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Qualitative Risk Assessment for the 100-FR-3 Groundwater Operable Unit

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HANFORD

Prepared for the U.S. Department of Energy
Office of Environmental Restoration and
Waste Management

Bechtel Hanford, Inc.
Richland, Washington

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Qualitative Risk Assessment for the 100-FR-3 Groundwater Operable Unit

Author
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EXECUTIVE SUMMARY

This report provides the qualitative risk assessment (QRA) for the 100-FR-3 groundwater operable unit at the U.S. Department of Energy's (DOE) Hanford Site in south-central Washington State. The extent of the groundwater beneath the 100-F Area is defined in the *Remedial Investigation/Feasibility Study Work Plan for the 100-FR-3 Operable Unit, Hanford Site, Richland, Washington* (DOE-RL 1992a). This QRA is an evaluation of risk using a limited amount of data and a predefined set of human and environmental exposure scenarios and is not intended to replace or be a substitute for a baseline risk assessment.

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BACKGROUND

The Washington Department of Ecology (Ecology), the U.S. Environmental Protection Agency (EPA), and DOE, signatories to the *Hanford Federal Facility Agreement and Consent Order* (Tri-Party Agreement) (Ecology et al. 1990), developed the *Hanford Past-Practice Strategy* (DOE-RL 1991) to emphasize initiating and completing waste site cleanups with a bias for action. This strategy relies, in part, on the use of a QRA to assist in decision making. This QRA was performed using the *Hanford Site Baseline Risk Assessment Methodology* (DOE-RL 1993) as guidance. The results will be used in the limited field investigation (LFI) report, along with other considerations, to make a recommendation regarding the need for interim remedial measures (IRMs).

This QRA was streamlined to consider only two human health exposure scenarios (frequent and occasional use) with two pathways (groundwater ingestion and inhalation of volatile organics from groundwater use), and a limited ecological evaluation, based on agreements by the 100 Area Tri-Party Agreement unit managers (December 21, 1992 and February 8, 1993). The exposure factors for the residential and recreational scenarios in HSBRAM were used in evaluating the frequent and occasional use scenarios, respectively. For humans, risks that might occur under frequent and occasional use were included to provide bounding estimates of risk. The inhalation pathway was only evaluated in the frequent-use scenario because it was assumed that exposures to volatile organics would occur during domestic water use within the confines of a residence, which would not be expected to occur in an occasional-use setting. The ecological evaluation concentrated on the hypothetical effects of contaminants on selected aquatic organisms present in or near the Columbia River. The limited scope of the evaluation and the lack of environmental transport modeling make the analysis qualitative.

The data for the 100-FR-3 groundwater operable unit QRA were from three rounds of data collected during recent LFI sampling. The data were evaluated as recommended in the risk assessment methodology (DOE-RL 1993). Maximum representative detected concentrations of inorganic analytes were screened by comparison with background levels for groundwater established in *Hanford Site Groundwater Background* (DOE-RL 1992c) consistent with agreements for other operable units made by 100 Area Tri-Party Agreement unit managers (February 8, 1993). No organic and radionuclide analytes, with the exception of the uranium isotopes, were screened by comparison to background because there were no background values agreed on. Human health risks were calculated for the maximum representative concentrations of the organic and radionuclide analytes using the appropriate methodology (e.g., hazard quotient [HQ], incremental cancer risk [ICR]). The ecological evaluation compared the maximum representative concentrations to risk-based benchmark concentrations (e.g.,

radiation dose limit, lowest observable effect level [LOEL]) to form an environmental hazard quotient [EHQ]. No evaluation of spatial or temporal distribution of the contaminants was performed.

RESULTS

The analysis of human health risks considered both carcinogenic and noncarcinogenic impacts. The carcinogenic impacts were further divided into those caused by exposure to radioactive and nonradioactive contaminants. The results of the human health risk estimations for carcinogenic contaminants were grouped into high (ICR $\geq$ 1E-02), medium (1E-04 $\leq$ ICR $<$ 1E-02), low (1E-06 $\leq$ ICR $<$ 1E-04), and very low (ICR $<$ 1E-06) categories to represent the qualitative nature of the assessment. EPA supports the concept of a risk range and defines the risk range of 1E-06 to 1E-04 as a "generally acceptable level," with 1E-06 being a "point of departure for establishing remediation goals" (40 CFR 300.430(e)(2)). These categories were defined to be consistent with this concept. For noncarcinogenic contaminants, the HQ estimations were considered a significant risk if they exceeded 1.0 and the converse if they did not exceed 1.0.

The following were the primary human health evaluation findings:

- The cumulative risk for all carcinogenic contaminants is classified as medium for the frequent-use scenario and low for the occasional-use scenario. The estimated risks for the frequent-use scenario are rated medium to very low. For the occasional-use scenario, the estimated risks are rated low to very low.

- Two radioactive contaminants (tritium and strontium-90) and one nonradioactive contaminant (arsenic) have frequent-use estimates in the medium carcinogenic risk category. Arsenic, tritium, and strontium-90 together account for over 90% of the total risk for both the frequent- and occasional-use scenarios.

- The highest-risk organic contaminants (chloroform and trichloroethene) produced estimates in the low carcinogenic risk category for the frequent-use scenario and the very low risk category for the occasional-use scenario.

- Four of the noncarcinogenic inorganic contaminants analyzed (chromium, arsenic, nitrate/nitrite, and manganese) produced an HQ greater than 1.0 for the frequent-use scenario, but none exceeded 1.0 for the occasional-use scenario.

The methodology (DOE/RL 1993) recommends that risk from background levels of contaminants of potential concern (COPC) be calculated. Only two COPC (arsenic and total uranium) have Hanford Site background values. The background concentration of arsenic corresponds to a medium carcinogenic risk level under the frequent-use scenario, and the noncarcinogenic HQ for arsenic background concentration exceeds the benchmark of 1.0. The background value for total uranium corresponds to a low carcinogenic risk.

The ecological evaluation analyzed the likelihood of an adverse effect occurring to riparian and aquatic life. As the maximum conservative assumption, the concentrations of contaminants in the near-river groundwater were used as exposure concentrations for assessing the risk to generic aquatic organisms. However, once contaminated groundwater entered the river, the effect of dilution was

virtually immediate; well- and spring-water contaminant concentrations were much higher than the corresponding river-water concentrations.

The following were the primary environmental evaluation findings:

- The ecological benchmark used for radionuclides is a total internal dose rate of 1 rad/day (DOE Order 5400.5; DOE 1989). No radionuclides were found to exceed this benchmark dose rate. The highest dose rate was calculated for strontium-90 to the plant-eating duck, which was 0.048 rad/day.

- Acute and chronic LOELs for fish were used as benchmarks for nonradiological contaminants to produce acute and chronic EHQs. Chromium (hexavalent), copper, and lead concentrations in the near-river groundwater resulted in chronic EHQs exceeding 1.0.

UNCERTAINTIES

Uncertainties exist in the results of the human health and ecological evaluations because of uncertainty in the contaminant concentration data, in the assumptions of the exposure scenarios analyzed, and in the toxicity values for both human and ecological receptors. The identification of contaminants and concentrations were based on three rounds of LFI sample data that represented a limited "snapshot" and were not likely to fully characterize the groundwater under the 100-F Area.

The conservative assumptions of the scenarios and the risk evaluation itself also led to uncertainty in the risk results, though the evaluation was meant to bound the current risks. Conservatism was introduced by the use of maximum representative, rather than average, concentrations in the risk evaluation. The risk calculations did not include dilution effects, radioactive decay, or bioavailability. The assumptions of exposure times for both humans and aquatic organisms as receptors were conservative. The two human health scenarios (frequent and occasional use) evaluated to provide estimates of hazard or risk do not currently occur in the 100-F Area. The assumption of contact duration with contaminant concentrations in the groundwater for fish does not account for the dilution of groundwater in the spring and river water or the mobility of the fish.

There are uncertainties in the toxicity information for both human health and ecological evaluations. The human toxicity values for many contaminants were based on limited acute animal studies with the effects extrapolated to the chronic dose levels of environmental contamination levels for human receptors. The same situation applies to ecological toxicity values, which are usually developed based on acute levels in laboratory studies on specific species and then applied to other species at lower concentration levels in the environment.

Quantitative uncertainty and sensitivity analyses were performed for the 100-FR-3 groundwater operable unit. The uncertainty analysis was an attempt to bound the range over which the risk estimates will vary as a result of uncertainties in the input parameters. The sensitivity analysis was performed to identify the input parameters that, when varied over their range, have the most impact on the risk estimates. The results of these analyses are presented in Appendix C. For the human health evaluation, the HQs and risks for the COPC in this QRA are within the range of the uncertainty analysis, with the exception of chromium; however, the reported HQs and risks tend to fall at

the upper end of the range. For the ecological evaluation, the radionuclide doses (and hence the EHQs) for the uranium isotopes exceeded the range of the uncertainty analyses.

In summary, it can be reasonably assumed that the actual human and ecological risks are less than the risks calculated as part of this QRA. These estimates of risk, with their associated uncertainties, are sufficient to support an initial decision for the 100-FR-3 groundwater operable unit.

ACRONYMS AND INITIALISMS

ARAR	applicable or relevant and appropriate requirement
AWQC	ambient water quality criteria
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act of 1980
CFWQC	chronic freshwater quality criteria
CLP	Contact Laboratory Program
COPC	contaminants of potential concern
DOE	U.S. Department of Energy
DOE-RL	U.S. Department of Energy, Richland Operations Office
Ecology	Washington Department of Ecology
EHQ	environmental hazard quotient
EPA	U.S. Environmental Protection Agency
ERA	expedited response action
HEAST	Health Effects Assessment Summary Tables
HFSUWG	Hanford Future Site Uses Working Group
HI	hazard index
HQ	hazard quotient
HWQHC	human water quality health criteria
HWQWC	human water quality welfare criteria
ICR	incremental cancer risk
IRIS	Integrated Risk Information System
IRM	interim remedial measure
LC_{50}	lethal concentration, 50% mortality
LFI	limited field investigation
LOEL	lowest observable effect level
MCL	maximum contaminant level
MCLG	maximum contaminant level goal
MTCACR	Model Toxics Control Act Cleanup Regulations
NCRP	National Council on Radiation Protection
ND	not detected
NPL	National Priorities List
NRC	U.S. Nuclear Regulatory Commission
NTU	nephelometric turbidity unit
PCB	polychlorinated biphenyl(s)
QA	quality assurance
QC	quality control
QRA	qualitative risk assessment
RAGS	Risk Assessment Guidance for Superfund
RCRA	Resource Conservation and Recovery Act of 1976
RfD	reference dose
RME	reasonable maximum exposure
SF	slope factor
UCL	upper confidence limit
WA	Washington (State of)
WAC	Washington Administrative Code
WHC	Westinghouse Hanford Company

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1.0 INTRODUCTION

This report documents the qualitative risk assessment (QRA) performed for the 100-FR-3 groundwater operable unit. This unit is located in the 100-F Area of the Hanford Site (Figure 1-1). The 100 Area of the Hanford Site was included on the U.S. Environmental Protection Agency's (EPA's) National Priorities List (NPL) under the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA).

The Washington Department of Ecology (Ecology), EPA, and the U.S. Department of Energy (DOE) are signatories to the *Hanford Federal Facility Agreement and Consent Order* (Tri-Party Agreement) (Ecology et al. 1990). The signatories have developed a strategy to emphasize initiating and completing waste site cleanups in the *Hanford Site Past-Practice Strategy* (DOE-RL 1991). The strategy identified three paths to support this bias for action. The paths are expedited response actions (ERAs) and interim remedial measures (IRMs) with or without a limited field investigation (LFI).

This QRA provides information, along with other considerations in the LFI report, to justify conducting or not conducting an IRM, though it may be used to support the other paths when agreed on by the Tri-Party Agreement signatories. An IRM, as defined in the past-practice strategy, is an onsite response conducted pursuant to CERCLA 40 CFR 300.430 involving interim remedial actions that are conducted at a CERCLA past-practice operable unit at any time prior to initiation of final remedial action.

This report documents the QRA performed for the 100-FR-3 groundwater operable unit. The application of the past-practice strategy at the 100-FR-3 groundwater operable unit is discussed in detail in the *Remedial Investigation/Feasibility Study Work Plan for the 100-FR-3 Operable Unit, Hanford Site, Richland, Washington* (DOE-RL 1992a).

1.1 SCOPE

The scope of this QRA for the 100-FR-3 groundwater operable unit focuses on a limited set of human health and ecological exposure scenarios to provide sufficient information to assist the Tri-Party Agreement signatories in making defensible decisions on the necessity of IRMs. Residential and recreational scenarios, though they do not reflect current land uses in the 100-FR-3 groundwater operable unit, are evaluated on the basis of agreements by the 100 Area Tri-Party Agreement unit managers. Ecological scenarios are evaluated using biological endpoints appropriate for the size and the nature of the operable unit. Land use recommended by the Hanford Future Site Uses Working Group (HFSUWG) for the 100 Area is unrestricted with four options (HFSUWG 1992): (1) Native American uses, (2) limited recreation and recreation-related commercial uses, (3) B Reactor as a museum/visitor center, and (4) wildlife and recreation.

This QRA for the 100-FR-3 groundwater operable unit is based primarily on the nature and extent of contaminated groundwater and the risk posed by discharge of this groundwater to the Columbia River. This QRA was conducted using the *Hanford Site Baseline Risk Assessment Methodology* (DOE-RL 1993) as guidance. Further, this QRA provides estimates of risk that might occur under

frequent-use (e.g., residential) or occasional-use (e.g., recreational) scenarios, as stipulated by agreements made by the 100 Area Tri-Party Agreement unit managers.

1.2 OPERABLE UNIT BACKGROUND

The 100-F Area at the Hanford Site was used by the U.S. Government to produce plutonium for nuclear weapons. These operations resulted in the release of chemical and radioactive wastes into the soil, air, and water. For cleanup purposes, the 100-F Area has been divided into three operable units, two of which are source operable units (100-FR-1 and 100-FR-2), while the third (100-FR-3) is the groundwater operable unit.

1.2.1 Location

The Hanford Site is a 1,434-km^2 (560-mi^2) tract of land located in Benton, Franklin, and Grant counties in the south-central portion of the state of Washington. The 100-F Area is situated in the north-central part of the Hanford Site along the southern shoreline of the Columbia River approximately 32 km (20 mi) northwest of the city of Richland, Washington, as shown in Figure 1-1. The 100-F Area is the closest of the old Hanford Site production reactor areas upstream from Richland, encompasses approximately 2.8 km^2 (1.1 mi^2), and lies predominantly within Section 33, the eastern portion of Section 32, and the southeastern portion of Section 29 of Township 14 North, Range 27 East of the Willamette Meridian. The 100-F Area lies between the north/south Hanford Plant coordinates N75500 and N82500, and the east/west coordinates W27600 and W33000. This area contains the facilities associated with operation of the F Reactor.

The 100-FR-3 groundwater operable unit includes the groundwater below the 100-F Area source operable units plus the adjacent groundwater, saturated soils, surface water, and aquatic biota impacted by 100-F Area operations. The 100-F Area source operable units are being addressed in separate QRAs. This QRA only addresses the 100-FR-3 groundwater operable unit. Figure 1-2 shows the approximate boundaries of the 100-FR-3 groundwater operable unit.

1.2.2 History of Operations

The F Reactor was constructed from 1943 to 1945 and operated from 1945 to 1965. Most of the facilities associated with the F Reactor were also retired in 1965. Biological research was conducted between 1945 and 1976 to study the effects of ionizing radiation on plants and animals. Decontamination and decommissioning activities are ongoing at the 100-F Area. Final disposition of structures is addressed by the surplus facilities program and is not part of the remedial investigation/ feasibility study.

1.3 PROCESS OVERVIEW

This QRA was performed in accordance with guidance provided in DOE-RL (1993). The QRA process is composed of the following elements: data evaluation, human health evaluation, and ecological evaluation. Implicit in these elements is a discussion of uncertainty in the evaluations.

The data evaluation process begins with a review of the list of detected analytes obtained from LFI sampling activities. These data are subjected to several validation procedures to determine the list of contaminants to be included in the human health and ecological evaluations. The maximum representative concentration for the retained constituents is provided to the risk assessors.

The human health evaluation consists of exposure assessment, toxicity assessment, and characterization of risk for the two exposure scenarios agreed on for the site. The ecological evaluation is conducted in three phases: problem formulation, analysis, and risk characterization.

Uncertainty in a QRA is introduced at all stages of the process. The human health risks presented in this QRA are based on multiple assumptions about exposures, toxicity, and other variables. The ecological evaluation includes assumptions about populations and uptake of contaminants that incorporate many variables. Both the human health and ecological evaluations are based on data values that have a measure of uncertainty associated with them. The net result of the assessments is that this QRA produces an upper bound for both human health and ecological risk for the 100-FR-3 groundwater operable unit.

Figure 1-1. The Hanford Site.

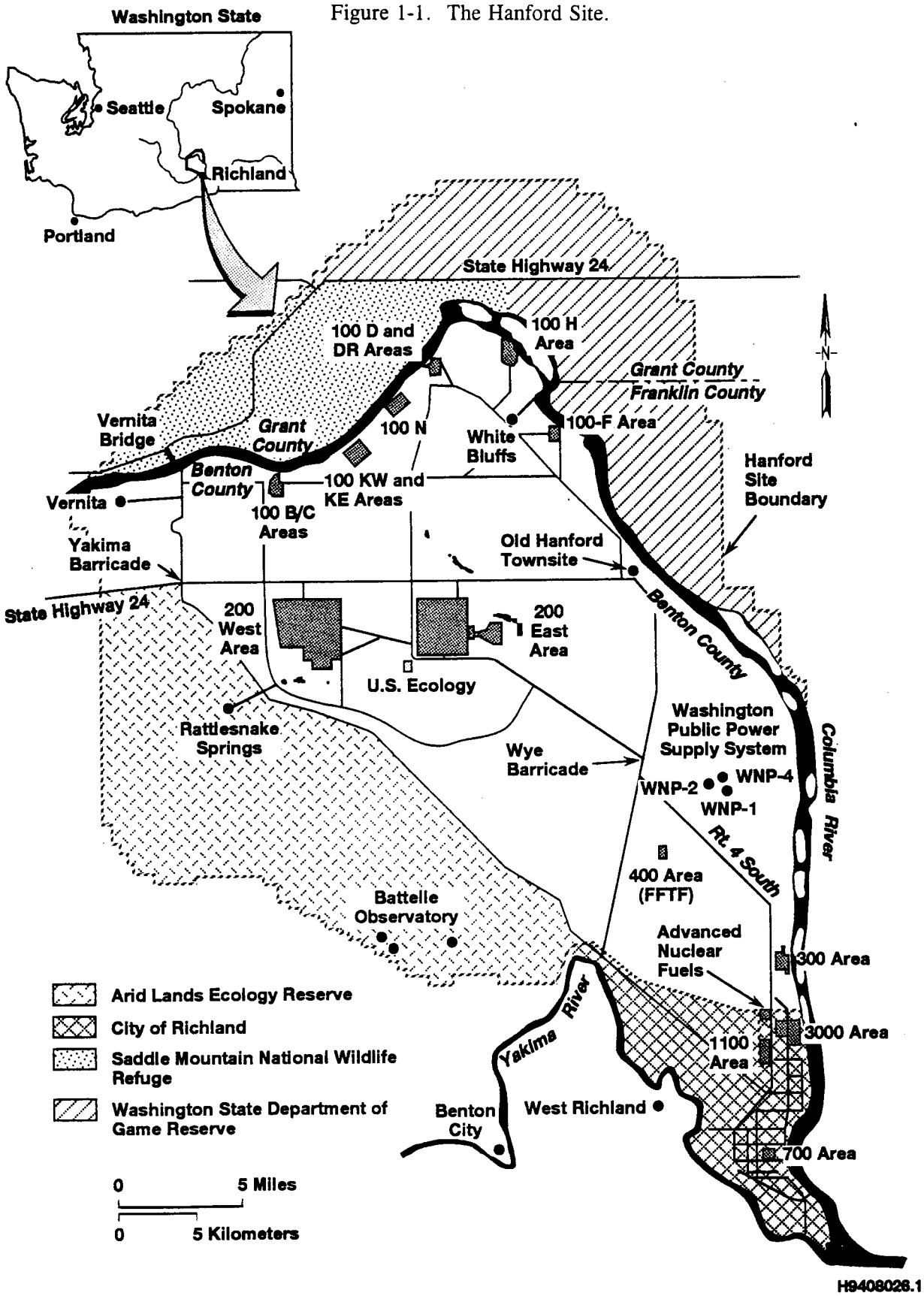
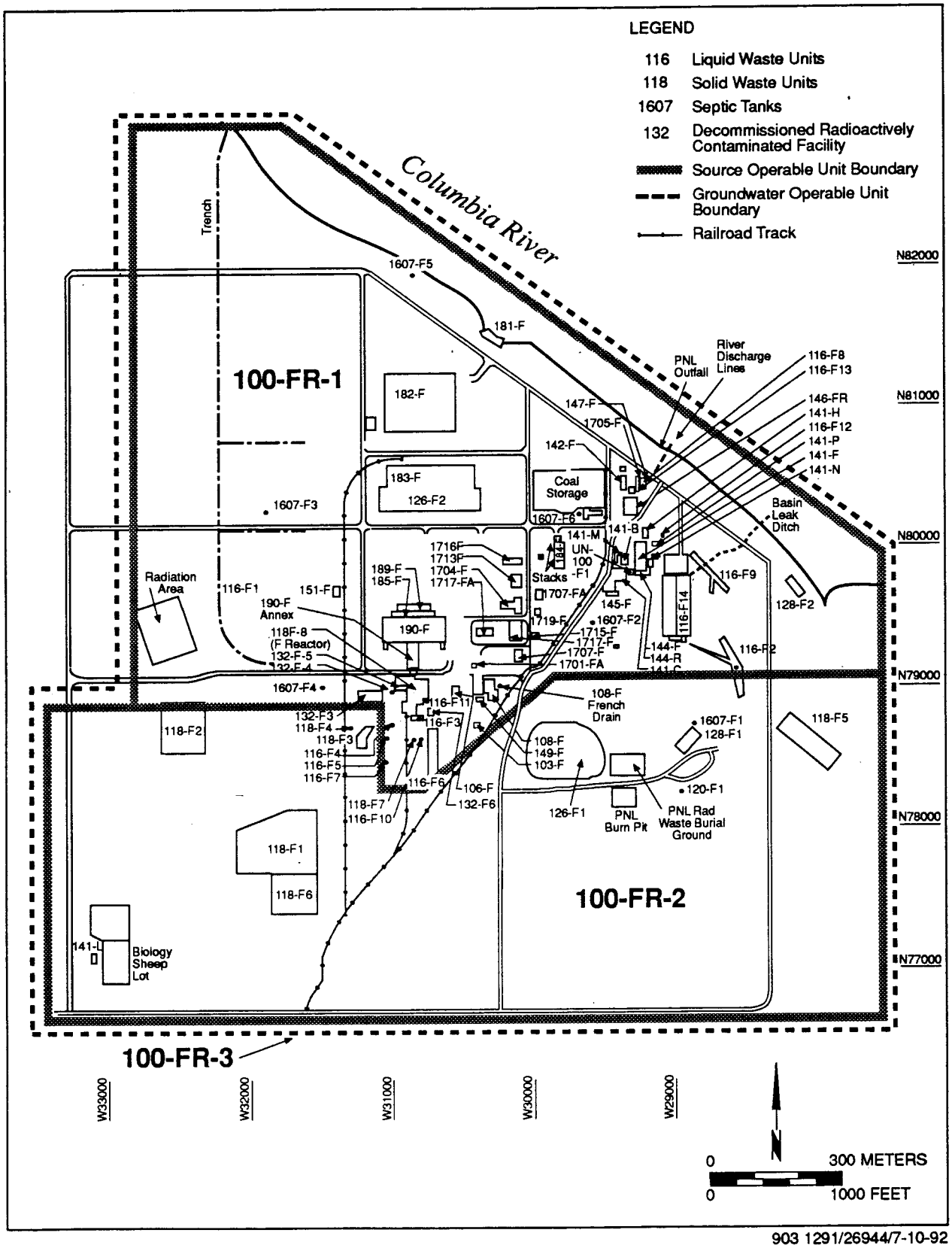


Figure 1-2. 100-F Area Operable Unit Boundaries.



2.0 DATA EVALUATION

This chapter describes the process of selecting the data to be used in the human health and ecological evaluations. The raw data sources are identified, and the screening procedures used to refine the data are presented. A summary of the results of the data evaluation is provided, and the uncertainty in the data is discussed.

2.1 DATA SOURCES

An overview of the general sources of information consulted to prepare this QRA is discussed in this section. Four data sets were developed, and a set of background data was used in the screening process. The data sets used are two sets of LFI data, 100-F Area spring-water data, and Columbia River water data. A more comprehensive discussion of data sources is provided in the LFI report for this operable unit.

2.1.1 Limited Field Investigation Data

An LFI was completed in accordance with the work plan (DOE-RL 1992a) and the *Description of Work for the 100-FR-3 Groundwater Operable Unit* (Roberts 1992a) to provide additional information and characterization needed to support selection, design, and implementation of IRMs. Monitoring wells were installed during the LFI to define groundwater quality in areas of potential exposure (e.g., near seeps and springs along the Columbia River shoreline that are downgradient of contamination sources), to define groundwater quality immediately downgradient of 100-F Area waste sites, and to identify potential sources of groundwater contamination. A survey and inspection of existing wells were conducted to evaluate their "fitness-for-use" for environmental monitoring (*Summaries of Well Construction Data and Field Observations for Existing 100 Aggregate Area Operable Unit Resource Protection Wells*; Ledgerwood 1991).

Figure 2-1 is a map showing the locations of the monitoring wells within the 100-F Area. Nineteen wells included in the LFI were used in evaluating the 100-FR-3 groundwater operable unit. They are: F1-2, F5-1, F5-3, F5-4, F5-6, F5-42, F5-43A, F5-44, F5-45, F5-46, F5-47, F5-48, F6-1, F7-1, F7-2, F7-3, F8-2, F8-3, and F8-4. All of these wells were used in developing the data set (Table 2-1) containing the overall site representative maximum values used in the human health evaluation. The well F5-43B was completed in the deep aquifer and was not used in the QRA.

A second data set was constructed from the LFI data for use in the ecological evaluation (Table 2-2). This data set is composed of the maximum representative concentration observed in the set of groundwater wells determined to be "near river." These are wells that are sufficiently close to the river to experience the influence of the river water. It was assumed that contaminants in these wells could be discharged to the Columbia River system, where they would be available to the aquatic foodweb. The interaction of the Columbia River and the groundwater at the 100-F Area is not fully known. A total of seven wells were classified as near-river: F1-2, F5-1, F5-6, F5-42, F5-43A, F5-44, and F6-1.

The data from three sampling rounds of the LFI were used in this QRA. The maximum representative contaminant concentrations were derived from the *Data Validation Reports for the 100-FR-3 Groundwater Operable Unit* (Roberts 1992b, 1992c; Vukelich 1992).

Sample results for the inorganic data include both filtered and unfiltered data. Only the unfiltered values were used in reporting the maximum representative concentration for inorganics. The data progression over the three sampling rounds was examined to determine whether the wells constructed for the LFI (see Figure 2-1) have reached equilibrium. If the unfiltered sample results for inorganic constituents declined by an order of magnitude in successive rounds, the higher data values from the well were not used in this QRA. Also, well equilibrium is judged by comparison of the filtered and unfiltered sample results. The filtered values should be comparable to the unfiltered values in an equilibrated well.

2.1.2 100-F Area Spring- and River-Water Data

Spring- and river-water samples were collected in the fall of 1991 (*Sampling and Analysis of 100 Area Springs*; DOE-RL 1992b) from the south and west banks of the Columbia River during a low-flow period of the river. The most upstream sample location was the intake structure at the 100-B/C Reactor, and the most downstream sample location was in the Hanford Townsite below the 100 Area boundary. The spring- and river-water samples were analyzed for chemical and radiological parameters (DOE-RL 1992b). Six of the springs sampled in this investigation are located at the 100-F Area. There are two springs located at the F Area. Four more springs, located within three miles downstream, were also used in determining the spring concentrations for the F Area. River-water samples were taken at the same approximate locations as the springs were found. Filtered and unfiltered samples were analyzed for the 100-F Area spring and river water, but only unfiltered samples were used in this QRA. These data are presented in Table 2-3 and are used for comparison purposes only, because they are from a single sampling round and it is not clear whether this snapshot in time is representative of the discharges.

2.1.3 Hanford Site Background Data

Naturally occurring inorganic material in groundwater at the Hanford Site was recently characterized (*Hanford Site Groundwater Background*; DOE-RL 1992c). The characterization effort identified the types of inorganic analytes that exist naturally in the groundwater within the unconfined aquifer and provided a reference concentration for each analyte. Provisional threshold levels for 40 inorganic analytes were developed to represent groundwater background concentrations at the Hanford Site. These site-wide data are used in this QRA to represent background for the 100-FR-3 groundwater operable unit, consistent with agreements made by Tri-Party Agreement unit managers (February 8, 1993).

There are no site-wide background concentrations that have been agreed on for organic analytes or for most radionuclide analytes. Detected levels of organic and radionuclide analytes in LFI data are assumed to be site-related contaminants and are not compared to background.

2.2 DATA EVALUATION SCREENING

The representative values detected in the groundwater well sampling were subjected to several screening procedures in accordance with the Contaminant Identification Process: Phase 1 presented in DOE-RL (1993, Figure 2-1A). The methodology directs the use of screening procedures as recommended in the *Risk Assessment Guidance for Superfund: Volume 1, Human Health Evaluation Manual* (EPA 1989). These data screening procedures include data validation, consistency checks, comparison to blank concentrations, comparison to background concentrations, elimination of non-toxic substances, and elimination of infrequently occurring analytes and risk-based screening. The following is a summary of the results of these procedures.

2.2.1 Data Validation

Samples from the LFI for the 100-FR-3 groundwater operable unit were analyzed for volatile, semivolatile, pesticide/polychlorinated biphenyls (PCBs), inorganic, radionuclide, and wet chemistry parameters according to Roberts (1992a) and DOE-RL (1992a). Laboratories performing the analysis were Weston Laboratory of Lionville, Pennsylvania, and TMA-Norcal Laboratory of Richmond, California.

The LFI data collected for non-radionuclides were analyzed using methods specified in *Quality Criteria for Water 1986* (EPA 1986b) with contract laboratory program (CLP) deliverables. Radiologic data were obtained by analyses performed using methods specified in WHC contact laboratory program deliverables. Based on the validation activities, data results were assigned qualifiers in accordance with criteria specified in *Data Validation Procedures for Chemical Analyses* (Bechtold 1992). Data that are termed "usable" (detected compounds or estimated "J" values) can be used in the QRA. Examples of data that are not considered usable are data that were rejected (qualified with an "R") by the data validator. However, if on review of the rejected data, the reason for rejection was due to administrative concerns (e.g., missing data sheets) and not because of other quality assurance/quality control (QA/QC) issues (e.g., technical concerns), the rejected data were used in this QRA.

2.2.2 Data Screening in the LFI

Several screening processes were applied to the data in the LFI evaluation. The results of these processes are presented in Appendix A of the LFI. These screening processes are:

- Elimination of inconsistent data
- Elimination of infrequently-occurring analytes
- Comparison to blank concentrations.

In addition, two more screens are applied in the LFI whose results are shown in Tables 2-1 and 2-2. These screens are:

- Comparison to background concentrations
- Elimination of nontoxic substances.

All LFI screening processes are described in Section 2.5.1 of the LFI.

2.2.3 Risk-Based Screening

Risk-based screening is only performed as part of the human health evaluation. Risk-based screening of constituents eliminates from the evaluation those analytes below risk levels defined in DOE-RL 1993, Figure 2-1. The objective of risk-based screening is to use risk and toxicity information to evaluate which constituents are most likely to contribute significantly to risk. The values used are a 1E-07 incremental cancer risk (ICR) for carcinogenic contaminants, and a 0.1 hazard quotient (HQ) for noncarcinogenic contaminants. These values are one order of magnitude more conservative than the levels below which risks are considered insignificant, 1E-06 ICR for carcinogens and 1.0 HQ for noncarcinogens. The exposure parameters for the frequent-use scenario are used for the risk-based screen. This involves the ingestion of 2 L/day of groundwater for 365 days.

The analytes are then compared to contaminant-specific potential applicable or relevant and appropriate requirements (ARARs) (federal and state ambient water quality criteria [AWQC]). If the contaminant-specific maximum concentration exceeds any potential ARAR value, the analyte is considered a contaminant of potential concern (COPC) and is retained for further evaluation. Any analytes that are eliminated in the risk-based screen may be retained for the ecological risk assessment based on professional judgment.

2.2.4 Screening Calculations

For carcinogenic nonradioactive contaminants, the general equation to calculate ingestion or inhalation risk-based screening concentrations is:

$$C = \frac{TR \times BW \times AT \times CF}{SF \times IR \times EF \times ED} \qquad 2\text{-}1$$

where:

C	=	risk-based benchmark concentration (mg/L for water, mg/m^3 for air)
TR	=	target risk (1E-07)
BW	=	body weight (kg)
AT	=	averaging time (365 d/yr x 70 yr)
CF	=	conversion factor (as appropriate)
SF	=	contaminant-specific slope factor (mg/kg-d)$^{-1}$
IR	=	intake rate (L/d for water, m^3/d for air)
EF	=	exposure frequency (d/yr)
ED	=	exposure duration (yr).

For noncarcinogenic effects, the general equation to calculate a risk-based screening concentration is:

$$C = \frac{THQ \times RfD \times BW \times AT \times CF}{IR \times EF \times ED} \qquad 2\text{-}2$$

where:

THQ	=	target hazard quotient (0.1)
RfD	=	contaminant-specific chronic reference dose (mg/kg-d)

For radioactive contaminants, the general equation to calculate a risk-based screening concentration is:

$$C = \frac{TR \times CF}{SF \times IR \times EF \times ED} \qquad 2\text{-}3$$

where:

C	=	risk-based benchmark concentration (pCi/L for water, pCi/m^3 for air)
SF	=	radionuclide-specific slope factor (pCi)$^{-1}$.

2.2.5 Results of the Risk-Based Screening

The risk-based screening calculations done for this QRA are given in Tables 2-4a through 2-4d. Table 2-4a presents the results for drinking water ingestion of volatile organics, Table 2-4b presents the results for inhalation of volatile organics, Table 2-4c presents the results of ingestion of inorganics, and Table 2-4d presents the results for ingestion of radionuclides. The tables also include the potential ARAR values used in the screening.

Any constituent whose risk-based concentration levels or potential ARAR values are exceeded by its representative measured concentration is shaded in the tables. These constituents are retained as COPC and carried through the risk assessment. Constituents that were eliminated through the risk-based screening are nickel, zinc, chloride, and sulfate.

2.3 SUMMARY OF CONTAMINANTS OF POTENTIAL CONCERN

The COPC that were carried forward into the ecological evaluation were shown in Table 2-2; those for the human health evaluation were shown in Table 2-4. No screening was performed for the data in Table 2-3 that are compared qualitatively to the results of both the human health and ecological evaluations in their respective chapters (Chapters 3.0 and 4.0, respectively).

2.4 DATA UNCERTAINTY

The major issues in data uncertainty for this QRA are confidence in the chosen concentrations and confidence in contaminant identification. The data used to conduct this QRA are LFI data from three rounds of sampling. These are CLP data and the confidence level is "high" for both concentration and contaminant identification. It is important to note that the data used in this QRA represent a snapshot of the concentrations at a given time. This snapshot is not likely to fully characterize the groundwater under the 100-F Area. Water concentrations will vary over time in a way that cannot be predicted without modeling. The existing radioactive constituents will decay with time but the sources in the 100-F Area will continue to contribute to the constituent concentrations.

The effect of the river on the groundwater in the 100-F Area is not fully known. The determination of the near-river well concentrations depends on a somewhat arbitrary partition of the wells into near-river and not near-river groups.

The distribution of contaminants in the groundwater varies with location within the 100-FR-3 groundwater operable unit. The maximum representative concentrations of the COPC occur in several different wells. This QRA assumes that the maximum representative concentrations of COPC are associated with DOE activities at the operable unit but makes no attempt to associate specific sources of contamination with each of the COPC. In addition, there is also uncertainty pertaining to the effects of upgradient sources on the 100-FR-3 groundwater.

The uncertainty in the identification of contaminants present in the groundwater is low. The LFI data available to identify contaminants in the groundwater are of known quality, are analyzed using EPA methods, and are validated prior to use, though the degree of result acceptance is less rigorous than for a regular baseline risk assessment. For instance, all J (estimated) values are used, and R (rejected) values are used when they are rejected because of missing calibration sheets.

There is uncertainty associated with the identification arsenic as COPC. Arsenic was not used in Hanford Site processes. Therefore, the risks associated with arsenic are likely related to background.

Uncertainty is also associated with using the lower of two concentrations from analysis of duplicate samples in the assessment of human health and ecological risk. Duplicate and split samples are taken as an audit on the analytical laboratory(ies) performing the sample analyses and are not part of the data set obtained for performance of risk assessments. However, the existence of variant duplicate or split sample analyses points out that exposure point concentrations can be underestimated or overestimated.

Figure 2-1. Identification of Groundwater Well Locations.

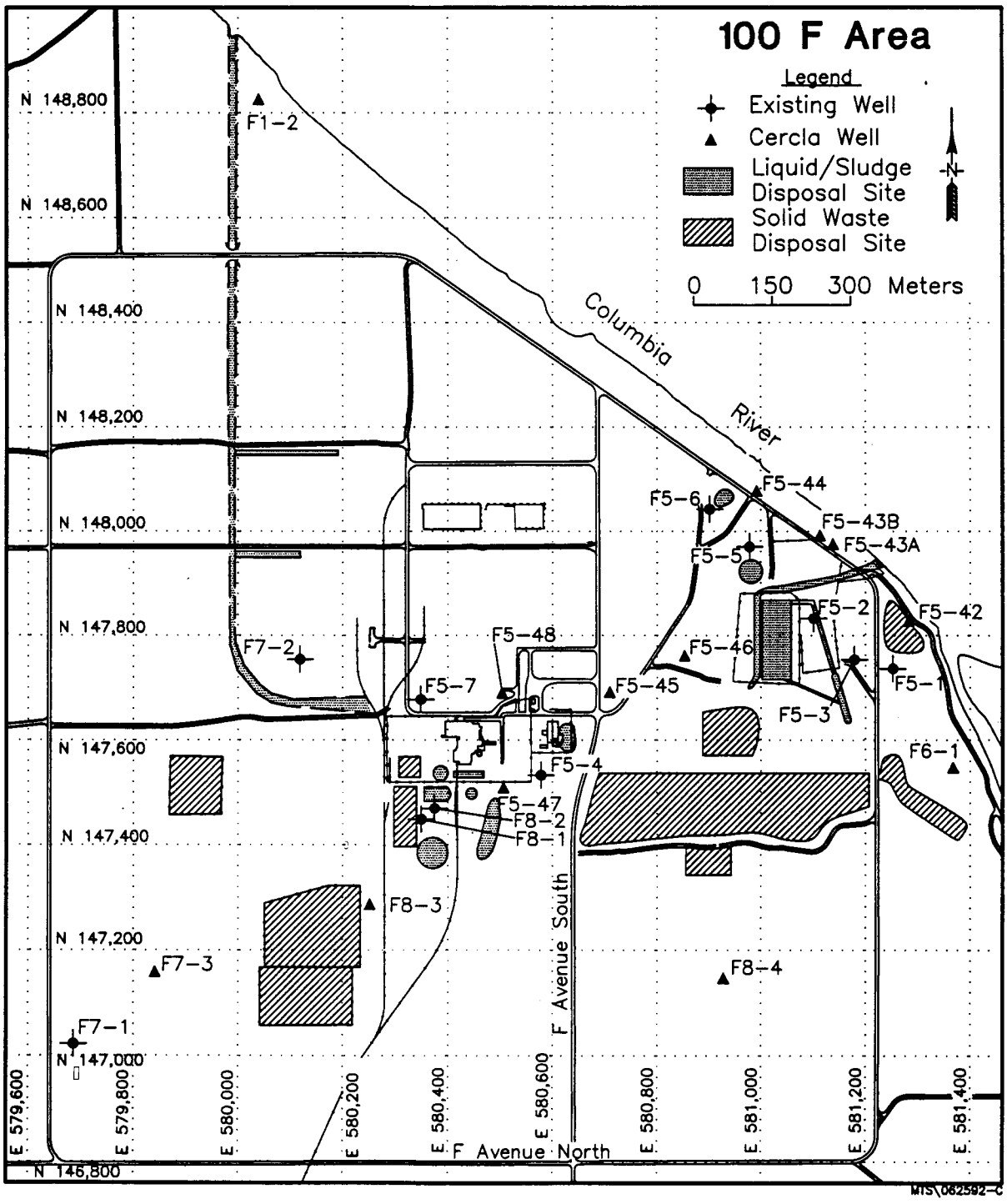


Table 2-1. Summary of Detected Analytes: 100-FR-3
All Groundwater Wells - Human Health Evaluation
(2 Sheets)

Analyte	Maximum Representative Concentration		# of Detects[1]	Data Range	Back-ground[2]	Analyte Status
Volatile Organics (All concentrations in μg/L)						
Chloroform	10		15/63	1-10	NA	Retained
Trichloroethene	28		26/63	1-28	NA	Retained
Inorganics (All concentrations in μg/L)						
Aluminum	80.6	B	37/57	22.5-80.6	<200	Eliminated: Nutrient
Arsenic	11.7		30/63	1.8-11.7	10	Retained
Barium	127	B	63/63	14.8-127	68.5	Retained
Calcium	144000		63/63	20300-144000	63600	Eliminated: Nutrient
Chromium	303		53/63	3.5-303	<30	Retained
Copper	14.7	B	22/63	2.4-14.7	<30	Retained
Iron	78.6	B	56/57	3.9-78.6	86	Eliminated: Nutrient
Lead	3.6	N,J	45/63	1.1-3.6	<5	Retained
Magnesium	36900		63/63	3650-36900	16480	Eliminated: Nutrient
Manganese	96.6		48/63	1.1-96.6	24.5	Retained
Nickel	19.8	B	20/63	3.1-19.8	<30	Retained
Potassium	8410		63/63	1300-8410	7975	Eliminated: Nutrient
Selenium	5.2	S,*	9/63	3.6-5.2	<5	Retained
Sodium	77500		63/63	2380-77500	33500	Eliminated: Nutrient
Vanadium	19.5	B	43/63	2.5-19.5	15	Retained
Zinc	33.4		34/63	4.2-33.4	<50	Retained
Radionuclides (All concentrations in pCi/L)						
Carbon-14	460		11/63	2.5-460	NA	Retained
Strontium-90	250		23/63	1.0-250	NA	Retained
Tritium	180000		51/63	200-180000	NA	Retained

Table 2-1. Summary of Detected Analytes: 100-FR-3
All Groundwater Wells - Human Health Evaluation
(2 Sheets)

Analyte	Maximum Representative Concentration		# of Detects[1]	Data Range	Back-ground[2]	Analyte Status
Radionuclides (Contd.)						
Uranium-233/234	10.0		62/63	0.17-10.0	3.43	Retained
Uranium-235	0.53		38/63	0.026-0.53		Retained
Uranium-238	10.0		61/63	0.11-10.0		Retained
Wet Chemistry and Anions (All concentrations in mg/L, except pH)						
Alkalinity	513		62/62	66-513	210	Retained
Ammonia Nitrogen	0.13		7/61	0.05-0.13	NA	Retained
Chloride	35.9		63/63	1.0-35.9	8.69	Retained
Fluoride	0.9		59/63	0.1-0.9	0.8	Retained
Nitrate/Nitrite	32.4		60/63	0.32-32.4	12.4	Retained
pH (Std. units)	7.2-8.3		63/63	7.2-8.3	7.2-8.3	Eliminated: Background
Sulfate	106		62/63	10-106	90.5	Retained
Total Dissolved Solids	792		62/62	94-792	NA	Retained

[1] = Number of detects based on three rounds of data.
[2] = < Number indicates that the analyte was not detected at the given detection level.
B = Value below the contract-required detection limit.
N = Spiked sample recovery not within control limits.
J = Estimated value.
S = Determined by the method of standard additions.
* = Duplicate analysis not within control limits.
NA = No data available.

Table 2-2. Summary of Detected Analytes: 100-FR-3 Near-River Groundwater Wells - Ecological Evaluation (2 Sheets)

Analyte	Maximum Representative Concentration		# of Detects[1]	Data Range	Back-ground[2]	Analyte Status
Volatile Organics (All concentrations in µg/L)						
Chloroform	2	J	3/21	2-2	NA	Retained
Inorganics (All concentrations in µg/L)						
Aluminum	80.6	B	14/21	28-80.6	<200	Retained
Arsenic	11.7		6/21	1.8-11.7	10	Retained
Barium	43.9	B	21/21	16.4-43.9	68.5	Eliminated: Background
Calcium	44400		21/21	20300-44400	63600	Eliminated: Background
Chromium	32.7		19/21	3.8-32.7	<30	Retained
Copper	14.7	B	12/21	2.4-14.7	<30	Retained
Iron	56.2	B	21/21	3.9-56.2	86	Eliminated: Background
Lead	3.4		15/21	1.3-3.4	<5	Retained
Magnesium	11700		21/21	3650-11700	16480	Eliminated: Background
Manganese	44.5		20/21	1.1-44.5	24.5	Retained
Nickel	19.8	B	6/21	3.3-19.8	<30	Retained
Potassium	4630	B	21/21	1300-4630	7975	Eliminated: Background
Sodium	48400		21/21	2380-48400	33500	Eliminated: Eco-nutrient
Vanadium	19.5	B	7/21	2.5-19.5	15	Retained
Zinc	33.4		14/21	4.4-33.4	<50	Retained
Radionuclides (All concentrations in pCi/L)						
Strontium-90	26		14/21	1.1-26	NA	Retained
Tritium	1200		8/21	200-1200	NA	Retained

Table 2-2. Summary of Detected Analytes: 100-FR-3
Near-River Groundwater Wells - Ecological Evaluation
(2 Sheets)

Analyte	Maximum Representative Concentration		# of Detects[1]	Data Range	Back-ground[2]	Analyte Status
Radionuclides (Contd.)						
Uranium-233/234	2.2		21/21	0.17-2.2	3.43	Retained
Uranium-235	0.29		4/21	0.14-0.29		Retained
Uranium-238	1.9		19/21	0.16-1.9		Retained
Wet Chemistry and Anions (All concentrations in mg/L, except pH)						
Alkalinity	163		21/21	66-163	210	Eliminated: Background
Ammonia Nitrogen	0.13		2/21	0.07-0.13	NA	Retained
Chloride	10.7		21/21	1.0-10.7	8.69	Retained
Fluoride	0.8		20/21	0.1-0.8	0.8	Eliminated: Background
Nitrate/Nitrite	5.03		19/21	0.32-5.03	12.4	Eliminated: Background
pH (std. units)	7.4-8.3		21/21	7.4-8.3	7.2-8.3	Eliminated: Background
Sulfate	53		21/21	10-53	90.5	Eliminated: Background
Total Dissolved Solids	311		21/21	94-311	NA	Retained

1 = Number of detects based on three rounds of data.
2 = < Number indicates that the analyte was not detected at the given detection level.
J = Estimated value.
B = Value below the contract- required detection limit.
NA = No data available.

Table 2-3. Summary of Detected Analytes: 100-FR-3
100-F Area Spring and Columbia River Water

Analyte	Maximum Representative Spring Concentration	Maximum Representative River Concentration
Volatile Organics (All concentrations in µg/L)		
Chloroform	NA	NA
Inorganics (All concentrations in µg/L)		
Aluminum	334	36 B
Arsenic	NA	NA
Chromium	9.6 B	ND
Copper	ND	ND
Lead	NA	NA
Manganese	45	9.5 B
Nickel	ND	5.5 B
Vanadium	5 B	2 B
Zinc	18 B	13.6 B
Radionuclides (All concentrations in pCi/L)		
Strontium-90	46	ND
Tritium	590	110
Total Uranium	2.6	0.46
Wet Chemistry (All concentrations in mg/L)		
Ammonia	ND	ND
Chloride	9.8 J	1.02 J
Total Dissolved Solids	232	94

ND = Not detected.
NA = No data available.
B = Value below the contract-required detection limit.
J = Estimated value.

Table 2-4a. Human Health Risk-Based Screening Calculations for Drinking Water Ingestion of Organics: 100-FR-3

Analyte	Maximum Concentration (mg/L)	Oral RfD (mg/kg-d)	Conc. at HQ=0.1 (mg/L)	Oral SF 1/(mg/kg-d)	Conc at R=e-7 (mg/L)	Drinking Water Standards		WA State	EPA Water Quality Criteria	
						MCL (mg/L)	MCLG (mg/L)	CFWQC (mg/L)	HWQHC (mg/L)	HWQWC (mg/L)
Chloroform	1.00E-02	1.00E-02	1.60E-02	6.10E-03	1.34E-03	1.00E-01	NA	1.24E+00	1.90E-04	NA
Trichloroethene	2.80E-02	6.00E-03	9.60E-03	1.10E-02	7.42E-04	5.00E-03	0.00	2.20E+01	NA	NA

NA - No data available
Note: Shading indicates contaminant concentrations exceed concentration at target risk or exceed an ARAR.

Table 2-4b. Human Health Risk-Based Screening Calculations for Inhalation of Volatile Organics: 100-FR-3

Analyte	Maximum Concentration (mg/L)	Inhalation RfD (mg/kg/-d)	Conc. at HQ=0.1 (mg/L)	Inhalation SF 1/(mg/kg-d)	Conc. at R=e-7 (mg/L)
Chloroform	100E-02	NA	--	8.10E-02	2.69E-05
Trichloroethene	2.80E-02	NA	--	6.00E-03	3.63E-04

NA - No data available.
Note: Shading indicates contaminant concentrations exceed concentration at target risk or exceed an ARAR.

Table 2-4c. Human Health Risk-Based Screening Calculations for Ingestion of Inorganics: 100-FR-3

Analyte	Maximum Concentration (mg/L)	Oral RfD (mg/kg-d)	Conc. at HQ=0.1 (mg/L)	Oral SF 1/ (mg/kg-d)	Conc. at R=e-7 (mg/L)	Drinking Water Standards		WA State	EPA Water Quality Criteria	
						MCL (mg/L)	MCLG (mg/L)	CFWQC (mg/L)	HWQHC (mg/L)	HWQWC (mg/L)
Arsenic	1.17E-02	3.00E-04	4.80E-04	1.70E+00	4.80E-06	5.00E-02	NA	4.80E-02	NA	NA
Barium	1.27E-01	7.00E-02	1.12E-01	NA	--	2.00E+00	2.00E+00	NA	1.00E+00	NA
Chromium	3.03E-01	5.00E-03	8.00E-03	NA	--	1.00E-01	1.00E-01	1.10E-02	5.00E-02	NA
Copper	1.47E-02	4.00E-02	6.40E-02	NA	--	1.30E+00	NA	7.00E-03	NA	NA
Lead	3.60E-03	NA	--	NA	--	1.50E-02	0.00	1.20E-03	5.00E-02	NA
Manganese	9.66E-02	5.00E-03	8.00E-03	NA	--	5.00E-02	NA	NA	1.00E-01	5.00E-02
Nickel	1.98E-02	2.00E-02	3.20E-02	NA	--	1.00E-01	1.00E-01	1.00E-01	NA	NA
Selenium	5.20E-03	5.00E-03	8.00E-03	NA		5.00E-02	5.00E-02	5.00E-03	1.00E-02	NA
Vanadium	1.95E-02	7.00E-03	1.12E-02	NA	--	NA	NA	NA	NA	NA
Zinc	3.34E-02	3.00E-01	4.80E-01	NA	--	5.00E+00	NA	6.30E-02	NA	5.00E+00
Alkalinity	5.13E+02	NA	--	NA	--	NA	NA	NA	NA	NA
Ammonia Nitrogen	1.30E-01	3.40E+01	5.44E+01	NA	--	1.21E+01	NA	2.40E-02	NA	NA
Chloride	3.59E+01	NA	--	NA	--	2.50E+02	NA	2.30E+02	NA	NA
Fluoride	9.00E-01	6.00E-02	9.60E-02	NA	--	4.00E+00	4.00E+00	NA	NA	NA
Nitrate/Nitrite	3.24E+01	1.60E+00	2.56E+00	NA	--	1.00E+01	1.00E+01	NA	1.00E+01	NA
Sulfate	1.06E+02	NA	--	NA	--	2.50E+02	NA	NA	NA	NA
Total Dissolved Solids	7.92E+02	NA	--	NA	--	5.00E+02	NA	NA	NA	NA

NA - No data available.
Note: Shading indicates contaminant concentrations exceed concentration at target risk or exceed an ARAR.

Table 2-4d. Human Health Risk-Based Screening Calculations for Ingestion of Radionuclides: 100-FR-3

Analyte	Maximum Concentration (pCi/L)	Oral SF 1/pCi	Conc at risk 1.0E-7	40 CFR 141 MCL (pCi/L)	10 CFR 20 NRC (pCi/L)
Carbon-14	4.60E+02	9.00E-13	5.07E+00	2.00E+03	8.00E+05
Strontium-90	2.50E+02	3.60E-11	1.27E-01	8.00E+00	3.00E+02
Tritium	1.80E+05	5.40E-14	8.46E+01	2.00E+04	3.00E+06
Uranium-233/234	1.00E+01	1.60E-11	2.85E-01	NA	3.00E+04
Uranium-235	5.30E-01	1.60E-11	2.85E-01	NA	3.00E+04
Uranium-238	1.00E+01	2.80E-11	1.63E-01	NA	4.00E+04

NA - No data available.
Note: Shading indicates contaminant concentrations exceed concentration at target risk or exceed an ARAR.

3.0 HUMAN HEALTH EVALUATION

The human health evaluation for the 100-FR-3 groundwater operable unit is presented in this chapter. The human health evaluation consists of calculating exposure, presenting toxicity data, and characterizing risk.

3.1 EXPOSURE ASSESSMENT

Included in the exposure assessment are the determination of exposure scenarios, exposure pathways, exposure parameters, exposure point concentrations, and quantification of exposures. The methodology for exposure assessment was presented in Section 2.2 and the methodology for risk assessment was given in DOE-RL (1993, Appendices A and C).

3.1.1 Groundwater-Use Scenarios and Parameters

The pathways and scenarios used in the 100-FR-3 groundwater operable unit QRA are those discussed and selected by the 100 Area Tri-Party Agreement unit managers (February 8, 1993). The exposure pathways selected for analysis are ingestion of groundwater and inhalation of volatile contaminants during groundwater use.

Two scenarios were selected to provide a bounding estimate of potential risk: frequent use and occasional use. There are no frequent or occasional users of groundwater at the 100-FR-3 groundwater operable unit, so the risks presented in this QRA are not actual risks but estimates of potential risks under frequent and occasional groundwater usage. The occasional-use scenario may approximate a trespasser scenario, the only scenario under which current groundwater use could occur. There is no industrial use of groundwater in the 100-F Area.

The exposure parameters include the intake rate of contaminated groundwater, frequency and duration of exposure, body weight, and averaging time. A summary of the parameters used for this QRA are presented in Tables 3-1a (occasional use) and 3-1b (frequent use). As recommended by the Model Toxics Control Act Cleanup Regulations (MTCACR), the reasonable maximum exposure (RME) for noncarcinogens is to a child, and the RME for carcinogens is to an adult. The exposure point concentrations used for this QRA are the maximum representative concentrations for all groundwater wells for those contaminants retained in the initial data evaluation.

3.1.2 Exposure Quantification

The quantification of exposures involves estimating the intake of contaminants using the parameters for the scenarios and pathways described above. The basic equation for calculating intakes of nonradioactive contaminants via groundwater ingestion or inhalation of volatile organic compounds from groundwater use is:

$$\text{Intake} = \frac{C \times IR \times CF \times EF \times ED}{BW \times AT} \qquad 3\text{-}1$$

where:

Intake	=	chronic daily intake of the contaminant (mg/kg-d)
C	=	contaminant concentration (mg/L)
IR	=	intake rate (L/d for water or m^3/d for air)
CF	=	conversion factor (L/m^3 for inhalation exposures)
EF	=	exposure frequency (d/yr)
ED	=	exposure duration (yr)
BW	=	body weight (kg)
AT	=	averaging time (yr x 365 d/yr).

The quantification of exposures to radioactive contaminants requires a separate treatment because the units used to express environmental concentrations of radioactive and nonradioactive contaminants are different. In addition, intake estimates for radionuclides should not be divided by body weight or averaging time. Instead, the calculated intakes for radioactive contaminants represent radionuclide activities that are inhaled or ingested over a lifetime.

The basic equation for calculating intakes of radioactive contaminants via groundwater ingestion is:

$$\text{Intake} = C \times IR \times EF \times ED \qquad 3\text{-}2$$

where:

Intake	=	radionuclide-specific lifetime intake (pCi)
C	=	radionuclide concentration (pCi/L for water, pCi/m^3 for air).

3.2 TOXICITY ASSESSMENT

The general procedures for toxicity assessment are presented by DOE-RL (1993, Section 2.3). The toxicity assessment for this QRA identifies contaminant-specific toxicity factors and briefly discusses the key toxicities associated with contaminants identified in the data evaluation process. The intent is to include sufficient toxicity information to assist project managers in reaching decisions on IRMs but not to evaluate all potential toxicities.

The toxicity information for carcinogenic contaminants is the slope factor (SF), an estimate of chemical-specific risk per unit dose. The toxicity information for the noncarcinogenic contaminants is the reference dose (RfD), the chemical-specific provisional reference dose for toxicity from chronic inhalation and oral exposure. A limited number of contaminants have sufficient data to have established toxicity values. However, there are uncertainties associated with the toxicity values as outlined in DOE-RL (1993).

The toxicity values and supporting information for both noncarcinogenic and carcinogenic substances carried through the risk assessment are included in the risk-based screening calculation tables (see Tables 2.4a through 2.4d). A brief discussion of the primary toxic effects for each COPC is provided in Appendix A.

3.3 RISK CHARACTERIZATION

The risk characterization for the human health evaluation is conducted in accordance with DOE-RL (1993, Section 2.4), based on the information from the data evaluation, the exposure assessment, and the toxicity assessment. It forms the basis for characterizing risks and human health hazards from potential exposures to COPC detected at the 100-FR-3 groundwater operable unit.

The risk characterization process is divided into discussions of carcinogenic and noncarcinogenic calculations. The distinction is made because the methodology differs for these two modes of chemical toxicity. In both modes, the calculated intakes and toxicity information are combined to quantify the potential for human health effects.

For a carcinogenic contaminant, the projected intake is multiplied by the contaminant-specific SF to estimate the incremental probability of an individual developing cancer over a lifetime above the background cancer rate in the general population as a result of exposure to that carcinogen. This risk is called the lifetime ICR. Calculated ICRs are compared to an ICR of 1E-06. For noncarcinogenic contaminants, potential human health hazards are estimated through a contaminant-specific quantity known as HQ, which is the intake divided by the contaminant-specific chronic RfD. Calculated HQs are compared to an HQ of unity.

3.3.1 Human Health Risk Calculations

Human health risk is quantified for noncarcinogens by the HQ. The basic equation for determining the HQ for the ingestion and inhalation exposure pathways is:

$$HQ = I/RfD \qquad 3\text{-}3$$

where:

HQ	=	hazard quotient (unitless)
I	=	intake (mg/kg-d)
RfD	=	contaminant-specific chronic reference dose (mg/kg-d).

The basic equation for determining the ICR for the ingestion and inhalation pathways is:

$$ICR = I \times SF \qquad 3\text{-}4$$

where:

ICR	=	lifetime incremental cancer risk (unitless)
I	=	intake (mg/kg-d or pCi for nonradioactive and radioactive constituents, respectively)
SF	=	chemical-specific slope factor ([mg/kg-d])$^{-1}$ or [pCi]$^{-1}$ for nonradioactive and radioactive constituents, respectively).

3.3.2 Results of Risk Characterization

The calculations performed for risk characterization were separated into contaminant class, carcinogenic and noncarcinogenic contaminants, and ingestion and inhalation (for volatile organics only). These risk calculations are shown in Tables 3-2a through 3-2f. For the noncarcinogens, the HQs are summed to produce a total hazard index (HI) for each contaminant class and exposure pathway combination. For the carcinogens, the ICRs are summed to produce a total ICR for radionuclides and nonradionuclides separately for each exposure pathway. All ICRs exceeding 1E-06 and all HQs or HIs exceeding unity are shown in shaded boxes in the tables.

Calculations for the organic contaminants are presented in Tables 3-2a, 3-2b, and 3-2c. As presented in Table 3-2a, there are no adverse noncarcinogenic effects for ingestion of organics at the maximum representative concentrations. All observed HQs are well below unity. As presented in Tables 3-2b and 3-2c, there is significant carcinogenic risk associated with both ingestion and inhalation of organics at the maximum representative concentrations. Table 3-2b indicates that, under the frequent-use scenario, the risk estimate for ingestion of trichloroethene exceeds 1E-06. This is not the case for the occasional-use scenario. Table 3-2c shows that both chloroform and trichloroethene exceed 1E-06 for the frequent-use inhalation pathway. Inhalation is not an exposure pathway for the occasional-use scenario, so no risks are estimated.

The results for inorganic contaminants are presented in Tables 3-2d and 3-2e. Table 3-2d contains estimates of the noncarcinogenic HQs for inorganic contaminants. Four contaminants (arsenic, chromium, manganese, and nitrate/nitrite) show HQs in excess of 1.0 for the frequent-use scenario. None of these contaminants has an HQ greater than unity under the occasional-use scenario. The carcinogenic risk from inorganic contaminants is presented in Table 3-2e. It can be seen that arsenic exceeds the 1E-06 HQ for both the frequent- and occasional-use scenarios.

The risk from radioactive contaminants is presented in Table 3-2f. Five radionuclides have an estimated risk in excess of 1E-06 for the frequent-use scenario (carbon-14, strontium-90, tritium, uranium-233/234, and uranium-238). Only tritium and strontium-90 have ICRs in excess of 1E-06 for the occasional-use scenario.

3.4 UNCERTAINTY IN EXPOSURE AND TOXICITY ASSESSMENT

Two scenarios have been evaluated to provide estimates of hazard or risk based on the frequent-use exposure (e.g., drinking water ingestion) or occasional use (e.g., recreational water ingestion). Neither of these scenarios currently occurs in the 100-F Area. This QRA is based on a potential

exposure to the maximum representative concentration, assuming that it will not increase or decrease over the 30-year assumed lifetime for the exposure calculation. Therefore, there is uncertainty in the risk results because the use of a maximum representative concentration may not be indicative of the actual concentration over time.

The risk characterization focuses on only the ingestion of water and the inhalation of volatile organic compounds from groundwater use. Exposure through other pathways, such as external exposure from submersion in radionuclide-contaminated waste, may result in additional risk, though it is not known if the additional risk would be significant. In general, for most inorganics and radionuclides, exposure through the ingestion route is greater than for other routes of exposure to contaminants in water.

Intake and risk as the result of inhalation of volatile organics are calculated for the drinking water ingestion scenario only. These exposures assume inhalation of volatile organics from water use within a residence. Recreational ingestion of volatile organics could occur during recreational use of groundwater; factors needed to evaluate such exposures have not been developed. However, given the lower frequency of recreational exposures, the potential risks for receptors from inhalation of volatile organics would be at least an order of magnitude less than the risks estimated for residential receptors because of the difference in exposure durations for the two scenarios.

Despite the uncertainties in the various steps of the risk assessment, the effect of the assumptions provides a conservative estimate of risk.

Table 3-1a. Exposure Factors for the Occasional Use Scenario: 100-FR-3[1]

	Route	Daily Intake Rate	Exposure Frequency (d/yr)	Exposure Duration (yr)	Body Weight (kg)	Averaging Time (yr x d/yr)	Conversion Factors
Noncarcinogens	Ingestion	1 L	7	6	16	6 x 365	--
Nonradioactive Carcinogens	Ingestion	2 L	7	30	70	70 x 365	--
Radioactive Carcinogens	Ingestion	2 L	7	30	--	--	--

[1]From DOE-RL (1993).

Table 3-1b. Exposure Factors for the Frequent Use Scenario: 100-FR-3[1]

	Route	Daily Intake Rate	Exposure Frequency (d/yr)	Exposure Duration (yr)	Body Weight (kg)	Averaging Time (yr x d/yr)	Conversion Factors
Noncarcinogens	Ingestion	1 L	365	6	16	6 x 365	--
	Inhalation	15 m3	365	30	70	30 x 365	0.5 L/m3
Nonradioactive Carcinogens	Ingestion	2 L	365	30	70	70 x 365	--
	Inhalation	15 m3	365	30	70	70 x 365	0.5 L/m3
Radioactive Carcinogens	Ingestion	2 L	365	30	--	--	--

[1]From DOE-RL (1993).

Table 3-2a. Human Health Risk Calculations for Noncarcinogenic Effects of Ingestion of Organics: FR-3

Analyte	Maximum Concentration (mg/L)	Oral RfD (mg/kg-d)	Occasional		Frequent	
			Daily Intake (mg/kg-d)	Hazard Quotient	Daily Intake (mg/kg-d)	Hazard Quotient
Chloroform	0.01	1.00E-02	1.20E-05	0.001	6.25E-04	0.1
Trichloroethene	0.028	6.00E-03	3.36E-05	0.006	1.75E-03	0.3
Total HI from ingestion of organics.				0.007		0.4

Table 3-2b. Human Health Risk Calculations for Carcinogenic Effects of Ingestion of Organics: 100-FR-3

Analyte	Maximum Concentration (mg/L)	Oral SF 1/(mg/kg-d)	Occasional		Frequent	
			Daily Intake (mg/kg-d)	Lifetime ICR	Daily Intake (mg/kg-d)	Lifetime ICR
Chloroform	1.00E-02	6.10E-03	2.35E-06	1.43E-08	1.22E-04	7E-07
Trichloroethene	2.80E-02	1.10E-02	6.58E-06	7.23E-08	3.43E-04	4E-06
Total risk from ingestion of organics.				8.67E-08		5E-06

Table 3-2c. Human Health Risk Calculations for Carcinogenic Effects of Inhalation of Organics: 100-FR-3

Analyte	Maximum Concentration (mg/L)	Inhalation SF 1/(mg/kg-d)	Occasional		Frequent	
			Daily Intake (mg/kg-d)	Lifetime ICR	Daily Intake (mg/kg-d)	Lifetime ICR
Chloroform	1.00E-02	8.10E-02	--	--	4.59E-04	3.72E-05
Trichloroethene	2.80E-02	6.00E-03	--	--	1.29E-03	7.71E-06
Total risk from inhalation of volatile organics.						4.49E-05

Table 3-2d. Human Health Risk Calculations for Noncarcinogenic Effects of Ingestion of Inorganics: 100-FR-3

Analyte	Maximum Concentration (mg/L)	Oral RfD (mg/kg-d)	Occasional		Frequent	
			Daily Intake (mg/kg-d)	Hazard Quotient	Daily Intake (mg/kg-d)	Hazard Quotient
Arsenic	1.17E-02	3.00E-04	1.40E-05	0.047	7.31E-04	2.44
Barium	1.27E-01	7.00E-02	1.52E-04	0.002	7.94E-03	0.11
Chromium	3.03E-01	5.00E-03	3.63E-04	0.073	1.89E-02	3.79
Copper	1.47E-02	4.00E-02	1.76E-05	0.000	9.19E-04	0.02
Lead	3.60E-03	NA	4.32E-06	--	2.25E-04	--
Manganese	9.66E-02	5.00E-03	1.16E-04	0.023	6.04E-03	1.21
Selenium	5.20E-03	5.00E-03	6.23E-06	0.001	3.25E-04	0.07
Vanadium	1.95E-02	7.00E-03	2.34E-05	0.003	1.22E-03	0.17
Alkalinity	5.13E+02	NA	6.15E-01	--	3.21E+01	--
Ammonia Nitrogen	1.30E-01	3.40E+00	1.56E-04	0.000	8.13E-03	0.00
Fluoride	9.00E-01	6.00E-02	1.08E-03	0.018	5.63E-02	0.94
Nitrate/Nitrite	3.24E+01	1.60E+00	3.88E-02	0.024	2.03E+00	1.27
Total Dissolved Solids	7.92E+02	NA	9.49E-01	--	4.95E+01	-
Total HI from ingestion of inorganics.				0.192		10.01

Table 3-2e. Human Health Risk Calculations for Carcinogenic Effects of Ingestion of Inorganics: 100-FR-3

Analyte	Maximum Concentration (mg/L)	Oral SF 1/(mg/kg-d)	Occasional		Frequent	
			Daily Intake (mg/kg-d)	Lifetime ICR	Daily Intake (mg/kg-d)	Lifetime ICR
Arsenic	1.17E-02	1.70E+00	2.75E-06	4.67E-06	1.43E-04	2.44E-04
Total risk from ingestion of inorganics.				4.67E-06		2.44E-04

Table 3-2f. Human Health Risk Calculations for Carcinogenic Effects of Ingestion of Radionuclides: 100-FR-3

			Occasional		Frequent	
Analyte	Maximum Concentration (pCi/L)	Oral SF (1/pCi)	Lifetime Intake (pCi)	Lifetime ICR	Lifetime Intake (pCi)	Lifetime ICR
Carbon-14	4.60E+02	9.00E-13	1.93E+05	1.74E-07	1.01E+07	9.07E-06
Strontium-90	2.50E+02	3.60E-11	1.05E+05	3.78E-06	5.48E+06	1.97E-04
Tritium	1.80E+05	5.40E-14	7.56E+07	4.08E-06	3.94E+09	2.13E-04
Uranium-233/234	1.00E+01	1.60E-11	4.20E+03	6.72E-08	2.19E+05	3.50E-06
Uranium-235	5.30E-01	1.60E-11	2.23E+02	3.56E-09	1.16E+04	1.86E-07
Uranium-238	1.00E+01	2.80E-11	4.20E+03	1.18E-07	2.19E+05	6.13E-06
Total risk from ingestion of radionuclides.				8.10E-06		4.23E-04

4.0 ECOLOGICAL EVALUATION

This chapter presents the ecological evaluation for the 100-FR-3 groundwater operable unit. The ecological evaluation is concerned with the potential risks to riparian and aquatic ecosystems , associated with the discharge of contaminants in groundwater to the Columbia River. No ecological data were collected for the LFI; therefore, the effects of contaminants are estimated.

This evaluation was conducted in three phases: problem formulation, analysis, and risk characterization. A short evaluation of uncertainty in the results follows the discussion of these phases.

4.1 PROBLEM FORMULATION

This phase identifies the environmental stressors and their characteristics, ecosystems potentially at risk, and potential ecological effects. Also, endpoints are selected and a conceptual model is developed. The major purpose of the problem formulation phase is to understand the movement of contaminants of potential concern and the receptors that are likely to be impacted.

4.1.1 Stressor Identification

Broadly defined, a stressor is any physical, chemical, or biological entity that can induce an adverse response. However, for the purposes of the ecological evaluation, a stressor is limited to hazardous chemicals and radionuclides. The potential stressors in the groundwater from the near-river wells are the constituents given in Table 2-2 that were retained for further analysis. The constituents that are potential stressors detected in spring water and Columbia River water in the vicinity of the 100-F Area were listed in Table 2-3.

4.1.2 Ecosystems Potentially at Risk

The COPC can migrate through the groundwater to springs and ultimately enter the Columbia River. Potentially affected ecosystems are discussed in the conceptual model description and Appendix B (see Figure B-2).

4.1.2.1 Conceptual Model. The riparian and aquatic ecosystems that are potentially affected are generalized in a conceptual model along with the key ecological receptors (Appendix B, Figures B-1 and B-2). In this model, contaminant transport is assumed through the groundwater to the springs and then into the Columbia River. Contaminant uptake into the aquatic foodweb is by algae and other primary producers. Organism exposure results from both food uptake and direct exposure in the river. Selected endpoint organisms potentially affected in the Columbia River and riparian zone are aquatic plants, fish, crustaceans, ducks, and herons.

A foodweb conceptual model of the Columbia River biota is given in Appendix B (Figure-B-1). The center of the Columbia River ecosystem consists of the water and dissolved nutrients that nourish the photosynthetic organisms (which are the primary producers) in the river. The ecosystem also contains sediments and heterotrophic bacteria. The sediments provide a physical substratum for rooting, as

well as a source of chemical nutrients for the rooted aquatics. The heterotrophic bacteria play a major role in recycling nutrients (tied up in dead organisms) into a dissolved state that can be used by plants. The bacteria are also food organisms for some consumers.

The conceptual model proposes that the maximum representative near-river well concentrations are exposure point concentrations for the aquatic and riparian ecosystems. It is assumed that the organisms are exposed to these levels irrespective of their habitat. All contaminants are assumed to be 100% biologically active and bioavailable and uniformly distributed in the river. These are conservative assumptions, based on conditions that do not generally occur because many contaminants in aquatic systems are transported via suspended particulate material. It is assumed that contaminants will bioaccumulate in aquatic organisms, such as fish, through direct uptake from the water column and foodweb.

4.1.2.2 Endpoints. As described/defined in *Screening Level Risk Assessment for Off-Site Ecological Effects in Surface Waters Downstream from the U.S. Department of Energy Oak Ridge Reservation* (Suter 1991), an endpoint is a measurable effect on an organism from exposure to a stressor. For example, increased mortality in fish is a measurable endpoint. For the ecological evaluation, the measurement endpoints are (1) adverse effect of radiological dose to riparian and aquatic organisms and (2) systemic toxicity of nonradiological contaminants to riparian and aquatic organisms. Both measurement endpoints are generic (i.e., not species specific).

The generic endpoints (effects) are based on DOE Order 5400.5 (DOE 1989) and the national water quality criteria (EPA 1986b) for radionuclides and nonradionuclides, respectively. These criteria are intended to protect aquatic life and other water users.

4.1.3 Potential Ecological Effects

Ionizing radiation and hazardous chemicals can impact riparian and aquatic organisms, depending on the level of exposure. Exposure can be either acute or chronic. Acute and chronic exposures can result in organism mortality. Mortality is generally characterized as the LC_{50}, the concentration to cause 50% mortality in a specified period of time. Other possible effects from acute or chronic exposure are physiological and morphological changes and developmental, growth, and reproductive effects.

Exposure can result from external environmental sources and internal dosage. For radionuclides, all exposure pathways are added in determining total organism dose. The regulatory limit for exposure to radionuclides for native aquatic organisms is a dose of 1 rad/day (DOE Order 5400.5; DOE 1989).

In general, for hazardous chemicals, toxicity is typically expressed as an LC_{50}. This follows a dose/response relationship--similar to radionuclides--for a variety of aquatic organisms. These criteria consider the effects of bioaccumulation and are protective of most aquatic life. The applicable regulatory limits are the contaminant-specific AWQC (EPA 1986b) for acute and chronic lowest observable effect levels (LOELs). The AWQC were developed by the EPA after their review of numerous toxicity tests that evaluated metal and organic toxicity under various test conditions.

4.2 ANALYSIS

This phase evaluates the potential effects of exposure to COPC on receptor organisms.

The primary scenario in the ecological evaluation uses the maximum representative contaminant concentrations from the near-river wells, with no dilution, to establish an upper bound river exposure. The near-river wells reflect potential contaminant concentrations most likely entering the river via groundwater flow. It is assumed that organisms are exposed to the concentrations in the springs and Columbia River; however, the spring- and river-water samples were collected at only one time (DOE-RL 1992b) during a particular stage of the river and are not considered truly representative.

For radionuclides, dose rates are calculated based on the CRITR2 computer code developed by Baker and Soldat (1992). The steady-state model embodied in CRITR2 uses generic aquatic and riparian plants and animals and assumes exposed organisms reach an equilibrium with the water concentration or food uptake. Selected multiple receptors are evaluated at various levels of the aquatic foodweb. The organisms evaluated using CRITR2 are aquatic plants, fish, crustaceans, a plant-eating duck, a fish-eating duck, and a heron. All of these organisms are present on the Hanford Site. The transfer of contaminants to aquatic plants is evaluated via Hanford Site-specific bioconcentration factors or transfer ratios from water to plant (Baker and Soldat 1992). Animal uptake is evaluated using transfer ratios, biological half-lives, and food intake rates.

For constituents other than radionuclides, the dose/response relationship is based on the toxicity criteria (i.e., the acute and chronic LOELs, as thresholds). If a chemical exceeds the threshold LOEL, it is assumed that some component of the ecosystem may be adversely affected.

4.3 RISK CHARACTERIZATION

In this phase of the ecological evaluation, exposure information and toxicity data are integrated to produce estimates of risks to riparian and aquatic organisms. This forms the basis for characterizing the ecological hazards from hypothetical exposures to COPC detected in the 100-FR-3 groundwater.

The likelihood of an adverse effect on one or more organisms is expressed in the form of an environmental hazard quotient (EHQ). The EHQ is defined as the ratio of the contaminant dose or dose rate to a limiting dose or dose rate (1 rad/day or the LOEL).

For example, in the case of ionizing radiation for a radionuclide,

$$\text{EHQ} = \frac{\text{organism's dose rate}}{\text{criterion or benchmark}} \tag{4.1}$$

where the criterion is 1 rad/day. The EHQ is calculated for the nonradiological chemicals by dividing the source (e.g., near-river well concentration) by the corresponding LOEL.

For nonradionuclides (chemicals),

$$EHQ = \frac{\text{groundwater concentration}}{\text{LOEL}} \tag{4.2}$$

The EHQs for aquatic and riparian receptors from internal exposure to radionuclides, assuming the concentrations found in the near-river wells, are shown in Table 4-1. The EHQs are the same as the calculated dose rates because the criterion for radionuclides is 1 rad/day. The "Totals" row represents the sum of the EHQs for the listed radionuclides for each organism. In addition, immersion and sediment exposures were calculated for each organism; however, they contribute little, if any, to the total EHQ and were omitted from the table.

No EHQ exceeded 1.0. An EHQ of 0.048 resulted from the exposure of plant-eating duck to strontium-90. The next highest EHQ of 0.0046 was to aquatic plants and this was also from strontium-90.

For chemicals, the acute or chronic LOELs are used to assess risk and serve as a limiting value for calculation of EHQs. An EHQ at or above 1 (exceeding or meeting the LOEL) would indicate a potentially measurable risk. Table 4-2 shows the maximum representative concentrations, the acute and chronic aquatic LOELs, and the corresponding acute and chronic EHQs for inorganic nonradioactive contaminants. Chloride, ammonia, and other general water quality parameters were not evaluated as COPC because there are no LOELs to serve as limiting doses. Chromium, lead, and copper have chronic EHQs >1.0 for near-river wells in the 100-F Area. Chromium has an acute EHQ >1.0. Aluminum was detected in the 100-F Area springs, but not in the river (see Table 2-3). This may be caused by the spring-water sample-collection method that resulted in high-alumina particles in the unfiltered samples (DOE-RL, 1992b).

4.4 UNCERTAINTY EVALUATION

Significant uncertainty exists in the ecological evaluation because undiluted source terms are used and all of a contaminant is assumed available for bioaccumulation. No allowance is made for environmental fate that would affect contaminant bioavailability in the Columbia River. The radiological doses were calculated using the conservative assumptions that the organism and its food source spend 100% of their time in the area containing the maximum groundwater concentrations. Actual exposure point concentrations of radioactive and nonradioactive contaminants are below these concentrations.

Most of the available information on ionizing radiation is for acute dose and not for low dose exposure and chronic effects (see, for example, "Lower Limits of Radiosensitivity in Organisms, Excluding Man;" Rose 1992). The use of acute data extrapolated to chronic levels is not always appropriate and must be viewed with caution. For example, during chronic exposure, there is a point where competition between injury and natural organism repair mechanisms are balanced, resulting in no effect ("Effects of Ionizing Radiations on Aquatic Organisms, Effects of Ionizing Radiation on Aquatic Organisms and Ecosystems;" Ophel et al. 1976).

Risk is expressed as an EHQ, which implies a single conclusion has been reached. This EHQ is the result of the interaction, uncertainty, and conservatism of many different factors that enter into the risk characterization. The environmental relevancy of the characterization will depend on the accuracy of these factors.

Table 4-1. Environmental Hazard Quotients for Radionuclides in the Near-River Groundwater Wells: 100-FR-3

Analyte	Plant	Fish	Crustacean	Duck-P	Duck-F	Heron
Strontium-90	4.6E-03	7.6E-05	1.5E-04	4.8E-02	1.6E-03	1.0E-03
Tritium	3.6E-07	3.6E-07	3.6E-07	5.1E-07	1.0E-06	6.7E-07
Uranium-233/234	5.0E-04	2.8E-05	5.5E-05	3.3E-04	3.7E-05	2.4E-05
Uranium-235	6.2E-05	3.4E-06	6.8E-06	4.1E-05	4.5E-06	3.0E-06
Uranium-238	3.8E-04	2.1E-05	4.2E-05	2.5E-04	2.8E-05	1.8E-05
Totals	5.5E-03	1.3E-04	2.6E-04	4.8E-02	1.7E-03	1.1E-03

Duck P - Plant-eating duck.
Duck F - Fish-eating duck.

Table 4-2. Environmental Hazard Quotients for Non-Radionuclides in the Near-River Groundwater Wells: 100-FR-3

Analyte	Maximum Concentration (μg/L)	Acute LOEL (μg/L)[1]	Chronic LOEL (μg/L)[1]	Acute EHQ	Chronic EHQ
Aluminum	80.6	1894	146.7	<0.1	0.5
Ammonia Nitrogen (mg/L)	0.13	NA	NA	--	--
Arsenic	11.7	360	190	<0.1	0.1
Chloride (mg/L)	10.7	NA	NA	--	--
Chloroform	2	28900	1240	<0.1	<0.1
Chromium[2]	32.7	16	11	2.0	3.0
Copper	14.7	18	12	0.8	1.2
Lead	3.4	42.6	1.7	<0.1	2.0
Manganese	44.5	1500	NA	<0.1	--
Nickel	19.8	920	102	<0.1	0.2
Total Dissolved Solids (mg/L)	311	NA	NA	--	--
Vanadium	19.5	80	NA	0.2	--
Zinc	33.4	76	69	0.4	0.5

NA - No data available.
LOEL - Lowest observable effect level (EPA 1986c).
[1]Derived from EPA's ambient water quality criteria.
[2]Chronium is assumed to be hexavalent form.

5.0 SUMMARY AND CONCLUSIONS

This chapter provides a summary and key uncertainties associated with the results of this QRA.

5.1 RESULTS OF HUMAN HEALTH EVALUATION

Two exposure scenarios (frequent and occasional use) and two pathways (groundwater ingestion and inhalation of volatile organics from groundwater use) have been discussed and selected by the 100 Area Tri-Party Agreement unit managers for evaluation in this QRA. Currently, there are no residential or recreational users of the groundwater or overlying surface area of the 100-FR-3 groundwater operable unit. Thus, the risks presented in this QRA are not actual risks but estimates of potential risks under high-frequency or low-frequency use. The frequent- and occasional-use scenarios were evaluated using the residential and recreational exposure parameters from the risk assessment methodology (DOE-RL 1993).

The risk assessment results for the COPC for human health are summarized in Tables 5-1 and 5-2. Table 5-1 presents a list of COPC in descending order of the noncarcinogenic HQ, and Table 5-2 presents a list of COPC in descending order of carcinogenic risk. The contaminant ranking in these tables is based on the results of assessment using the frequent-use scenario. Table 5-3 shows the maximum water concentrations of COPCs from the LFI in all wells, near-river wells, springs and river.

5.1.1 Noncarcinogenic Hazard

Table 5-1 summarizes the noncarcinogenic hazard for both frequent- and occasional-use scenarios and includes:

- an indication of whether the HQ exceeded 1.0
- percent of total HI (sum over contaminants of the HQs) contributed by the contaminant
- cumulative percent of total HI contributed by the contaminants.

Four COPC for noncarcinogenic risk (chromium, arsenic, nitrate/nitrite, and manganese) have HQs that are > 1.0 under the frequent-use scenario. For all COPC, the HQ is < 1.0 under the occasional-use scenario.

5.1.2 Carcinogenic Risk

Table 5-2 summarizes the carcinogenic risk for both frequent- and occasional-use scenarios and includes:

- a qualitative risk estimation
- percent of total risk contributed by the contaminant
- cumulative percent of total risk contributed by the contaminants.

The qualitative risk estimations presented in Table 5-2 are assigned values of high (ICR ≥ 1E-02), medium (1E-04 ≤ ICR < 1E-02), low (1E-06 ≤ ICR < 1E-04), and very low (ICR < 1E-06), based on the results presented in Chapter 3.0. In general, the risk is two orders of magnitude (one level) lower for the occasional-use than for the frequent-use scenarios. This is true because the only difference in the risk calculations is the exposure frequency (7 days/year for occasional use versus 365 days/year for frequent use). This rule of thumb will hold, except when a contaminant has both an ingestion and inhalation SF. If this is the case, the risk is summed across pathways for the frequent-use scenario, but only the ingestion risk applies for the occasional-use scenario.

There are 9 COPC for carcinogenic risk. Under the frequent-use scenario, the total risk is medium. Arsenic, tritium, and strontium-90 have medium-risk estimations. Arsenic was not used in Hanford Site processes; therefore, the risks associated with arsenic are likely related to background. The risk estimates for chloroform, trichloroethene, carbon-14, uranium-238, and uranium-233/234 are low. The risk estimate for uranium-235 is very low.

The total risk under the occasional-use scenario is low. The risk for the top three contaminants (arsenic, tritium, and strontium-90) is low, and the risk for the remaining contaminants is very low.

5.1.3 Risk from Background Levels of COPC

The risk assessment methodology (DOE-RL 1993) prescribes that the risk from background concentrations of COPC be addressed in characterizing risk. The only COPC that have both background values and RfDs for noncarcinogenic hazard assessment are arsenic, manganese, vanadium, and nitrate/nitrite. Under the frequent-use scenario, only the HQ for arsenic is >1.0. The HQs are <1.0 for all contaminants under the occasional-use scenario.

An evaluation was done for the carcinogenic COPC to determine the risk associated with the levels of the contaminant background concentrations. Only arsenic and total uranium have both background values and SF. The risk estimate for background arsenic is >1E-06 for both frequent- and occasional-use scenarios. There is a medium risk under the frequent-use scenario and a low risk under the occasional-use scenario. The risk for total uranium is low under the frequent-use scenario and is very low under the occasional-use scenario.

5.2 RESULTS OF ECOLOGICAL EVALUATION

The ecological evaluation for the 100-FR-3 groundwater operable unit was completed for selected riparian and aquatic organisms expected to be in or associated with the Columbia River. Estimated receptor doses were compared to criteria such as DOE Order 5400.5 (DOE 1989) and AWQC (EPA 1986b). The risks developed in the ecological evaluation are not actual risks but estimates of potential risk under high-frequency use by the organism. The actual use is not known; however, it can be assumed that exposure would be less than presented in this QRA.

The 100-FR-3 groundwater operable unit potentially affects the Columbia River. There is only one sampling round of data for the 100-F Area springs and Columbia River, so these data are not used directly in the ecological evaluation but are presented for comparison purposes. Source term information was developed from near-river groundwater well constituent concentrations. The groundwater concentrations establish an upper bound exposure for the organisms that were analyzed.

It is assumed that the values from near-river wells represent concentrations entering the 100-F Area springs and then the Columbia River. In the springs, concentrations are below the adverse effect levels, except for aluminum. Once contaminants enter the Columbia River, dilution should result in rapid reduction of the concentrations to levels below any possible risk level. This appears to be the case, even for aluminum. The highest concentration of aluminum was found in spring water., This may reflect the presence of high alumina clay particles in the unfiltered sample used for this QRA analysis. As a point of comparison, Table 5-3 presents the concentrations of the COPC for the groundwater wells, the near-river wells, the 100-F Area springs, and the Columbia River near the 100-F Area.

5.2.1 Radionuclide Hazard

Radionuclide doses were calculated for the potentially affected organisms in the Columbia River and riparian zone. These organisms are aquatic plants, fish, crustaceans, a plant-eating duck, a fish-eating duck, and a heron. An EHQ was calculated using the criterion of 1 rad/day established by DOE Order 5400.5 (DOE 1989). For all constituents evaluated, none exceeded an EHQ of 1.0. The resulting EHQs are presented in Table 5-4.

5.2.2 Nonradionuclide Hazard

The ecological summary (Table 5-5) for nonradionuclides (hazardous chemicals) indicates that the chronic EHQs, based on near-river well concentrations, exceeded 1.0 for chromium, lead, and copper. The acute EHQ exceeded 1.0 for chromium. As is shown in the concentration summary table (see Table 5-3), the concentration of chromium decreases significantly in the spring water, and chromium was not detected in the river water. However, the concentration of aluminum found in the spring water exceeds the chronic LOEL. Lead was not included in the analyses of the spring- and river-water samples.

5.3 SUMMARY OF UNCERTAINTY

Uncertainty in the evaluation of data, human health risk, and ecological risk are discussed in this section. A more detailed analysis of the uncertainty in the risk estimates is presented in Appendix C.

5.3.1 Uncertainty in Data

The data available to conduct this QRA are LFI data from three rounds of sampling. Confidence levels are estimated for the data, based on available knowledge of the waste site. Confidence in the contaminant identification is based primarily on the quality of the data used in this QRA. The confidence in the concentrations is based on the data quality and confidence in the representativeness of that data. Confidence levels used are high, medium, and low.

A high confidence rating is given for contaminant identification at the 100-FR-3 groundwater operable unit because the LFI data used in this QRA were collected specifically for characterization of the 100-

FR-3 groundwater operable unit and are of known quality. The confidence in the concentrations is given a high rating as well because three sampling rounds of data were used. A low confidence rating was given to the spring- and river-water data because only one round of sampling was performed.

In general, the use of maximum concentrations to calculate risk for this QRA may result in an overestimation. The data represent a snapshot of concentration at a given time. Also, the effect of the Columbia River on the groundwater concentrations at the 100-F Area is not known.

5.3.2 Uncertainty in Human Health Evaluation

This QRA estimates risk that might occur under frequent-use (i.e., residential) or occasional-use (i.e., recreational) scenarios based on the agreements by the 100 Area Tri-Party Agreement unit managers. While these risks are based on the best knowledge of current contamination conditions, they do not represent actual risks because neither residential nor recreational uses currently occur at the operable unit. The scenarios evaluated for the 100-FR-3 groundwater operable unit are based on assumed receptors under current contaminant conditions. For some radionuclides, radioactive decay over time can significantly reduce the concentrations to which a receptor may be exposed.

Uncertainty is associated with the toxicity values and the toxicity information available to assess potential adverse effects. This uncertainty in the information and the lack of specific toxicity information contribute to uncertainty in the toxicity assessment. For nonradioactive contaminants identified at the 100-FR-3 groundwater operable unit, there is relatively good information for potential exposures through the ingestion route. However, toxicity values and information to evaluate the inhalation route of exposure is more limited.

Uncertainty exists as to whether chromium is in the hexavalent or trivalent state. Hexavalent chromium is assumed for this QRA because it provides the most conservative evaluation and was the form used (e.g., sodium dichromate) at some 100-F Area waste units.

The estimated risks or HQs by themselves do not fully characterize the risk impacts associated with environmental contamination. Such an evaluation must be understood in light of the uncertainties presented. The risk estimates are based on single-point estimates from LFI data, assuming two different sets of exposure assumptions (i.e., residential and recreational).

Uncertainty in the risk characterization results from summing cancer risks or HQs across contaminants and pathways, which gives equal weight to toxicity information derived from different sources or species. Exposures to multiple contaminants may result in additive effects or effects that are greater or less than additive.

5.3.3 Uncertainty in Ecological Evaluation

The ecological evaluation depicts the potential exposure of selected riparian and aquatic life to contaminants present in groundwater near the river. This creates two primary uncertainties for the ecological evaluation, the source term and the conceptual model. In the case of the ecological evaluation, the maximum representative groundwater concentration was used as the source term and no river dilution was considered. The selected organisms used to evaluate the risk do not represent the

river's entire ecosystem; however, this limited conceptual model was agreed to by the Tri-Party Agreement unit managers as a sufficient scenario for an IRM decision (February 8, 1993).

Additional uncertainties associated with toxicity values also are significant, particularly for nonradiological contaminants. Benchmark or toxicity values (LOELs) were developed, based on laboratory tests and are extrapolated to the environment. The effects of chronic exposure of organisms to radionuclides are not known. At low-dose levels, organisms can repair damage to correct for radiological dose. However, existing dose/response relationships were developed at high-dose levels and extrapolated to chronic levels. In addition, no regulatory criteria exist for radionuclides other than the 1 rad/day reported in DOE Order 5400.5 (DOE 1989).

Risk is expressed as an HQ, which implies a single conclusion has been reached. As discussed above, this HQ is the result of the interaction, uncertainty, and conservatism of many different factors that enter into the risk characterization. The environmental relevancy of the characterization will depend on the accuracy of these factors.

5.4 CONCLUSIONS

The QRA is used in the LFI process to (1) screen out contaminants from the remedial action list and (2) assess the need for IRM. The QRA results suggest that some unacceptable risks might exist from exposure to groundwater at the 100-FR-3 groundwater operable unit. While it is reasonable to conservatively estimate the risks from contaminants for these purposes, none of the calculated risks are based on current exposure scenarios, and future land uses have not yet been determined.

The upper-bound estimates of risk, even with their associated uncertainties, are sufficient to support an initial decision for the 100-FR-3 groundwater operable unit. The current risk from the groundwater at the 100-F Area is less than the risk estimates presented in this QRA.

Table 5-1. Human Health Risk Summary Noncarcinogenic Effects: 100-FR-3

Analyte	Occasional			Frequent		
	Comparison of HQ to 1.0	Percent of Total HI	Cumulative Percent of Total HI	Comparison of HQ to 1.0	Percent of Total HI	Cumulative Percent of Total HI
Chromium[1]	Below	36.9	36.9	Above	36.3	36.3
Arsenic[2]	Below	23.7	60.6	Above	23.4	59.7
Nitrate/Nitrite[3]	Below	12.1	72.7	Above	12.2	71.9
Manganese[4]	Below	11.6	84.3	Above	11.6	83.5
Fluoride	Below	9.1	93.4	Below	9.0	92.5
Trichloroethene	Below	3.0	96.5	Below	2.9	95.4
Vanadium	Below	1.5	98.0	Below	1.6	97.0
Barium	Below	1.0	99.0	Below	1.1	98.1
Chloroform	Below	0.5	99.5	Below	1.0	99.0
Selenium	Below	0.5	100.0	Below	0.7	99.7
Copper	Below	<0.1	100.0	Below	0.2	99.9
Aluminum	Below	<0.1	100.0	Below	0.1	100.0
Ammonia Nitrogen	Below	<0.1	100.0	Below	<0.1	100.0
Alkalinity	No Data	NA	--	No Data	NA	--
Electrical Cond. (umho/cm)	No Data	NA	--	No Data	NA	--
Lead	No Data	NA	--	No Data	NA	--
Total Dissolved Solids	No Data	NA	--	No Data	NA	--
Total Hazard Index	Below			Above		

[1]The toxic effects of chromium are dependent on the valence state and route of exposure. The route evaluated here is oral ingestion. The effects of chromium exposure by routes other than oral ingestion were not considered because no other pathway for exposure exists. Chromium (VI) is classified a Group A human carcinogen, based on evidence that it causes lung tumors or skin tumors in animals when inhaled or injected (Integrated Risk Information System; EPA 1992).
[2]The critical noncarcinogenic effects of chronic oral exposure to inorganic arsenic are hyper-pigmentation, keratosis, and possible vascular complications. The level of confidence in the reference dose for arsenic is listed as medium (IRIS).
[3]There is a high level of uncertainty associated with the nitrate/nitrite evaluation. The nature of the contaminants, whether soluble or elemental, is unknown; therefore, the toxicity values used may not be appropriate.
[4]Manganese is an essential human nutrient, but appears to cause neuromuscular effects at high concentrations.

Table 5-2. Human Health Risk Summary Carcinogenic Effects: 100-FR-3

Analyte	Occasional			Frequent		
	Qualitative Risk	Percent of Total Risk	Cumulative Percent of Total Risk	Qualitative Risk	Percent of Total Risk	Cumulative Percent of Total Risk
Arsenic[1]	Low	36.0	36.0	Medium	33.8	33.8
Tritium[2]	Low	31.4	67.4	Medium	29.5	63.3
Strontium-90[3]	Low	29.1	96.5	Medium	27.3	90.5
Total Chloroform	Very Low	0.1	96.6	Low	5.2	95.8
Total Trichloroethene	Very Low	0.6	97.2	Low	1.6	97.4
Carbon-14	Very Low	1.3	98.5	Low	1.3	98.6
Uranium-238	Very Low	0.9	99.5	Low	0.8	99.5
Uranium-233/234	Very Low	0.5	100.0	Low	0.5	100.0
Uranium-235	Very Low	<0.1	100.0	Very Low	<0.1	100.0
Total Risk	Low			Medium		

[1]Inorganic arsenic is classified as a Group A human carcinogen. Arsenic caused an increased incidence of skin cancer in several populations consuming drinking water containing high concentrations of arsenic (Integrated Risk Information System; EPA 1992).
[2]The half-life of tritium is approximately 12 years. The risk estimate is appropriate for 1993.
[3]The physical half-life of strontium-90 is approximately 29 years. It is chemically similar to calcium. The primary health effect is bone cancer resulting from ingestion.

Table 5-3. Comparison of Concentrations for Contaminants of Potential Concern: 100-FR-3

	All Groundwater Wells	Near-River Groundwater Wells	F-Area Springs	F-Area Columbia River
Organics (All Concentrations in μg/L)				
Chloroform	10	2 J	NA	NA
Trichloroethene	28	ND	NA	NA
Inorganics (All Concentrations in μg/L, except as noted)				
Alkalinity (mg/L)	513	163	102 J	54.2 J
Aluminum	80.6 B	80.6 B	334^	36 B
Ammonia Nitrogen (mg/L)	0.13	0.13	NA	NA
Arsenic	11.7	11.7	NA	NA
Barium	127 B	43.9 B	50.8 B	28 J
Calcium	144000	44400	46400	18800
Chloride (mg/L)	35.9	10.7	9.8 J	1.02 J
Chromium	303	32.7	9.6 B	ND
Copper	14.7B	14.7 B	ND	ND
Fluoride	0.9	0.8	0.39	0.43
Lead	3.6NJ	3.4	NA	NA
Magnesium	36900	11700	9710	4070 B
Manganese	96.6	44.5	45	9.5 B
Nickel	19.8 B	19.8 B	ND	5.5 B
Nitrate/Nitrite (mg/L)	32.4	5.03	5.5 J	0.51 J
Selenium	5.2 S,*	ND	NA	NA
Sodium	77500	48400	10100 J	2220 J
Sulfate (mg/L)	106	53	49.39 J	9.65 J
Total Dissolved Solids (mg/L)	792	311	232	94
Vanadium	19.5 B	19.5 B	5 B	2 B
Zinc	3.4	33.4	18 B	13.6 B
Radionuclides (All Concentrations in pCi/L)				
Carbon-14	460	ND	NA	NA
Strontium-90	25	26	46	ND
Tritium	180000	1200	590	110
Uranium-233/234	10	2.2	NA	NA
Uranium-235	0.53	0.29	NA	NA
Uranium-238	10	1.9	NA	NA
Total Uranium	NA	NA	2.6	0.46

ND - Not Detected.
NA - No Data Available.
J - Estimated value.
B - Value below the contract required detection limit.
N - Spiked sample recovery not within control limits.
S - Determined by the method of standard additions.
* - Duplicate analysis not within control limits.
^ - From unfiltered sample which may reflect high alumina-clay particles due to method of spring sampling.

Table 5-4. Ecological Summary for Radionuclides: 100-FR-3
Organism: Plant-Eating Duck

Analyte	Near-River Groundwater Wells		
	Comparison to EHQ = 1.0	Percent of Total EHQ	Cumulative Percent of Total EHQ
Strontium-90	Below	98.8	98.8
Uranium-233/234	Below	0.7	99.5
Uranium-238	Below	0.5	100.0
Tritium	Below	<0.1	100.0
Uranium-235	Below	<0.1	100.0
Total EHQ	Below		

Table 5-5. Ecological Summary for Non-Radionuclides: 100-FR-3

Analyte	Near-River Groundwater Wells	
	Comparison to Acute EHQ = 1.0	Comparison to Chronic EHQ = 1.0
Chromium[1]	Above	Above
Lead[2]	Below	Above
Copper[3]	Below	Above
Zinc	Below	Below
Vanadium	Below	NA
Aluminum	Below	Below
Arsenic	Below	Below
Nickel	Below	Below
Chloroform	Below	Below
Manganese	Below	NA
Ammonia Nitrogen	NA	NA
Chloride	NA	NA
Total Dissolved Solids	NA	NA
NA - No Data Available		

[1]The toxicity of chromium ions is highly dependent on oxidation state. Only trivalent and hexavalent chromium is biologically significant. Hexavalent chromium is readily taken up by living cells and is highly active in diverse biological systems.
[2]Lead has a tendency to form compounds of low solubility with the major anions of natural water. Much of the lead carried by river water is in the form of suspended solids. Biomethylation of lead by benthic microorganisms can lead to its remobilization and reintroduction into the aqueous environment compartment.
[3]Copper is a required micronutrient, however, many species of fish are sensitive to its toxic effects at relatively low concentrations. Copper is likely to form complexes that render it less biologically available.

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APPENDIX A

TOXICOLOGICAL INFORMATION

INTRODUCTION

Appendix A presents toxicological information for contaminants of potential concern identified at the 100-FR-3 groundwater operable unit. The categories of information include:

- general background information
- exposure route
- chronic toxicity
- carcinogenicity.

Data sources for the information provided in this appendix include U.S. Environmental Protection Agency (EPA) documents and standard reference texts. These sources are:

- EPA *Integrated Risk Information System* (IRIS; EPA 1992a)
- EPA *Health Effects Assessment Summary Tables* (HEAST; EPA 1992b)
- Toxicological Profiles for Individual Compounds, Agency for Toxic Substances and Diseases Registry
- *Casarett and Doull's Toxicology, the Basic Science of Poisons* (Amdur et al. 1991).

CONTAMINANTS OF POTENTIAL CONCERN

INORGANIC COMPOUNDS (NONRADIOACTIVE)

Aluminum

Aluminum comprises approximately 8% of the Earth's crust in combination with oxygen, fluorine, silicon, and other constituents. Aluminum metal has a wide variety of uses (e.g., structural material in the construction, automotive, electrical, and aircraft industries). Although it is widely used for medicinal purposes, aluminum is not thought to be toxic to humans. However, excess exposure to this metal may be harmful to sensitive subpopulations, including pregnant women and Alzheimer's patients. The inhalation and dermal exposures of healthy individuals to aluminum are not associated with significant adverse health effects, but inhalation of aluminum dust may cause respiratory problems, while the ingestion of water containing high levels of this metal may result in neurological, teratogenic, and skeletal problems.

An interim oral reference dose (RfD) of 1.0 mg/kg-d has been recommended for aluminum by the EPA. The critical effects associated with exposure to this metal are decreased body weight and neurotoxicity.

Arsenic

Measurable concentrations of arsenic are commonly found in the western United States (Fetter 1993). The background concentration of arsenic at the Hanford Site has been determined to be 10 μg/L

(DOE-RL 1992c). Environmental sources of arsenic include sedimentary rocks emanating from volcanic sources and geothermal systems. Burning of coal and smelting of ores are examples of anthropogenic sources of arsenic.

Although the EPA notes a range of reference doses (RfD) values for arsenic, the value reported in the IRIS database is 3E-04 mg/kg-d. The adverse effects associated with oral arsenic exposure include hyperpigmentation and keratosis, and at high doses, possible vascular complications. The uncertainty of the oral RfD value spans nearly an order of magnitude with published RfD ranging from 1E-04 to 8E-04 mg/kg-d (EPA 1992a).

The EPA has a Group A human carcinogen weight of evidence classification for arsenic (EPA 1992a). The assigned arsenic oral SF is 1.7 $(mg/kg\text{-}d)^{-1}$. Skin cancer is the most common disease resulting from oral exposure to arsenic.

Chromium (+6)

Elemental chromium does not exist naturally in the environment but is found primarily as a part of chromite ore. In compounds, this element exists in one of three valence states, +2, +3, or +6. The trivalent form is an essential human micronutrient involved in carbohydrate metabolism. Adverse effects have not been associated with the trivalent form. The hexavalent form is important industrially (typically in the form of chromates) and has been associated with serious toxicities. Human toxicity has been associated with hexavalent chromium by all routes of exposure. Long-term exposure to airborne hexavalent chromium higher than natural background levels is known to produce lung and respiratory tract cancer in humans.

The EPA has determined the oral RfD for hexavalent chromium as 5E-03 mg/kg-d (EPA 1992a), based on a drinking water study in rats. Hexavalent chromium is classified by EPA as a known human carcinogen (weight-of-evidence classification is Group A) by inhalation exposure. The inhalation SF is 4.1E+01 $(mg/kg\text{-}d)^{-1}$. No evidence exists to indicate that chromium is carcinogenic by the oral route.

Iron

The predominant sources of iron in the atmosphere may be attributed to natural processes, including continental dust generated by wind erosion of weathering mineral deposits, volcanic gas and dust, and forest fires. Anthropogenic sources of iron in the atmosphere include industrial emissions and the burning of fossil fuels. The major interest in iron is that it is an essential nutrient with potential for toxicity at chronic high doses. Chronic iron toxicity or iron overload in adults, following oral ingestion, is characterized by clinical effects, such as disturbances in liver and endocrine functions, diabetes mellitus, and cardiovascular effects.

For the protection of human welfare, the EPA has recommended an ambient water quality criterion of 0.3 g/L for iron.

Lead

Lead is a naturally occurring, bluish-gray metal found in small amounts in the Earth's crust. Lead is widely distributed in the environment, and can be transported long distances. Anthropogenic sources

of lead come from gasoline additives, various metal products, ammunitions, paint, and storage batteries. The largest source of lead in air is from automobile exhaust. Children and pregnant women are the most sensitive subpopulations to chronic effects from lead exposure. The effects of lead exposure in children are reported as a decrease in intelligence quotient, neurological effects, including changes in brain function (encephalopathy) that may progress to coma. Transplacental transfer of lead from mother to fetus, resulting in nervous system damage or changes, has also been reported in humans. Exposure to lead has also been linked to carcinogenic effects in laboratory animals.

The EPA has classified lead as a Group B2 carcinogen (i.e., probable human carcinogen). Although the EPA has not derived a toxicity factor for lead, a range of 500 to 1,000 mg/kg of lead in soil has been determined as being protective of sensitive populations.

Manganese

The background manganese groundwater concentration is 24.5 μg/L at the Hanford Site (DOE-RL 1992c). Manganese is an essential human nutrient; however, toxic effects have been observed from exposures to high levels of manganese.

The EPA oral RfD for manganese is 5E-03 mg/kg-d, based on total dietary uptake. A separate RfD for oral groundwater exposure is being considered by the EPA. Muscle tonus, tremors, lethargy, and mental disturbances have been reported in humans exposed to high manganese levels. The EPA has given manganese the weight of evidence Group D classification (EPA 1992a). Group D is not classified as to carcinogeneity.

Zinc

Zinc is a ubiquitous metal detected in the Earth's crust. The Hanford Site's background groundwater concentration for zinc is 50 μg/L (DOE-RL 1992c). Zinc may be encountered in a number of manufacturing processes.

The oral RfD for zinc is 3E-01 mg/kg-d. The primary observed adverse effect is a reduction of blood erythrocyte superoxide dismutase (ESOD) levels, which alters metal metabolism in humans. The EPA considers zinc as Group D; not classifiable as to human carcinogeneity for oral exposures (EPA 1992a).

ORGANIC COMPOUNDS (NONRADIOACTIVE)

Chloroform

Chloroform is a colorless, volatile liquid at room temperature with a sweet taste and a characteristic odor. It is used as an industrial solvent and chemical intermediate in the manufacture of other compounds. The primary route of chloroform exposure is via inhalation and ingestion of contaminated drinking water. Target organs for chloroform toxicity are the liver, kidney, and central nervous system.

The EPA has set an oral RfD of 1E-02 mg/kg-d for chloroform, based on critical effects of fatty cyst formation in the liver (EPA 1992a). Chloroform is a B2 (probable) human carcinogen. The oral SF is 6.1E-03 mg/kg-d^{-1} (based on water ingestion), and the inhalation SF is 8.0E-02 mg/kg-d^{-1} (based on a gavage study) (EPA 1992a).

Trichloroethene

Trichloroethene (also known as trichloroethylene) is a colorless liquid with an odor similar to ether or chloroform. This chemical is a manmade solvent used for degreasing metal parts, extracting caffeine from coffee, and in numerous consumer products, such as typewriter correction fluid, paint removers, and spot removers.

Trichloroethene moves readily through soil and groundwater. Ingestion of contaminated water and inhalation of volatilized trichloroethane are the chief sources of exposure. Absorption is not significant from skin contact with this solvent.

Acute oral toxicity in humans is low. Death has occurred from an ingested dose of 70 mg/kg. Acute effects from inhalation of trichloroethane are associated with the central nervous system (dizziness, headache, sleepiness) and occur at a threshold of 436 to 592 mg/m^3. Extremely high acute exposures may produce cardiac rhythm disturbances. In animals, chronic exposure to trichloroethane by inhalation and ingestion has produced liver and kidney damage and may cause reproductive toxicity.

Neither IRIS (EPA 1992a) nor HEAST (EPA 1992b) currently provide an RfD for trichloroethane, and determination of an RfD is pending. Trichloroethene may induce lung cancer in animals when inhaled and may produce liver cancer in animals from oral administration. The EPA weight-of-evidence classification is B2 (probable human carcinogen), based on sufficient evidence in animals. The oral and inhalation SFs for trichloroethane have also been withdrawn from IRIS, pending further review of carcinogenicity studies. However, HEAST provides an inhalation SF of 1.7E-02 mg/kg/d^{-1}.

The Occupational Safety and Health Administration's final rule limits for occupational exposure to trichloroethane and the currently recommended American Conference of Governmental Industrial Hygienists exposure limits are a time-weighted average (TWA) of 269 mg/m^3 and a short-term exposure limit of 1,070 mg/m^3. Because trichloroethane is carcinogenic, the National Institute for Occupational Safety and Health (NIOSH) recommends a TWA of 135 mg/m^3. The NIOSH recommendations are considered the level that can be achieved by existing engineering controls and technology. The immediately dangerous to life or health concentration for trichloroethane is 5,380 mg/m^3.

The drinking water maximum contaminant level for trichloroethane is 0.005 mg/L and the maximum contaminant level goal is 0 mg/L. Based on water and fish consumption, the human water quality health criterion is 0.0027 mg/L.

RADIOACTIVE ELEMENTS

Carbon-14

Carbon-14 (Z = 6) is a naturally occurring, as well as manmade, neutron activation product.. Carbon-14 is ubiquitous because carbon distributes itself quickly among the major environmental compartments (the stratosphere, troposphere, biosphere, and surface ocean waters) and has a long half-life (5730 yr). The carbon-14 content of the atmosphere is believed to exist as (gaseous) carbon dioxide; therefore, it is not assigned a lung class. Carbon is assigned a gastrointestinal absorption factor of 100%. The carbon-14 body burden from natural sources is on the order of 0.1 μCi, providing an estimated equivalent whole body dose of 1 mrem/yr. Carbon-14 is a low-energy beta emitter, making it a relatively low-hazard radionuclide via the ingestion and inhalation pathways. The EPA has derived an SF of 9.0E-13 for oral exposures. Carbon-14 is not an external exposure hazard because it does not emit gamma or x-rays.

Strontium-90

This fission product (Z = 38), along with its daughter, yttrium-90, is only an internal hazard because both radionuclides have negligible gamma emissions. Strontium-90 is a relatively important ingestion hazard (ingestion SF = 3.6E-11 pCi^{-1}). Strontium-90 has a physical half-life of 28.8 years. Yttrium-90 has a short half-life (64 hr) and, therefore, exists in equilibrium with its parent. Being chemically similar to calcium, this element deposits in the bone and is removed very slowly. Bone cancer is the primary health effect of concern from intakes of radioactive isotopes of strontium. Strontium-90 is assigned a lung Class D and a gastrointestinal absorption factor of 30%.

Tritium

Tritium (Z = 1) exists in the environment in the form of tritiated water and is, therefore, very mobile. Tritium is readily absorbed, and is distributed uniformly throughout body tissues, providing a whole body dose. It is a pure, low-energy beta emitter and, therefore, represents only an internal hazard. Although tritium has a physical half-life of 12.3 yr, the biological half-life of water is approximately 10 days, significantly limiting the impact of intake. The EPA has derived an SF of 5.4E-14 for oral exposures.

Uranium-238

Uranium-238 (Z = 92) is naturally occurring, as well as manmade. Uranium-238 (half-life of 4.5E-09 yr) is naturally present at 99.27 wt% with respect to the other uranium isotopes. Uranium-238 is the parent of a long decay chain, one daughter of which is uranium-234 (half-life of 2.4E+05 yr). Because uranium is an alpha emitter, it is of greatest concern via the ingestion and inhalation pathways. In addition, daughters of uranium-238 are high-energy gamma emitters and can make the decay chains important external hazards. Following ingestion or inhalation, uranium concentrates in the kidneys and bone. Uranium is assigned a lung Class Y and a gastrointestinal absorption factor of 5%. The proposed national primary drinking water standard for uranium of 30 pCi/L is based on kidney toxicity.

WET CHEMISTRY

Nitrate/Nitrite

Nitrate is an odorless, colorless-to-white, crystalline substance. It is used as a fertilizer, in the manufacture of fireworks, ceramics, rocket propellants, or in the pickling of meats. Toxicity to nitrate has been reported from all routes of exposure (i.e., inhalation, ingestion, or dermal contact). An epidemiologic study on infants routinely fed formula prepared from nitrate-contaminated water has indicated the incidence of methemoglobinemia (i.e., the oxidation of blood hemoglobin to methemoglobin). The nitrate (nitrogen) content in the water ranged from 10 to over 100 ppm. It is important to note that no incidence of methemoglobinemia occurred in drinking water containing less than 10 ppm (10 mg/L) nitrate (nitrogen). Furthermore, it is also noteworthy that subsequent epidemiologic studies have shown that populations (1 to 8 years old) who ingested water containing greater than 10 mg/L nitrate-nitrogen did not have increased levels of methemoglobin. Thus, it was concluded that the most sensitive subpopulation to nitrate toxicity is the 4-kg infant who has high gut content of nitrate-reducing bacteria; a lower enzymatic capacity to reduce the methemoglobin to hemoglobin; and has hemoglobin F, which is more susceptible to oxidation.

An oral RfD of 1.6E+00 mg/kg-d has been derived from the EPA for exposure to nitrate/nitrite. The critical effect is the increased incidence of methemoglobinemia in infants, following the consumption of nitrate-contaminated fluid.

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APPENDIX B

ECOLOGICAL EVALUATION AND RADIOLOGICAL DOSE CALCULATIONS

INTRODUCTION

This appendix discusses the organisms (e.g., plants, animals) living in the Columbia River and its watershed that could be affected by radionuclide contamination from the 100-FR-3 groundwater operable unit and supplements the assumptions and analyses provided in the ecological qualitative risk assessment. This appendix identifies the organisms and provides the dose-response calculations for the ecological evaluation.

ORGANISMS

PLANTS

Three groups of plants constitute the primary producer level of the aquatic ecosystem: phytoplankton, periphyton, and macrophytes. Two of the groups are classified as algae. The algae are (1) phytoplankton--floating, free-living algae drifting with the current in the water column and (2) periphyton--algae colonizing solid substrata, such as rocks. Although the dominant phytoplankton species in the Columbia River are true lentic (lake) forms, many species in the water column are detached periphytic forms that have been washed off of rocks. The periphyton mat commonly found on solid substrata is made up of algae and other organisms; these include microcrustaceans, rotifers, fungi, bacteria, and detritus. These communities are restricted to the margins of the river in the vicinity of the 100 Area where conditions are suitable. Phytoplankton and periphyton are present year round in the Columbia River; populations are highest in spring and summer and lowest in winter.

Macrophytes can be found rooted to the bottom of the river, where the current slackens and fine sediments accumulate in sufficient amounts. Macrophytes are sparse in the Columbia River because of the strong currents, rocky bottom, and frequently fluctuating water levels. Rushes and sedges occur along the shorelines of the slack-water areas, such as the White Bluffs Slough below the 100-K Area, the slough area downstream of the 100-F Area, and the Hanford Slough. Macrophytes are also present along gently sloping shorelines that are subject to flooding during the spring freshet and daily fluctuating river levels. Macrophytes are present during the warmer months and usually die in the winter.

Commonly found macrophytes include lemna, potamogeton, elodea, and myriophyllum, and they have considerable ecological value. Macrophytes are most important as food after they die and decompose into fine particulate detritus. These macrophytes provide food and shelter for juvenile fish and spawning areas for some species of warm-water game fish. However, if some of the exotic macrophytes increase to nuisance levels, they may encourage increased sedimentation of fine particulate matter. This could negatively affect the spawning of salmonids but could increase the range for *Alosa sapidissima* (American shad) by providing more suitable spawning habitat. These changes could significantly impact the trophic relationships of the Columbia River.

HERBIVORES

Organisms that directly feed on the primary producers (usually macrophytes) are herbivores. The common herbivores in the vicinity of the 100 Area include zooplankton, immature insects, molluscs, and herbivorous fish. Zooplankton, insects, molluscs, and herbivorous fish are present at all times. The zooplankton are not abundant in this reach of the river. Immature aquatic insects are one of the basic food items and consist of the larvae and nymphs of several orders of insects. The aquatic insects are usually most abundant during fall and winter, when they mature until they emerge as adults in the spring and summer. Immature insects are most important as a food source in the aquatic system but are also important as adults, for insectivorous birds, such as swallows. Insects also enter the aquatic foodweb after they die if they fall back into the river. Molluscs are neither abundant nor important in terms of energy flow in the ecosystem. However, two species found in the Columbia River are listed as candidates for protection under the *Endangered Species Act of 1973*. These are the *Fisherola nuttalli* (shortfaced lanx), which is a state endangered species candidate, and the *Fluminicolla colombiana* (Columbia pebblesnail), which is both a federal and state candidate. Herbivorous fish, such as some species of suckers, actively graze on the periphyton; Dauble (1986) reported that *Catostomus macrocheilus* (largescale suckers) in the Columbia River feed predominantly on periphyton and insect larvae.

PRIMARY CARNIVORES

Primary carnivores feed on the herbivores. Dominant groups found in the Columbia River include several species of forage fish, *Prosopium williamsoni* (mountain whitefish), and juvenile salmonids. The carnivores in this group use several different sources of food, as shown in Figures B-1 and B-2. This group includes several species of primary concern from an economic, sport, and protected species viewpoint. These are the salmonids, including *Oncorhynchus mykiss* (steelhead trout) and the various species of salmon. The steelhead provides a major sport fishing in and above the 100 Areas. Because the Hanford Reach (which is within the 100 Area) is the last mainstem spawning area for both steelhead and salmon, the potential impacts to these migrating populations must be considered.

SECONDARY CARNIVORES

Secondary carnivores feed on a variety of sources but mainly the primary carnivores. This category includes species present in the river, such as *Micropterus dolomieui* (smallmouth bass), and other organisms in the vicinity of the river, such as *Haliaeetus leucocephalus* (bald eagles), hawks, and swallows.

OMNIVORES

Crayfish are omnivorous and feed on decaying animal and plant tissue. Waterfowl are also omnivores, feeding on macrophytes and primary carnivores.

FISH

Gray and Dauble (1977) list 43 species of fish in the Hanford Reach of the Columbia River. Collection of the *Ictalurus nebulosus* (brown bullhead) began after 1977, bringing the total number of fish species identified in the Hanford Reach to 44 (Table B-1). Of these species, the *Oncorhynchus tshawytscha* (Chinook salmon), *Oncorhynchus nerka* (sockeye salmon), *Oncorhynchus kisutch* (coho salmon), and steelhead trout use the river as a migration route to and from upstream spawning areas and are of great economic importance. The fall Chinook salmon and steelhead trout spawn in the Hanford Reach. The relative contribution of upper river bright stocks to fall Chinook salmon runs in the Columbia River increased from approximately 24% of the total in the early 1980s to 50% to 60% of the total by 1988 (Dauble and Watson 1990). The destruction of other mainstem Columbia River spawning grounds by dams has increased the importance of the Hanford Reach spawning (Watson et al. 1970; Watson 1973).

The upper estimates of the annual average Hanford Reach steelhead trout spawning population, based on dam counts from 1962 to 1971, were approximately 10,000 fish. The estimated annual sport catch from 1963 to 1968 in the reach of the river from Ringold to the mouth of the Snake River was approximately 2,700 fish (Watson 1973).

The American shad, an anadromous species, may also spawn in the Hanford Reach. The upstream range of the shad has been increasing since 1956, when fewer than 10 adult shad ascended McNary Dam. Since then, the number ascending Priest Rapids Dam, immediately upstream from the Hanford Reach, has risen to many thousands per year and the young-of-the-year have been collected in the Hanford Reach. The shad is not dependent on specific current and bottom conditions required by the salmonids for spawning and has apparently found favorable conditions for reproduction throughout much of the Columbia and Snake rivers.

Other fish of importance to sport fisherman are the whitefish, *Acipenser transmontanus* (white sturgeon), smallmouth bass, *Pomoxis annularis* and *nigromaculatus* (white and black crappie), *Ictalurus punctatus* (channel catfish), *Stizostedion vitreum vitreum* (walleye), and *Perca flavescens* (yellow perch). Large populations of rough fish, including *Cyprinus carpio* (carp), *Richardsonius balteatus* (redside shiners), suckers, and *Ptychocheilus oregonensis* (northern squawfish), are also present.

DOSE - RESPONSE CALCULATIONS

DOSE OF CONSTITUENTS OF CONCERN TO AQUATIC RECEPTORS.

This section describes the methods used to estimate radiological dose to aquatic organisms. The general response of aquatic organisms to ionizing radiation occurs at both the cellular and biochemical levels. The level of response is also controlled to some extent by environmental factors. Stressor-response relationships developed in a report by the National Council of Radiation Protection (NCRP) were based on *Effects of Ionizing Radiation on Aquatic Organisms* (NCRP 1991).

For ionizing radiation, the sensitivities of aquatic organisms to acute exposure during early developmental stages has a threshold of approximately 3 rad for the one-cell stage of development.

Radiosensitivity has been reported to decrease with increasing level of embryo development (Frank 1971). From laboratory studies, early life stages of Chinook salmon appear to be the most sensitive for fish. Damage has been reported to occur when the dose reached 9.64 rad/day over an 81-day development period (Hyodo-Taguchi 1980). Studies from Frank (1971) have shown that 224 rad reduced female germ cells in Chinook salmon. Frank (1971) has also shown that 600 rad reduced female germ cells in rainbow/steelhead trout.

Few studies have evaluated the effects of chronic exposure to ionizing radiation. The report by the NCRP (1991) stated that Chinook salmon chronically exposed to 5.1 rad/day for up to 69 days as embryos and alevins up to release as smolts produced no increase in mortality. Hershberger et al. (1978) reported lower return of spawning adult Chinook salmon after exposure of eggs and alevins to approximately 10 rad/day of gamma radiation. Gonadal development was retarded in Chinook salmon on exposure to 10 rad/day (Bonham and Donaldson 1972). Frank (1971) also shows that spermatogenesis of adult *Ameca splendens* was disrupted at an accumulated dose of 95 rad after 5 days.

For radionuclides, effects are assessed based on DOE Order 5400.5 (DOE 1989), which states that dose to aquatic animals should not exceed 1 rad/day. Based on available literature, it would appear that DOE Order 5400.5 is sufficiently conservative with regard to dose to protect most aquatic organisms. Because of its conservative nature, it should protect populations and the ecosystem in general until additional data indicate otherwise. One qualifier to this is the work of Erickson (1973), who reported reduced male *Poecilia reticulata* (guppy) courting activity when embryos had been exposed to 0.4 rad/day. However, little information exists with regard to behavioral changes in fish from exposure to ionizing radiation.

Exposure parameters for each organism are summarized by Baker and Soldat (1992). Doses from radionuclides are calculated, based on the computer code developed by Baker and Soldat (1992) for the CRITR2 computer model.

Total daily doses to an organism are estimated as the sum of doses (weighted by energy of radiation) received from all radioactive elements ingested, residing in the body, and available in the organism's environment. CRITR2 is a steady-state model that assumes exposed organisms reach an equilibrium with the water concentration or food uptake.

The internal total-body dose rate to an organism for N radionuclides is given as

$$R_c = \sum_{i=1}^{N} b_{i,c} \, E_{i,c} \qquad \text{(B-1)}$$

where R_c = dose rate to total body of organism c (rad/day)
$b_{i,c}$ = specific body burden of radionuclide i in organism c (Ci/kg)
$E_{i,c}$ = effective absorbed energy rate for radionuclide i per unit activity in organism c (kg-rad/Ci-day).

$$E_{i,c} = \epsilon_{i,c}(\text{MeV/dis}) \times 3.70\text{E}+10\ (\text{dis/s-Ci})$$
$$\times\ 86{,}400\ (\text{s/day}) \times 1.602\text{E-}11\ (\text{kg-rad/MeV}) = 5.12\text{E}04 \times \epsilon_{i,c}$$

where ϵ = effective absorbed energy for radionuclide i in organism c.

For a primary organism,

$$b_{i,c} = C_{i,c}\, B_{i,c} \times CF \qquad \text{(B-2)}$$

where $C_{i,c}$ = concentration of radionuclide i in water to which organism c is exposed (Ci/L)
$B_{i,c}$ = bioaccumulation factor for radionuclide i and organism c (m^3/kg).
CF = conversion factor [0.001 (L/m^3)].

Combining equations (B-1) and (B-2) yields the dose rate (rad/day) to the primary organism.

$$R_c = \sum_{i=1}^{N} C_{i,c}\, B_{i,c}\, \epsilon_{i,c} \qquad \text{(B-3)}$$

For the secondary organism, such as herbivores and carnivores, an expression can be written for a single radionuclide, equating the change in body burden to the uptake and removal of the radionuclide.

$$\frac{db^s}{dt} = \frac{P}{M} - \lambda b^s \qquad \text{(B-4)}$$

where b^s = specific body burden of the secondary organism (Ci/kg)
M = mass of secondary organism (kg)
P = rate of uptake of radionuclide by body of organism (Ci/d)
λ = ($\lambda_b + \lambda_r$) effective decay constant in secondary organism (d^{-1})

where $\lambda_b = \ln(2)/T_b$ is the biological removal rate constant for the radionuclide in the secondary organism

λ_r = $\ln(2)/T_r$ is the radiological decay constant for the radionuclide.

The secondary organism uptake rate is given by

$$P_i = b_i\, U_i\, f_{1,i} \qquad \text{(B-5)}$$

where b = body burden of primary organism (Ci/kg)
U = intake rate of primary organism by predator (kg/d)
f_1 = fraction of radionuclide initially retained in total body of secondary organism (unitless).

Solving equation (B-4) with $b^s = 0$ when $t = 0$ yields

$$b^{s_i} = \frac{P_i}{M} \frac{(1-e^{-\lambda_i T_e})}{\lambda_i} \tag{B-6}$$

where T_e = period of exposure (d).

Then, for a secondary organism c, the dose rate in terms of the body burden of the primary organism or prey for N radionuclide is

$$R_c = \sum_{i=1}^{N} \frac{b_{i,c} U_c f_{1,i}}{M_c} \frac{(1-e^{-\lambda_{i,c} T_e})}{\lambda_{i,c}} E_{i,c} \tag{B-7}$$

where U_c = intake rate of primary organism by secondary organism c (kg/d)
M_c = mass of secondary organism c (kg)
$\lambda_{i,c}$ = effective decay constant of radionuclide i in secondary organism c (d^{-1}).

In the absence of specific data, the removal constants, $\lambda_{i,c}$, and uptake fractions, $f_{1,i}$, are taken to be that of standard man as derived from Publication 2 of the International Commission on Radiological Protection (ICRP 1959). The values of effective energy, $\epsilon_{i,c}$, were determined knowing the effective radius of the organism. The exposure time, T_e, is usually assumed to be 1 year for regulatory purposes, and the concentration is averaged over 1 year.

Figure B-1. Columbia River Aquatic Ecosystem.

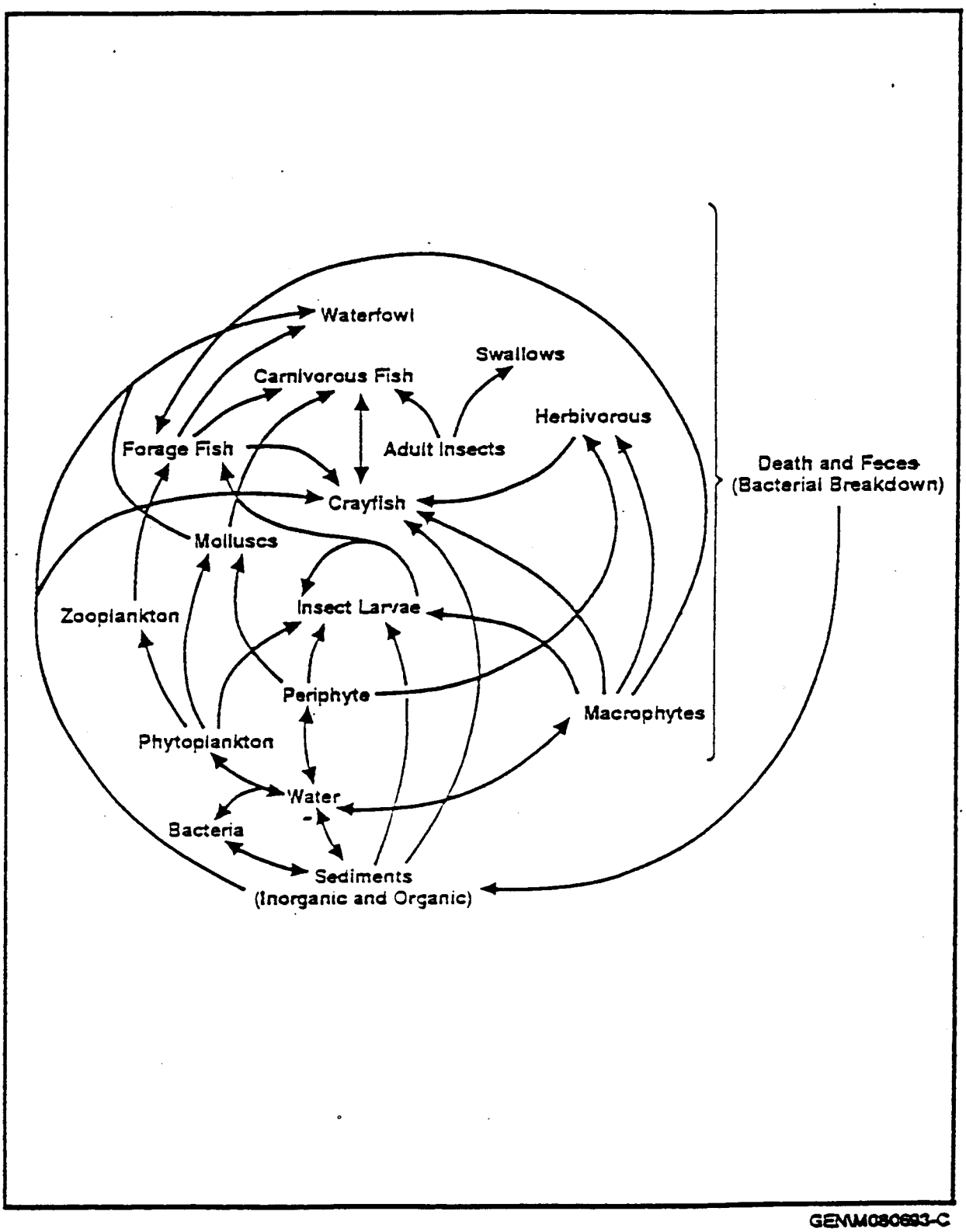

Figure B-2. Conceptual Model of Foodweb Relationships.

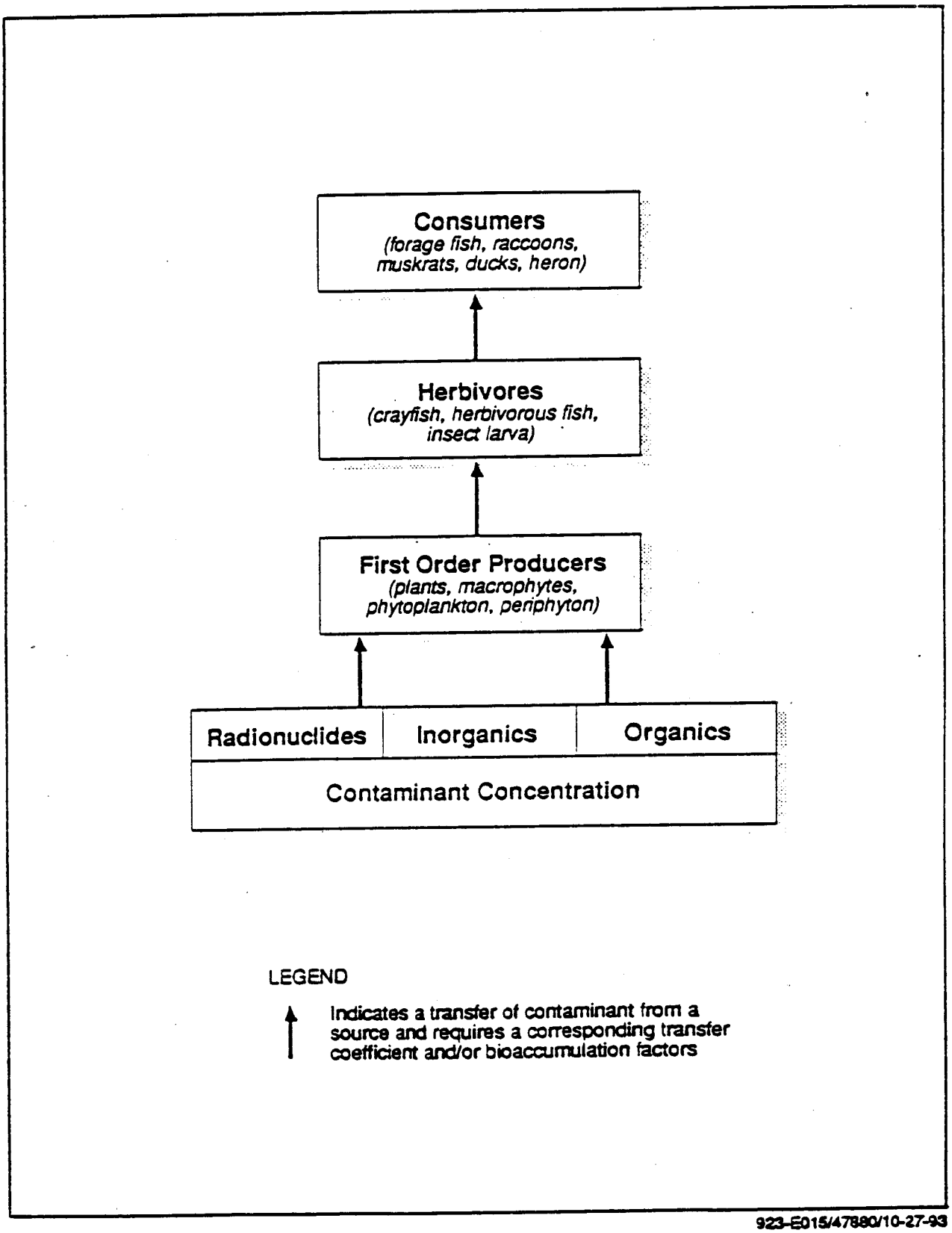

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Table B-1. Fish Species in the Hanford Reach of the Columbia River.

Common Name	Scientific Name
White sturgeon	*Acipenser transmontanus*
Bridgelip sucker	*Catostomus columbianus*
Largescale sucker	*Catostomus macrocheilus*
Mountain sucker	*Catostomus platyrhynchus*
Pumpkinseed	*Lepomis gibbosus*
Bluegill	*Lepomis macrochirus*
Smallmouth bass	*Micropterus dolomieui*
Largemouth bass	*Micropterus salmoides*
White crappie	*Pomoxis annularis*
Black crappie	*Pomoxis nigromaculatus*
American shad	*Alosa sapidissima*
Prickly sculpin	*Cottus asper*
Mottled sculpin	*Cottus bairdi*
Piute sculpin	*Cottus beldingi*
Reticulate sculpin	*Cottus perplexus*
Torrent sculpin	*Cottus rotheus*
Chiselmouth	*Acrocheilus alutaceus*
Carp	*Cyprinus carpio*
Peamouth	*Mylocheilus caurinus*
Northern Squawfish	*Ptychocheilus oregonensis*
Longnose dace	*Rhinichthys cataractae*
Leopard dace	*Rhinichthys falcatus*
Speckled dace	*Rhinichthys osculus*
Redside shiner	*Richardsonius balteatus*
Tench	*Tinca tinca*
Burbot	*Lota lota*
Threespine stickleback	*Gasterosteus aculeatus*
Black bullhead	*Ictalurus melas*
Yellow bullhead	*Ictalurus natalis*
Brown bullhead	*Ictalurus nebulosus*
Channel catfish	*Ictalurus punctatus*
Yellow perch	*Perca flavescens*
Walleye	*Stizostedion vitreum vitreum*
Sand roller	*Percopsis transmontana*
Pacific lamprey	*Entosphenus tridentatus*
River lamprey	*Lampetra ayresi*
Lake whitefish	*Coregonus clupeaformis*
Coho salmon	*Oncorhynchus kisutch*
Sockeye salmon	*Oncorhynchus nerka*
Chinook salmon	*Oncorhynchus tshawytscha*
Mountain whitefish	*Prosopium williamsoni*
Cutthroat trout	*Oncorhynchus clarki*
Rainbow trout (steelhead)	*Oncorhynchus mykiss*
Dolly Varden	*Salvelinus malma*

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