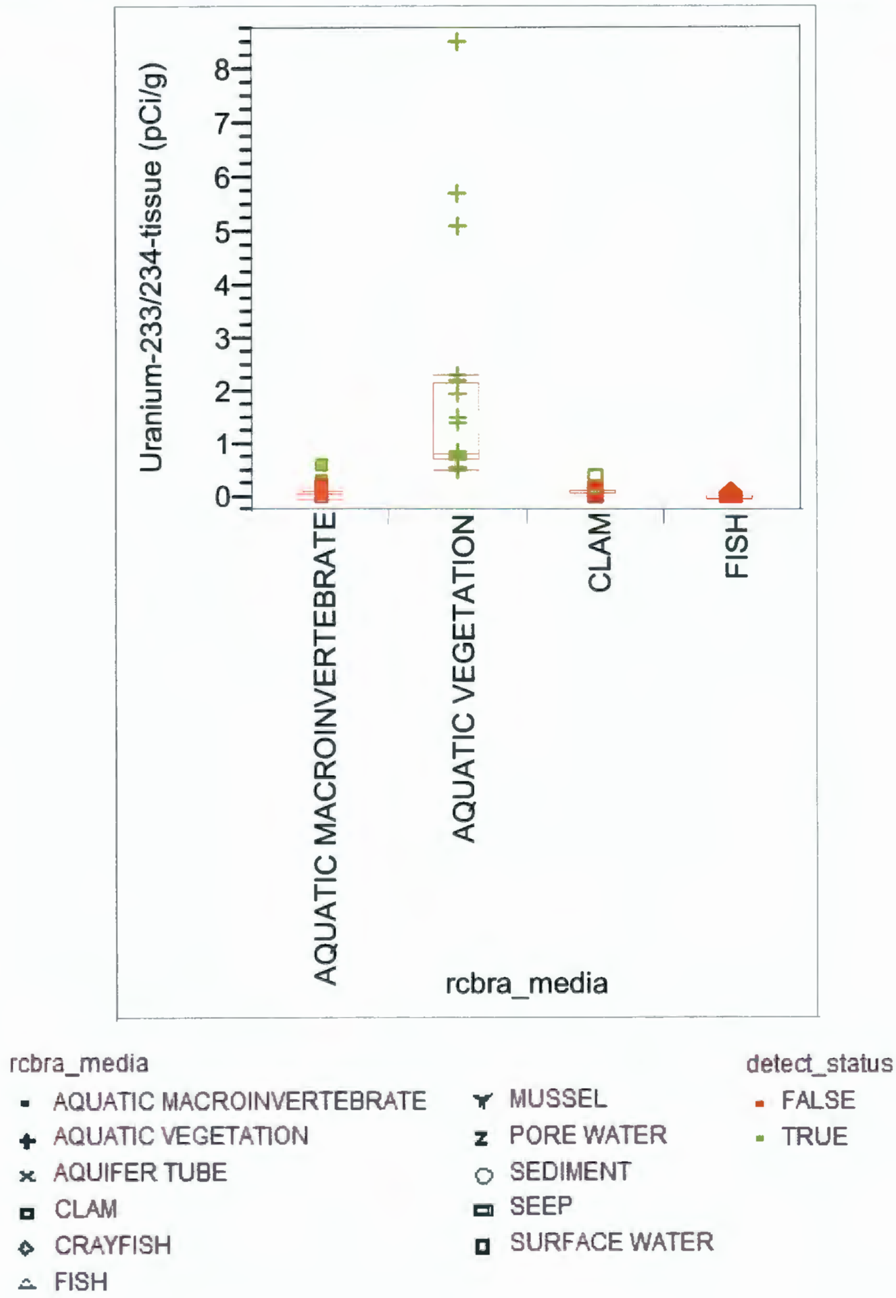


Figure 4-67. Concentrations of Uranium-233/234 in Sediment (pCi/g) by Hanford River Mile.

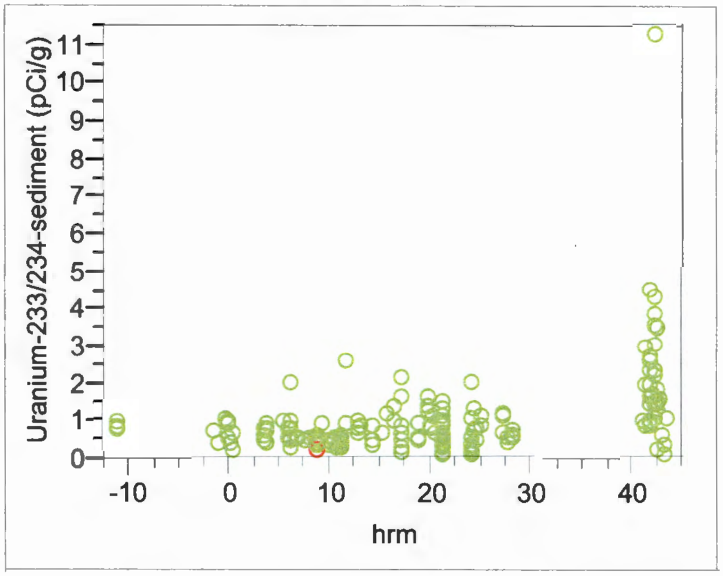
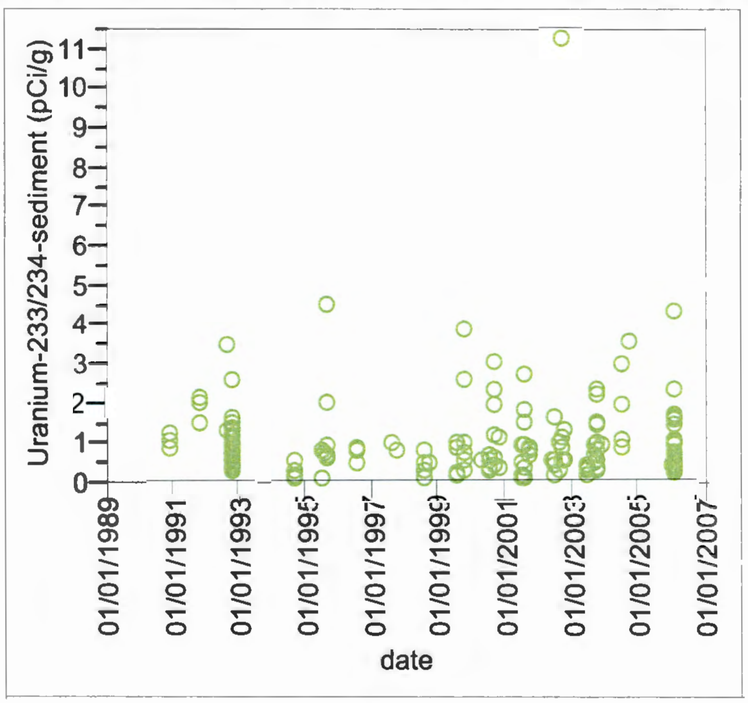


Figure 4-68. Concentrations of Uranium-233/234 in Sediment (pCi/g) by Date.



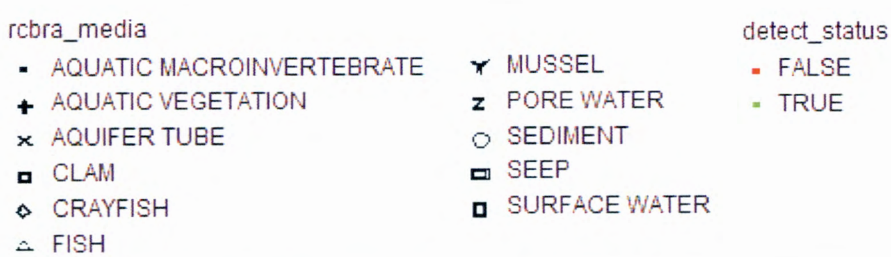


Figure 4-69. Box Plot of Uranium-233/234 in Sediment (pCi/g) by Category.

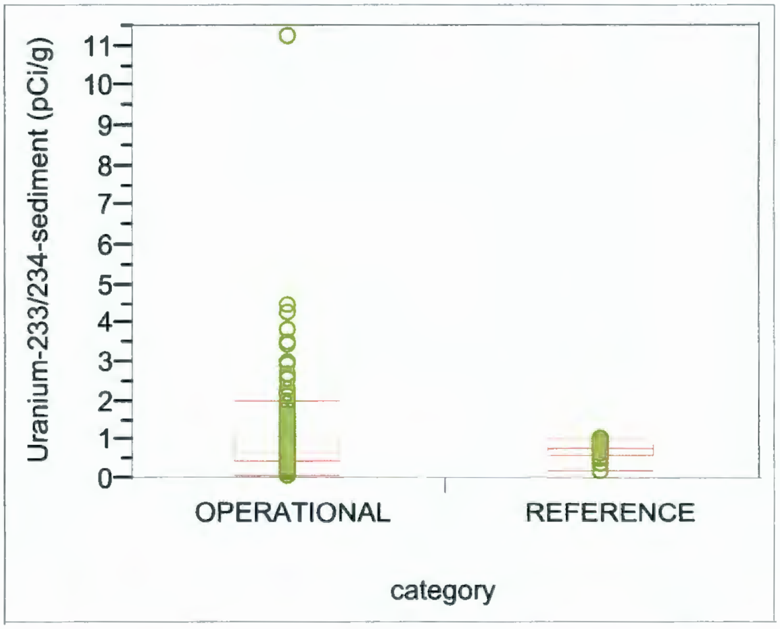
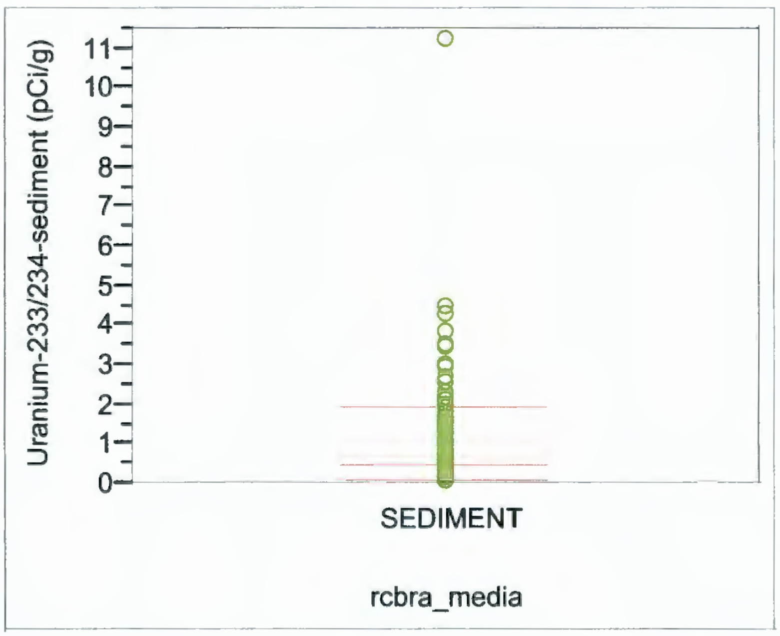


Figure 4-70. Box Plot of Uranium-233/234 in Sediment (pCi/g) by RCBRA Media.



rcbra_media
- AQUATIC MACROINVERTEBRATE
- AQUATIC VEGETATION
- AQUIFER TUBE
- CLAM
- CRAYFISH
- FISH
- MUSSEL
- PORE WATER
- SEDIMENT
- SEEP
- SURFACE WATER

detect_status
- FALSE
- TRUE

Figure 4-71. Concentrations of Uranium-235 in Water (pCi/L) by Hanford River Mile.

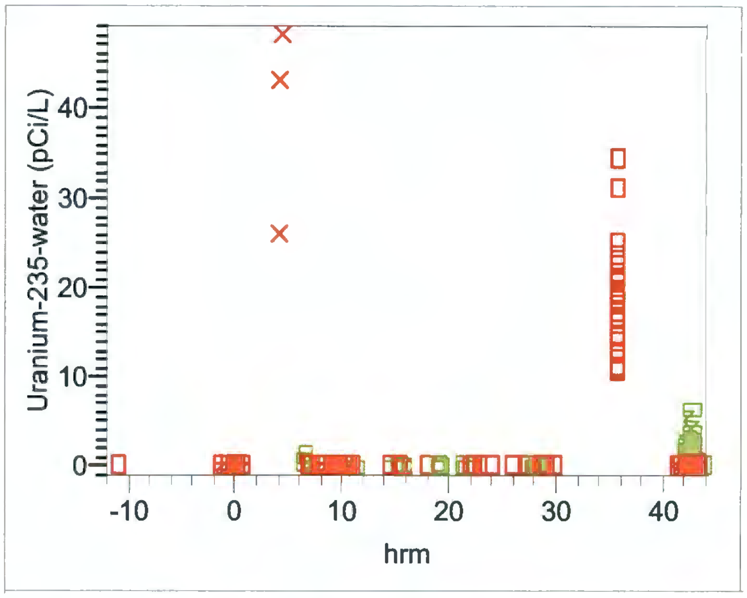


Figure 4-72. Concentrations of Uranium-235 in Water (pCi/L) by Date.

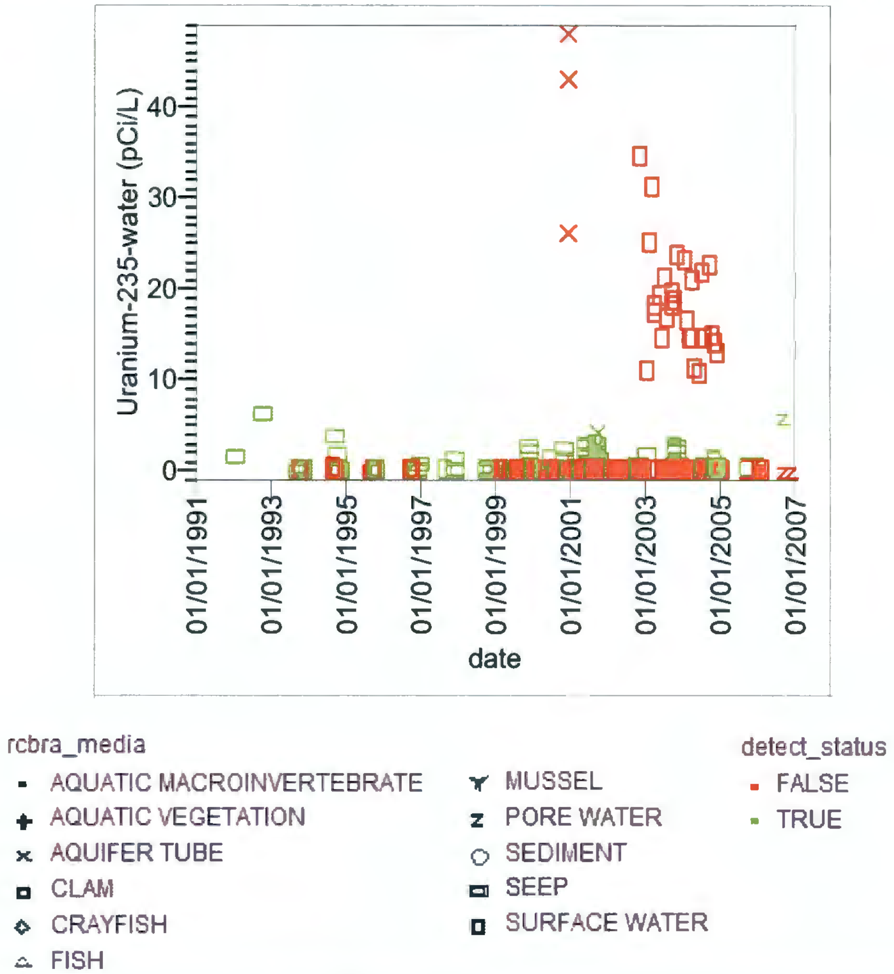


Figure 4-73. Box Plot of Uranium-235 in Water (pCi/L) by Category.