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Ecological Risks of DOE's Programmatic Environmental Restoration Alternatives

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DISCLAIMER

The results contained in this report are based on source term data that are incomplete because none of the facilities evaluated have been fully characterized. We assume that the information given to us is representative of the number, size, and kinds of contaminated sites present. An assessment based on this kind of data should be sufficient for comparing relative risks and benefits of broad program alternatives (e.g., cleanup to Applicable and/or Relevent and Appropriate Requirements (ARARS) vs. use of land-use restrictions). This assessment is not, however, intended to accurately characterize the true ecological risks of contaminated sites present at the facilities described in this report. This level of detail can be achieved only through site-specific assessments performed to satisfy facility-level Comprehensive Environmental Response Compensation and Liability Act (CERCLA) and National Environmental Protection Agency (NEPA) requirements.

CONTENTS

LIST OF ACRONYMS AND INITIALISMS

ARARS	Appropriate, Relevant, and Applicable Requirements
BLM	Bureau of Land Management
CEQ	Council on Environmental Quality
CERCLA	Comprehensive Environmental Response Compensation and Liability Act
DOE	U.S. Department of Energy
EIS	Environmental Impact Statement
ER	Environmental Restoration
FEMP	Fernald Environmental Management Project
HI	Hazard Index
INEL	Idaho National Engineering Laboratory
MEPAS	Multimedia Environmental Pathways Assessment System
NEPA	National Environmental Protection Agency
NOAEL	no-observable-adverse-effects level
NWI	National Wetland Inventory
ORNL	Oak Ridge National Laboratory
ORR	Oak Ridge Reservation
PEIS	Programmatic Environmental Impact Statement
PNL	Pacific Northwest Laboratory
TWRA	Tennessee Wildlife Resources Agency
WM	Waste Management

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ECOLOGICAL RISK ASSESSMENT FOR THE ENVIRONMENTAL RESTORATION PROGRAMMATIC ENVIRONMENTAL IMPACT STATEMENT

EXECUTIVE SUMMARY

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This report assesses the ecological risks of the Department of Energy's (DOE) Environmental Restoration Program. The assessment is programmatic in that it is directed at evaluation of the broad programmatic alternatives outlined in the DOE Implementation Plan. It attempts to (1) characterize the ecological resources present on DOE facilities, (2) describe the occurrence and importance of ecologically significant contamination at major DOE facilities, (3) evaluate the adverse ecological impacts of habitat disturbance caused by remedial activities, and (4) determine whether one or another of the programmatic alternatives is clearly ecologically superior to the others.

Methodology Overview

The assessment focuses on six representative facilities: the Idaho National Engineering Laboratory (INEL); the Fernald Environmental Management Project (FEMP); the Oak Ridge Reservation (ORR), including the Oak Ridge National Laboratory (ORNL), Y-12 plant, and K-25 plant; the Rocky Flats Plant; the Hanford Reservation; and the Portsmouth Gaseous Diffusion Plant. Six generic categories of ecological resources of concern were evaluated for each facility: threatened and endangered species, wetlands, recreational fish and wildlife, agriculture and timber production, parks and public lands, and general biodiversity. Specific resources (e.g., receptor species and communities) belonging to these categories were identified for each facility and, where possible, the spatial patterns of occurrence of these resources were described.

Information on the types, quantities, and distributions of contaminants on the six facilities was obtained from the Pacific Northwest Laboratory (PNL) Source Term Database; concentrations in soil, water, and sediment were obtained from the human exposure and risk assessment team in ORNL's Health Sciences Division. Estimates of the toxicity of radionuclides and chemical contaminants to aquatic biota, wildlife, and terrestrial plants were obtained from the published literature. These three kinds of information were used to perform a screening-level ecological risk assessment. The objectives of this assessment were (1) to separate those contaminants that clearly pose no risk at levels believed to be present from those contaminants that might be ecologically hazardous, and (2) to develop a rough rank ordering of the importance of different contaminants and the vulnerability of different biological resources. Risk assessments of this type are termed "screening-level" assessments because they do not include enough site or species-specific information to permit firm conclusions about the actual magnitude of risk present.

Finally, the significance of the potential risks identified in the screening-level risk assessment performed for each facility was addressed in a cumulative impact assessment. In this assessment an attempt was made to provide an ecological context for the contaminant risks by comparing the home rages of individual organisms and the distribution of species to the area believed (based on PNL's source-term data) to be contaminated. For the two most extreme of the alternatives identified in the Programmatic Environmental Impact Statement (PEIS) Implementation Plan [the Appropriate, Relevant, and Applicable Requirements (ARAR) alternative and the Restricted Land Use alternative], relative degrees of contaminant risk reduction and habitat disturbance impact were evaluated and compared.

Below is a summary of major findings and conclusions.

Ecological Resources at Risk

The DOE facilities collectively represent an important reservoir of biological diversity. The three largest reservations examined (Oak Ridge, INEL, and Hanford) occupy up to several hundred square miles of land. Only small fractions of these reservations are occupied by developed facilities; most of the undeveloped land has been isolated from major human intrusions (except for grazing at INEL and forestry at Oak Ridge) for up to 50 years. All three of these reservations are large enough to support substantial populations of wildlife and all contain species (including federal and state-listed species) and ecosystem types that are becoming rare in surrounding regions due to rapid increases in agricultural industrial, and residential development. All three reservations are included in DOE's National Environmental Research Park system.

The three smaller facilities examined (Rocky Flats, Fernald, and Portsmouth) were more variable in terms of ecological value but all contain some ecological resources. Rocky Flats, the most diverse and least disturbed of the three, contains many small, perennial wetlands and is utilized by the bald eagle, peregrine falcon, and several other endangered species. Fernald and Portsmouth were heavily disturbed by agricultural activities prior to acquisition by DOE; they nevertheless contain small areas of wetland and hardwood forest and provide habitat for a variety of wildlife.

Although they were not specifically examined in this study, available information suggests that other large DOE reservations such as the Savannah River Site, Los Alamos National Laboratory, and Nevada Test Site are probably as ecologically rich as are Oak Ridge, INEL, and Hanford. Smaller facilities may contain significant ecological resources in buffer zones surrounding developed plant areas.

Ecological Risks of Existing Contamination

The screening-level risk assessments showed that potentially ecologically significant contamination exists at all of the facilities examined. Although radionuclides are the most widespread environmental contaminants, heavy metals, PCBs, and other organic contaminants appear to be present in potentially toxic quantities on most facilities. Both aquatic and terrestrial biota were found to be at risk.

Although the most contaminated sites appear, based on PNL's data, to be highly hazardous to biota, the areal extent of these sites appear to be quite small. The spatial extent of contamination appears limited to relatively small fractions (1 to 25%, including developed plant areas) of most facilities. Most of these contaminated areas are waste disposal sites (trenches, burial grounds, etc.) or developed plant areas that are already highly disturbed and provide poor habitat for most biota. Surface water and sediment, including waste ponds, are important exceptions to this generalization. These habitats, some of which are relatively undisturbed streams, are far more important ecologically than is indicated by there surface area relative to the area of an entire reservation. Aquatic habitats such as streams, ponds, and wetlands are utilized by a wide variety of biota, including fish and terrestrial vertebrates (waterfowl, deer, fish-eating birds and mammals). Sediment and flood-plain soil are major sinks for many radionuclides and toxic chemicals, especially in regions were rainfall is abundant (e.g., Oak Ridge). Waste ponds themselves can be important ecological resources, especially in the arid West where they may be the only available surface water during large parts of the year.

Evaluation of Alternatives

Remedial actions taken to reduce human and ecological exposure to contaminants often involve removal of large quantities of soil or sediment. Roads and support facilities are also required. These activities cause adverse ecological impacts that must be balanced against the benefits of contaminant reduction. The alternatives described in the PEIS Implementation Plan differ significantly in terms of the degree of contaminant removal and concomitant habitat disturbance. The ES-1 summariezes result of a bounding analysis of the three most extreme alternatives included in the PEIS: the No Action alternative, th e ARAR alternative, and the Restricted Land Use alternative. Only radioncuclides were examined, but the results of the analysis probably are representative of other contaminants as well. The ARAR alternative involves the greatest contaminant removal and also the greatest habitat disturbance. The Restricted Land Use alternative involves little or no contaminant reduction but also little or no habit disturbance. The land use restricitions associated with this alternative would presumably preserve existing ecological resources and might also permit recovery of resources affected by past DOE activities. The No Action alternative would similarly minimize habitat disturbance, however, in the absence of land use restriction future development could lead to modification or destruction of existing ecosystems.

None of the alternatives appeared clearly preferable from an ecological perspective. Remediation alternatives focused on human health risk reduction, so that ecological risks are reduced only if they invole significant human exposures. In general, for extremely large reservations such as Hanford and INEL, the fraction of the total reservation area contaminated by past DOE activities is small enough that habitat disturbance impact appear negligible as well. For small facilities such as Rocky Flats and Fernald relatively large (up to 25%) fractions of the total reservation areas could be disturbed under the ARAR alternative. The benefit gained from contaminant removal at these sites could be relatively large, if the areas remediated are restored to a natural or semi-natural condition. For either alternative, the resources most likely to be at risk are (1) endangered and threatened species (because even very small impacts on the species have regulatory significance) and (2) wetlands and aquatic ecosystems. The optimal approach for minimizing ecological risks is probably an intermediate strategy in which remediation activities are focused on sites of highest contamination, where the degree of habitat disturbance per unit contaminant removed is the smallest. Specific remedial priority decisions would be made at the level of the individual facility's Environmental Restoration Program.

Uncertainties

Key uncertainties limiting this assessment include the (1) validity of source-term estimates, (2) the actual distribution of receptor species on the facilities relative to sites where contamination is present, and (3) the unknown degree of conservatism of the transfer coefficients and toxicity benchmarks used in the hazard assessment. The first two uncertainties can be addressed in facility-specific assessments that focus on optimizing the balance between remediation and habitat preservation based on reservation-wide distributions of contaminants and ecological resources. The third uncertainty is a function of the state-of-the-science of environmental toxicology; it can be reduced by performing (1) periodic updating of the toxicological data base as new information becomes available from the scientific community, and (2) field studies at the DOE facilities to generate site-specific exposure and effects data.

Table ES-1 - *Summary of Ecological Risks and Benefits of ER Alternatives*

Facility	Total Area (acres)	Resources at[1] Risk	Alternative[2]	% Risk Reduction[3]	% Facility Disturbed[4]
INEL[5]	570,000	Soil: none Water (waste ponds): wildlife, endangered species	No Action	Soil: NR Water: 0	0
			ARAR	Soil: NR water: 0	0.03
			Restricted land use	Soil: NR Water: 0	0
Hanford[6]	365,700	Soil: none Water (waste ponds): wildlife, endangered species	No Action	Soil: NR Water: 0	0
			ARAR	Soil: NR Water: 98	0.1
			Restricted land use	Soil: NR Water: 0	0.02
Fernald[7]	1050	Soil: wildlife, endangered species, biodiversity Water: fish	No action	Soil: 0 Water: 0	0
			ARAR	Soil: 99.95 Water:0.0	19
			Restricted land use	Soil: 0 Water: 0	19
Oak Ridge Reservation[8]	37,500	Soil: wildlife, endangered species, biodiversity Water: fish, wetlands	No action	Soil: 0 Water: 0	0
			ARAR	Soil: 99.99 Water: 99.5	1.1
			Restricted land use	Soil: 0 Water: 0	0.8
Rocky Flats[9]	6550	Soil: wildlife, endangered species, biodiversity Water: wetlands	No action	Soil: 0 Water: 0	0
			ARAR	Soil:99.99 Water:>99.99	26
			Restricted land use	Soil: 0 Water: 0	6

[1]Resources at risk are defined separately, by principal exposure medium. Resources were determined to be "at risk" if (1) the are present on the facility and possibly present in known contaminated areas, and (2) comparison of estimated contaminant concentrations to regulatory criteria or other toxicological benchmarks indicates a moderate or severe risk to organisms inhabiting contaminated areas.

[2]Alternatives are defined in the PEIS Implementation Plan.

[3]Percentage reduction in contaminant exposure, as approximated by % reduction in risk to on-site farmers. Radionuclides were used ans reference contaminants.

[4]% of total facility area either temporarily or permanently disturbed by remedial activities. Estimates include adjustments for access roads and soil borrow areas.

[5]Major areas of INEL containing contaminated soil (e.g., the Radioactive Waste Management Complex) are already heavily disturbed and provide poor habitat for terrestrial biota, hence, terrestrial resources are not at risk. Contaminated waste ponds are utilized by wildlife, hence these resources are considered to be at risk for purposes of the PEIS. None of the remediation alternatives for INEL include remediation of waste ponds.

[6]Major areas of Hanford containing contaminated soil are already heavily disturbed and provide poor habitat for terrestrial biota, hence, terrestrial resources are not at risk. Contaminated waste ponds are utilized by wildlife, hence these resources are considered to be at risk for purposes of the PEIS.

[7]Wildlife have free access to contaminated areas; aquatic resources at risk include waste ponds and statutory wetlands. None of the remediation alternatives for Fernald include remediation of waste ponds or wetlands.

[8]This facility has many widely-dispersed contaminated areas; wildlife have free access to many of these. Contaminated aquatic resources include both on-site waste ponds and on- and off-site streams.

[9]Wildlife have free access to some contaminated areas. Small wetlands are widely dispersed over the site.

[10]NR = no resources at risk

CHAPTER 1: INTRODUCTION

This report presents an assessment of impacts of environmental restoration and (ER) alternatives to be included in the Programmatic Environmental Impact Statement for Implementation (PEIS) of an Integrated Environmental Restoration and Waste Management Program (ER PEIS) by the U.S. Department of Energy (DOE). Impacts addressed in this report include current contamination, residual contamination following remedial action, and adverse ecological impacts of remediation and new facility construction.

The impacts assessment focuses on cumulative impacts of ER activities on reservation-wide ecological resources. Of the 30 facilities discussed in the ER PEIS, eight are singled out for detailed ecological risk assessments: the Idaho National Engineering Laboratory (INEL), the Hanford Reservation, the Fernald Environmental Management Project (FEMP),the Rocky Flats Plant (RFP), the Portsmouth Gaseous Diffusion Plant (PORT), and the three facilities [Oak Ridge National Laboratory (ORNL), Y-12 Plant, and K-25 Site] occupying the Oak Ridge Reservation (ORR).

The assessment process consists of the following five tasks:

1. Description of climatic regime and ecosystem types, drawn from environmental data available for each reservation. This information includes meteorology, surface and subsurface hydrology, topography, soil and vegetation types, land use, and ecology (aquatic and terrestrial). Locations of ecological resources falling into the six endpoint categories identified in chapter 2 were identified from site maps. Site maps were also used to identify areas for which ER activities are planned.

2. Specification of exposure pathways linking ER activities to ecological endpoints. Exposures considered include exposures to contaminants and physical disturbances caused by the remedial actions themselves.

3. Estimation of the exposure of ecological resources to habitat disturbance associated with site remediation.

4. Assessment of the ecological effects associated with contaminant exposure and physical disturbance. This task draws on current information on acute toxicity, chronic toxicity, and bioaccumulation of contaminants included in the source-term inventories developed for the ER PEIS.

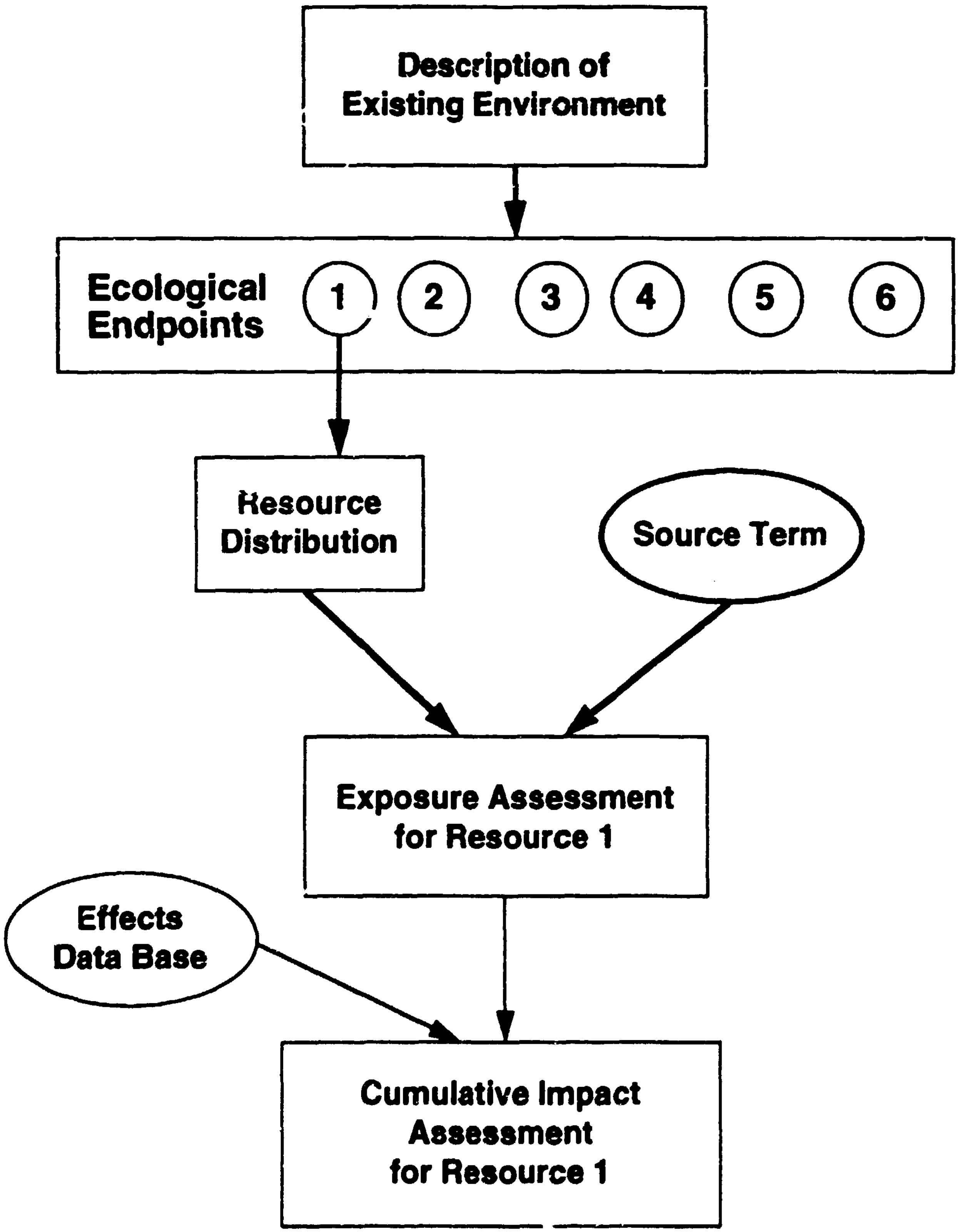
5. Evaluation of the cumulative ecological impact of remedial activities on ecological resources on or near the reservations included in the assessment.

The general procedure for the ecological risk assessment is shown in figure 1-1. First, the specific ecological resources falling into each of the six endpoint categories defined in chapter 2 are identified from documents, maps, and contacts with resource management personnel at each site. The distribution of each resource on and near the facilities is mapped. These resource distributions are overlaid on the distributions of ER activities at each facility. General locations of activities are available from the site ER programs. For contaminant exposures, transport media are identified and exposures are quantified from (1) existing environmental characterization reports and (2) output from the Multimedia Environmental Pathways Assessment System (MEPAS) (Droppo et al. 1989). For habitat alteration, disturbed areas are estimated for each remedial action or construction activity including both the actual contamination site and the surrounding area expected to be disturbed by road construction, dust, erosion, or noise.

The programmatic alternatives for both the ER and the waste management (WM) components of the PEIS consist of many individual remedial actions or waste types. The exposure assessment for each alternative consists of (1) estimates of the types and, if possible, quantities of contaminants to which each endpoint is exposed; and (2) the total area of habitat disturbed by restoration or construction activities (figure 1-1).

Researchers performed cumulative impact assessments (figure 1-1) for each endpoint by (1) using information on ecological effects of the identified contaminants to evaluate the likelihood of adverse impacts due to contaminant toxicity or bioaccumulation, and (2) comparing the area disturbed with the total area occupied by the resource.

Chapter 2 of this report describes the general classes of ecological resources for which impacts are addressed. These are often termed assessment endpoints in the ecological risk assessment literature (Suter and Barnthouse 1993). Chapter 3 describes the method to be used for cumulative impact assessment. Chapters 4-9 present the results obtained for the six reservations addressed in this report. appendices A and B present detailed documentation of the methods and data used for the assessments.


Description of
Existing Environment
Ecological
Endpoints
1
2
3
4
5
6
Resource
Distribution
Source Term
Exposure Assessment
for Resource 1
Effects
Data Base
Cumulative Impact
Assessment
for Resource 1

CHAPTER 2: ECOLOGICAL ENDPOINTS

This chapter describes the ecological resources to be addressed in the ecological impact sections of the ER PEIS. Once identified, these resources will serve as endpoints for the ecological risk assessment components of the PEIS, in the same way that cancerous and noncancerous health effects serve as endpoints for health risk assessments.

Any assessment must have defined endpoints. An endpoint is a formal expression of an environmental value to be protected during and after the action for which the assessment is being performed (Suter and Barnthouse 1993). A clear statement of an endpoint is as important to an assessment as a clear statement of a hypothesis is to an experimental research project. Defining an endpoint involves two steps: (1) identifying valued attributes of the environment that are considered to be at risk and (2) defining these attributes in operational terms. Suter and Barnthouse (1993) described five criteria that any endpoint should satisfy:

1. **Societal relevance**. The endpoint should be understood and valued by the public and the decision maker.

2. **Biological relevance**. The endpoint must represent important population or ecosystem characteristics.

3. **Unambiguous operational definition**. The endpoint must be explicitly defined.

4. **Accessibility to prediction and measurement**. The endpoint must be empirically measured or estimated; otherwise, an assessment of impacts on that endpoint is impossible.

5. **Susceptible to the hazardous agent**. The endpoint must be susceptible to exposure to the stress being evaluated; otherwise, there is no point in performing an assessment.

For the ER PEIS, selection of endpoints involved identification of (1) general categories of ecological resources that meet the criteria of Suter and Barnthouse (1993) and are inclusive of the ecological resources present on DOE facilities, and (2) for each facility, the specific resources (i.e., receptors) falling into those categories. Following are the descriptions of the six ecological endpoints used in this assessment.

1. **Threatened and endangered species**. Species that are legally protected under federal or state endangered species acts have by definition societal relevance. Because of the rarity of the endangered species, losses of even a small amount of habitat or a few individual organisms can have potentially adverse impacts on populations of those species. Population characteristics are amenable to study with the use of standard field techniques and hence meet the criteria of unambiguous operational definition and accessibility to prediction and measurement. Contaminants related to DOE operations or adverse impacts of remedial actions, including construction activities related to the ER/WM Program, may affect organisms or habitats at DOE facilities. Federally or state-listed and candidate species are known to occur at each of the facilities.

2. **Wetlands**. Wetlands are also legally protected and hence by definition have societal relevance. They are important for flood control and natural biodegradation of pollutants, and as spawning and nursery habitat for many fish and wildlife species. Methods for assessing wetland status are well developed, and data on wetlands are available for each of the DOE facilities.

3. **Recreational fish and wildlife**. Many species of fish and wildlife valued for recreation flourish on and in the immediate vicinity of DOE facilities. Methods for study of fish and wildlife populations are well developed, and some of the facilities with wildlife management programs have conducted wildlife population studies.

4. **Agricultural or timber production**. Portions of some DOE reservations are managed for timber, livestock, or crop

production. Although DOE activities do not threaten the survival of managed crops or forests, reductions in the productivity or marketability of these resources constitute valid endpoints for ecological risk assessment.

5. **Parks and other public lands**. Several of the DOE reservations border state parks, national forests, or other public lands. Contaminants migrating off DOE property may affect these other public lands; moreover, many wildlife species migrate freely between DOE and non-DOE lands so that actions having adverse impacts on DOE-resident populations can have impacts on wildlife inhabiting non-DOE land as well.

6. **Biodiversity**. The worldwide decline and disappearance of species and communities, generally termed loss of biodiversity, is attracting both scientific debate (Wilson 1988) and public attention (May 1992). As a result, special consideration of impacts to biodiversity is now part of the National Environmental Policy Act (NEPA) process (CEQ 1993). Generally, biological diversity is considered from the perspective of regional or local ecosystem diversity, species diversity, genetic diversity, and relationships and interactions among species (CEQ 1993). Global and large-scale biodiversity issues are more difficult to translate into endpoints, but assessment is possible if specific taxonomic groups or well-defined community types can be identified as being "at risk." For purposes of this assessment, species or communities that do not otherwise have explicit legal protection are defined as at risk if (1) they belong to a taxonomic group known or suspected to be declining worldwide, (2) they are rare outside areas that are protected from disturbance or development, or (3) they are a critical component of a larger landscape. Because of their long isolation from human influence, many DOE reservations provide refuge for such species and communities. Examples of the worldwide loss of biodiversity include the worldwide decline of amphibians, bats, and neotropical migratory birds (McCracken 1988; Blaustein and Wake 1990; Terborgh 1989). Wild stocks of anadromous salmonid fishes are also declining in many regions (Nehlsen et al. 1991); most of the wild stocks in the upper Columbia River basin in the northwestern United States are being considered for protection under the Endangered Species Act. Some types of plant communities are susceptible to invasion by nonnative species, especially after disturbance (Cheater 1992), and other once-common plant communities have become rare because land has been converted for agricultural use or urban/suburban development.

CHAPTER 3: INTEGRATION AND EVALUATION

BACKGROUND

Action-forcing requirements in the National Environmental Policy Act of 1969 (NEPA) (Sect. 102) and Council on Environmental Quality (CEQ) regulations that implement NEPA require analysis of potential cumulative impacts in environmental impact statements (EISs) [40 (CFR) Pts. 1508.7 and 1508.8]. Cumulative impact is defined as "... the impact on the environment which results from the incremental impact of the action when added to other past, present, and reasonably foreseeable future actions regardless of what agency (Federal or non-Federal) or person undertakes such other actions. Cumulative impacts can result from individually minor but collectively significant actions taking place over a period of time."

The concept of cumulative ecological impacts is still evolving, and researchers, regulators, and managers may differ in the emphasis placed on various aspects. However, there is a general agreement that cumulative impact assessment examines the consequences of multiple sources of environmental disturbance that impinge on the same set of valued environmental components. The characteristic "multiple" nature of the sources of cumulative impacts may arise in three ways: (1) the same kind of source recurs sufficiently frequently through time; (2) the same kind of source recurs sufficiently densely through space; and (3) different kinds of sources impose similar consequences on a valued environmental component, such that the individual disturbances cannot be assimilated by the natural environment. The key components of an analysis should (1) identify a threshold of acceptable effect (i.e., within a regulatory standard or by public perception) and (2) determine the extent to which the proposed action or actions add to effects from other actions in approaching or exceeding that threshold.

The cumulative effects analysis for the PEISs differs from those in most site-specific EISs in that it is an analysis of proposed actions to remediate unacceptable conditions at existing waste sites. Thus, for some of the ecological endpoints, the cumulative effects of the proposed action(s), when added to other past, present, and reasonably foreseeable future actions, might be beneficial in the long term, whereas short-term impacts might be expected from habitat alteration during remediation. Specifically, the proposed ER alternatives would tend to reduce contaminant exposure risk to ecological endpoints while tending to simultaneously increase risks from construction activities.

The objective of the programmatic cumulative risk assessment is to compare the ecological benefits of remedial activities with the ecological impacts of those activities.

APPROACH

Cumulative risks to ecological endpoints should be considered within the context of well-defined spatial and temporal scales; otherwise, there are endless possibilities that trivialize the effort. The barriers to effective cumulative risk analysis at the programmatic level include a lack of both data and models, particularly at the regional level, and more fundamentally, the limited understanding of environmental processes and how biological effects occur. Chances for success rely on recognition of the important connections on which we need to concentrate. For purposes of this analysis, the relevant spatial scales are local and regional. Relevant temporal scales range from short to long term or permanent. For these analyses, cumulative risks are believed to occur at the local level (e.g., within the reservation) and at the regional level as defined by the region of influence for the human health analyses. Traditionally, cumulative risks at the local level would include risks from existing and planned sources other than those of the proposed actions. In this analyses, cumulative risks at the local level are considered to be the aggregate risks from all restoration or WM activities for each alternative.

Existing sources of contaminants subject to remediation within each reservation are included in the analyses here, and any contaminant releases from future developments would be subject to current Appropriate, Relevant, and Applicable Requirements (ARARs). Although source terms were not available for the reservations in areas not currently considered for remediation, this is believed to be a reasonable approach to assessment of cumulative risks from contaminant exposure for each reservation and will provide adequate information for comparing proposed alternatives.

Construction could result in habitat alteration that would pose direct and indirect risks to the ecological endpoints. Such risks are assumed to be proportional to the amount of habitat altered (i.e., the total area affected on each reservation) as a result of remediation of the contaminated site, soil borrow areas, new roads, and newly constructed waste treatment or storage areas. Risk from construction of current and future projects other than ER/WM projects was excluded from these cumulative analyses because of uncertainty in predicting habitat alteration.

Furthermore, quantitative assessment of cumulative risks to ecological endpoints from regional (i.e., off-site) activities that result in habitat alteration (i.e., urban development, forestry, agriculture) is precluded because of financial constraints and data availability. For regional cumulative analysis of habitat loss, natural ecosystems within the DOE reservations are compared with similar ecosystems in the surrounding regions for each alternative.

Analysis of cumulative risks for the purposes of the PEIS will include on-site and off-site risks to the six ecological endpoints defined in chapter 2. Ecological risks associated with remediation of the three facilities located on ORR are aggregated because they lie or exist within a single contiguous ecosystem. Further aggregation (i.e., across all DOE reservations) is unnecessary because the geographic distances and ecological dissimilarities among reservations are large enough to ensure independence of impacts.

On-site cumulative construction risks consist of the total areas disturbed by capping, soil/ sediment removal, and construction (i.e., roads, waste treatment facilities, and storage areas). Methods used to calculate the total disturbed area for each remediation alternative are described in appendix B.

For on-site cumulative contaminant exposure risks, base-line exposure concentrations were derived from source terms provided by Pacific Northwest Laboratory (PNL) (see appendix B).

There are no scientifically defensible methods for directly comparing or combining habitat disturbance risks and contaminant risks. Thus, these two kinds of risks were addressed separately, and results were summarized in tabular form. A qualitative comparison of these sources of risk was performed by establishing scales of relative severity. For contaminants, a cumulative hazard index (HI) (appendix A) of less than 1 was assumed to indicate no long-term contaminant risk; an HI from 1 to 10 was assumed to indicate a moderate risk, and an HI of 10 or greater was assumed to indicate a potentially severe contaminant risk. A negligible habitat disturbance risk was assumed to exist for a given alternative if less than 3% of the total area of the reservation (or of the habitat occupied by a particular endpoint) was expected to be disturbed; a moderate habitat disturbance risk was assumed to exist if 3–10% of the total reservation (habitat) area was expected to be disturbed; and a severe habitat disturbance risk was assumed to exist if more than 10% of the reservation (habitat) was expected to be disturbed.

CHAPTER 4: IDAHO NATIONAL ENGINEERING LABORATORY

The Idaho National Engineering Laboratory (INEL) reservation covers 230,500 ha (570,000 acres) in Idaho, and elevations range from 1,400 m (4,770 ft) to more than 2,000 m (6,570 ft) at the top of several extinct volcanoes (figure 4-1). All of the reservation was Bureau of Land Management (BLM) land prior to acquisition, and sheep or cattle currently graze on 60% of the reservation (Reynolds 1993). The Little Lost River, Lemhi, Bitterroot, and Beaverhead mountain ranges border INEL on the north and northwest. The Big Lost River, the Little Lost River, and Birch Creek originate in the mountains to the north and west of INEL. These rivers do not usually extend onto the INEL reservation. When flow is adequate, they end in playas within the site boundaries (Tkachyk et al. 1990). Vegetation is principally shrub-steppe; and sagebrush-grassland, juniper-grassland, crested wheatgrass, and giant wild rye are the dominant plant communities. Trees are found in juniper-grassland communities in the foothills to the northwest and southeast and in the riparian communities along the Big Lost River (Arthur et al. 1984). McBride et al. (1978) describe the vegetation in detail, and Adams et al. (1979) describe vegetation and wildlife at the waste management (WM) complex of INEL.

Contaminated sites are associated with facilities that lie mostly in the southwestern portion of the INEL reservation. Additional facilities and associated waste sites are in the southeastern and northern portions of the reservation. No contaminated sites are known to exist in the central region of INEL. According to the ER PEIS source-term data base (appendix A), 4,500 ha (11,000 acres) of the 230,500-ha (570,000-acre) INEL reservation are contaminated, including 15 ha (36 acres) of buried waste and 10 ha (24 acres) of waste ponds. The ER PEIS data base contains data on surface areas of 20% of the waste areas on the INEL reservation. We assumed that these were a representative sample of the surface areas of all waste sites at INEL.

ECOLOGICAL ENDPOINTS AND SPECIES DISTRIBUTION

The dominant ecosystem type on the INEL reservation is shrub-steppe, and there are some trees in the surrounding foothills and riparian areas. Nine federally listed or candidate species are known to visit, breed, winter, or stay year-round (table 4-1). Waste ponds are important wetlands on the reservation, and natural ephemeral wetlands are found along the rivers and in depressions in lava flows. Recreational fish are found in the rivers on the reservation when they contain water, but flow is intermittent on-site. Although hunting is not allowed on most of the site, several recreational wildlife species are present. Sheep or cattle currently graze 60% of the reservation, and the reservation is surrounded by Bureau of Land Management (BLM) and national forest lands. The INEL reservation is a very large, relatively undisturbed, and protected block of native sagebrush-steppe ecosystem. Important species groups of concern for conservation of biodiversity at INEL include bats, raptors, and wintering/migratory wildlife; sensitive habitats include lava tube caves, wintering grounds for wildlife, and wetlands.

Determining risks to endpoints requires (1) defining distribution and composition of endpoints and (2) selecting receptor species. The distribution of endpoints must be known in order to determine both exposure pathways for contaminants and risks to endpoints from construction.

For purposes of determining risk of exposure to contaminants, distribution of endpoints is considered to be either ubiquitous (i.e., more or less uniformly distributed throughout the reservation or region), discrete (i.e., located in one clearly identified location), or discontinuous (i.e., found in several locations within a limited area or areas). Risks to ubiquitous endpoints are assumed to be related to the total surface area

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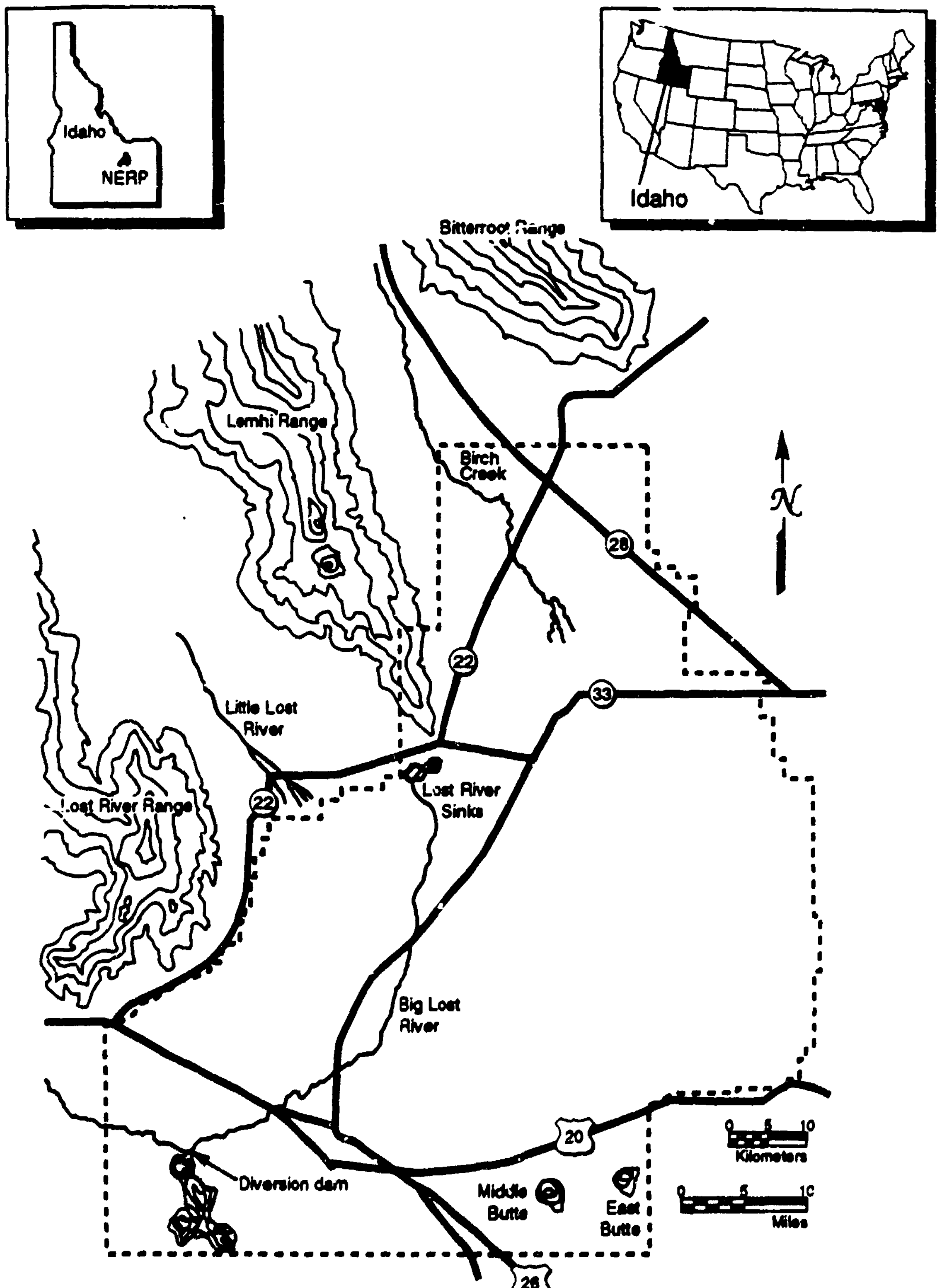

Idaho National Engineering Laboratory

TABLE 4-1—*Distribution of Endpoints on the Idaho National Engineering Laboratory*

Ubiquitous	Discontinuous	Discrete
Resident, breeding, and wintering **federally listed and candidate species** Lava tube caves[1] (**biodiversity**) Small playa **wetlands** in lava flows **Recreational wildlife** Important components of **biodiversity** not included in the above (bats, food sources for protected species, sagebrush communities)	**Wetlands** and riparian vegetation along rivers Waste pond **wetlands** and associated migratory waterfowl (**biodiversity, recreational wildlife**) **Recreational fish** when water flow in rivers is sufficient	Grazing land for sheep and cattle (**agricultural production**) **Public lands** surrounding the reservation

[1] The distribution of all lava tube caves at INEL is not documented, and we assume they are found throughout the reservation.

affected by contaminant exposure or by disturbance from remediation. Risks to discontinuous and discrete endpoints are determined if their locations are known to be within contaminated areas or within areas affected by remedial activities or contaminant exposures.

As a result of the relative ecological uniformity of the INEL reservation, most endpoints are ubiquitous (table 4-1). Exceptions are wetlands and associated species, which are discontinuous along the rivers and waste ponds, and grazing areas on the reservation and surrounding public lands, which are discrete. Locations of endpoints were determined from existing maps and publications, as well as personal communications with ecologists at INEL (Reynolds 1993).

4.1.1 Threatened and Endangered Species

4.1.1.1 Receptors

There are nine federally listed or candidate birds and mammals at INEL but no known federally listed or candidate plants (table 4-2) and no known designated or proposed critical habitats. Of the nine species, four birds (the endangered peregrine falcon and the candidate white-faced ibis, northern goshawk, and black tern) are present only for a few days during migration (Reynolds 1993) and were, therefore, not included in our risk analysis.

The endangered bald eagle is usually present from November through March, mostly in the northern part of the reservation (Reynolds 1993; Arthur et al. 1984). This species roosts off-site. Although normally a fish eater, the bald eagle feeds almost exclusively on carrion at INEL, and it may occasionally kill a jackrabbit. The candidate ferruginous hawk breeds on the reservation and is usually present from March through September (Reynolds 1993). It is found throughout INEL and feeds almost exclusively on jackrabbits. There is also a breeding population of the candidate loggerhead shrike on the reservation, which we assume is present from March through September (Reynolds 1979). Shrikes eat mostly insects and small mammals; although small birds are a minor component of the shrike's diet, they were not included in our analyses. The candidate pygmy rabbit lives in sagebrush, which is its food source, but little is known about the abundance or distribution of the rabbit on the reservation (Reynolds 1993). The candidate Townsend's big-eared bat is a colonial hibernating species that roosts and hibernates in lava tube caves (Reynolds 1993). It eats flying insects. Both of these mammals are on the reservation year-round.

4.1.1.2 Distribution

Except for the pygmy rabbit, all of the federally listed or candidate species are known to occur throughout the INEL reservation. Although many species of concern are likely to be unevenly distributed rather than uniformly dispersed over the entire reservation (Morris 1992), for this programmatic analysis, we assume all listed and candidate species are uniformly distributed.

4.1.2 Wetlands

4.1.2.1 Receptors

Benthic macroinvertebrates, fish, muskrats, and aquatic plants are representative wetland species for which some toxicity benchmark data are available. Although these biota do not necessarily occur in all wetlands on the reservation, they were selected as receptors in our risk analysis because they cover the range of wetland ecosystem components that could be present. We therefore calculate risks to these receptors in all wetlands.

4.1.2.2 Distribution

The only perennial wetlands on the reservation are the waste ponds, which are a source of drinking water for wildlife, a rest area for migratory waterfowl, and habitat for breeding and summer resident waterfowl (Arthur et al. 1984; Reynolds 1993). Most of the waste ponds are in the southwest corner of the reservation. Ephemeral wetlands along the Big Lost River and the Little Lost River, especially near the sinks, and in many small playas [mostly less than 2 ha (5 acres)] on old lava beds primarily in the central portion of the reservation are also water sources for wildlife and livestock and rest areas for migratory birds (Arthur et al. 1984).

National Wetland Inventory (NWI) maps (USFWS 1980 and 1984) were used to identify locations of waste ponds and wetlands along the Big Lost River. Major wetlands on the INEL reservation total 800 ha (2000 acres) (Arthur et al. 1984). Because most of the small ephemeral playa wetlands on the NWI maps are in lava flows, which are mainly in the central part of the INEL reservation, we assume none are located in currently contaminated areas. However, these playa wetlands could occur in areas where treatment facilities might be located in the future. Although the NWI maps probably underrepresent these small wetlands, for our analyses we assume these small ephemeral wetlands are found throughout the reservation at a density comparable to that of a representative sample area of INEL from the NWI quad maps. We estimate that at least 0.2% of the

TABLE 4-2—*Rare Species on the Idaho National Engineering Laboratory*

Species	Common Name	Status[2]
Birds		
Haliaeetus leucocephalus	Bald eagle	E
Falco peregrinus	Peregrine falcon	E
Accipiter gentilis	Northern goshawk	C2
Buteo regalis	Ferruginous hawk	C2
Chlidonias niger	Black tern	C2
Lanius ludovicianus	Loggerhead shrike	C2
Plegadis chihi	White-faced ibis	C2
Mammals		
Brachylagus idahoensis	Pygmy rabbit	C2
Plectotus .ownsendii	Townsend's big-eared bat	C2

[1] Compiled from Markham 1987; DOE 1985; Arthur et al. 1984; Cholewa and Henderson 1984; Moseley and Groves 1992; and Reynolds 1993.

[2] Endangered and threatened wildlife and plants. 50 CFR 17.11 & 17.12, July 15, 1991; endangered and threatened wildlife and plants: animal candidate review, 56 FR 58804–58836, November 21, 1991. E=endangered, C2=candidate under review.

reservation is in small ephemeral wetlands in any given area.

4.1.3 Recreational Fish and Wildlife

4.1.3.1 Receptors

Determining contaminant risks to aquatic species, including recreational fish, does not require the use of specific receptor species. We determined risks to fish in general to represent recreational fish in the Big Lost River (e.g., the rainbow trout). The sage grouse, mallard, pronghorn antelope, jackrabbit, and coyote were selected as common species representative of recreational wildlife, which are also important components of the food web on the reservation. Except for the mallard, all of these species are year-round residents on the reservation, although some of the sage grouse and antelope populations come from surrounding areas to winter in the northern part of the reservation (Rope and Stahly 1993). To be conservative in our analyses, we assume that all populations are year-round residents, except for the mallard, which we assume to be present when ponds are not frozen, from March through October. Thus, our analysis estimates potential risks to populations continuously exposed to contaminants. Exposure risks to sage grouse and antelope populations that winter off the reservation would be lower than to resident populations.

4.1.3.2 Distribution

Recreational fish are present on the reservation only when the Big Lost River contains enough water for them to survive. Although the reservation is closed to public access, many wildlife species suitable for recreational use are present, including resident bird species, migratory waterfowl, ruminants, furbearers, and large predators (Arthur et al. 1984).

4.1.4 Agricultural or Timber Production

4.1.4.1 Receptors

Sheep and cattle are ecologically similar: both are grazing livestock. Exposure and uptake data were available only for cattle; therefore, cattle were chosen to represent the agricultural endpoint. For calculating maximum potential risk, assume that livestock would be exposed to contaminants year-round.

4.1.4.2 Distribution

Sheep or cattle graze approximately 60% of the reservation. (Rope and Stahly 1993; Reynolds 1993).

4.1.5 Parks and Other Public Lands

4.1.5.1 Receptors

Risks to these endpoints were determined by calculating risks to food web components at reservation boundaries adjacent to public lands. We assume that risks are maximal closest to the reservation.

4.1.5.2 Distribution

Public lands (national forest and BLM lands) surround most of the reservation.

4.1.6 Biodiversity

4.1.6.1 Receptors

The candidate Townsend's big-eared bat, which is ecologically similar to most bats found on the reservation and is a large year-round resident, was chosen as a conservative representative of bat species. Raptors are well represented in our analyses by federally listed or candidate species (e.g., endangered bald eagle and candidates ferruginous hawk and shrike), and migratory waterfowl are represented by the mallard. The robin, which is a common sitewide, summer breeding migrant, was chosen as a representative songbird. Other important food web components (figure 4-2) include major food organisms of receptors chosen to represent other endpoints (i.e., small mammals eaten by raptors and coyotes, and insects eaten by loggerhead shrikes and bats) and other endpoints discussed in the preceding paragraphs. Although very important to ecosystem function and as food for other species, invertebrates were not included in our analyses because there was a lack of benchmark data for them. Benchmark data were generally not available for reptiles, another important species group at the site.

4.1.6.2 Distribution

All of the reservation may be classified as sagebrush-steppe (Morris 1992). Its existence as a large block of relatively undisturbed sagebrush-steppe ecosystem is its greatest value to biodiversity. The surrounding counties contain extensive BLM and national forest lands, which also support native sagebrush-steppe rangeland and lava flows comparable to most of the INEL reservation. The northern portion of the INEL reservation is an important wintering ground for pronghorn and sage grouse from surrounding mountains, and the reservation is an important nesting and wintering ground for raptors (Reynolds et al. 1986). The large undisturbed expanse of sagebrush-steppe provides protected habitat for several species groups whose populations are in general decline. These groups include 22 species of raptors (e.g., bald and golden eagles, American kestrels, owls, and vultures), 6 species of bats, 6 species of carnivores, and 11 species of reptiles and amphibians (e.g., the Great Basin spadefoot toad, snakes, and lizards) (Reynolds et al. 1986).

Within the sagebrush-steppe ecosystem on the INEL reservation lava tube cave habitats and associated lava flows are important sensitive habitats, providing shelter for bats, snakes, owls, and carnivores (Rope and Stahly 1993). The distribution of all lava tube caves on the reservation is not documented. We therefore made the conservative assumption that the caves are ubiquitous.

Invasion of sagebrush-steppe communities by nonnative cheatgrass on the reservation is an increasing threat to native biodiversity on the reservation (Markham and Morris 1991). Cheatgrass invades disturbed areas, crowding out native species and inhibiting or preventing their establishment on fresh disturbances. We assume that the abundance of this species is inversely proportional to the quality of native sagebrush-steppe habitat and that cheatgrass is most abundant in and adjacent to disturbed sites.

4.2 Contaminants of Potential Concern

The constituents of potential concern on INEL include radionuclides, inorganic, and organic contaminants. The primary radionuclides, according to relative average concentrations, are ^{137}Cs and ^{60}Co; the primary inorganics are Ba, Cr, Pb, Ni, and Zr. The concentrations of organic chemicals on the site are relatively low and thus are not expected to pose a potential hazard.

Maximum and average concentrations of chemical and radiological constituents in soil, surface water, and sediment were determined from the source terms provided by PNL (tables 4-3, 4-4, and 4-5, respectively). Determination of these average and maximum concentrations required that certain assumptions be made with regard to data interpretation and compensation for data gaps. Appendix A describes the methodology used to develop the source terms for input into the exposure and risk assessment.

4.3 Exposure Assessment

Estimating contaminant exposure for representative species on the INEL reservation depends on knowing the amount of time spent in waste areas, and the amount of contaminants ingested. Since specific home ranges and habits of many of the representative species on INEL are not well known, and only a few species with small home ranges (e.g., small mammals, birds) would reside within contaminated areas for most of their lives, and very few individuals would contact areas of maximum concentrations (see Appendix B for discussion of home ranges), an initial screening assessment for contaminant exposure was conducted. Where available for INEL, the maximum concentrations of each contaminant in each medium (i.e., soil, water, and sediment) were used to identify the worst-case potential contaminants. Contaminants that did not pose a risk to any of the receptor species from exposure to the maximum values were not considered further. If exposure to the maximum concentrations of contaminants posed a risk to organisms, then the average concentrations of those contaminants were used in the assessment to estimate the most probable and reasonable exposure and risk.

The risk assessment considers chronic exposures of vegetation, terrestrial wildlife, and aquatic organisms to radiological and nonradiological contaminants. Due to limited availability of sensitivity data for many species (e.g., threatened and endangered species) and to similarities in exposure (e.g., similarly sized raptors feeding on the same prey), representative organisms for each endpoint were chosen for evaluation. A food web showing relationships among these representative receptors is presented in figure 4-2. Conservative estimates of exposure and risk were made by selecting receptors most sensitive to contaminants or habitat alteration, most likely to experience additional risk due to bioaccumulation or larger body size, or at greatest risk due to rarity. Other abundant species on the reservation were included as important prey components of the food web, such as mice and insects (risk estimates were not determined for insects).

The primary exposure routes for terrestrial wildlife species are exposure to external radiation, ingestion of food (including soils for some species) and water. Table 4-6 lists the body weights and consumption rates for the representative species. The rabbits, pronghorn, cow, and sage grouse are assumed to feed exclusively on the vegetative parts of plants. The mouse and mallard duck are assumed to feed exclusively on the fruiting bodies of plants (i.e., seeds). On the basis of a review of the literature, the percentage of prey items consumed by omnivores and predators was estimated (table 4-6; figure 4-2). The robin is assumed to eat 70% fruit/seeds and 30% insects; the loggerhead shrike eats 60% insects and 40% mice; the ferruginous hawk eats 100% jackrabbits; the coyote eats 45% mice, 45% jackrabbits, and 10% sage grouse; and the bald eagle is assumed to eat only carrion, consisting of 50% jackrabbits and 50% pronghorn. The bat is assumed to eat 100% insects, and the insects are assumed to eat 100% vegetative plant parts.

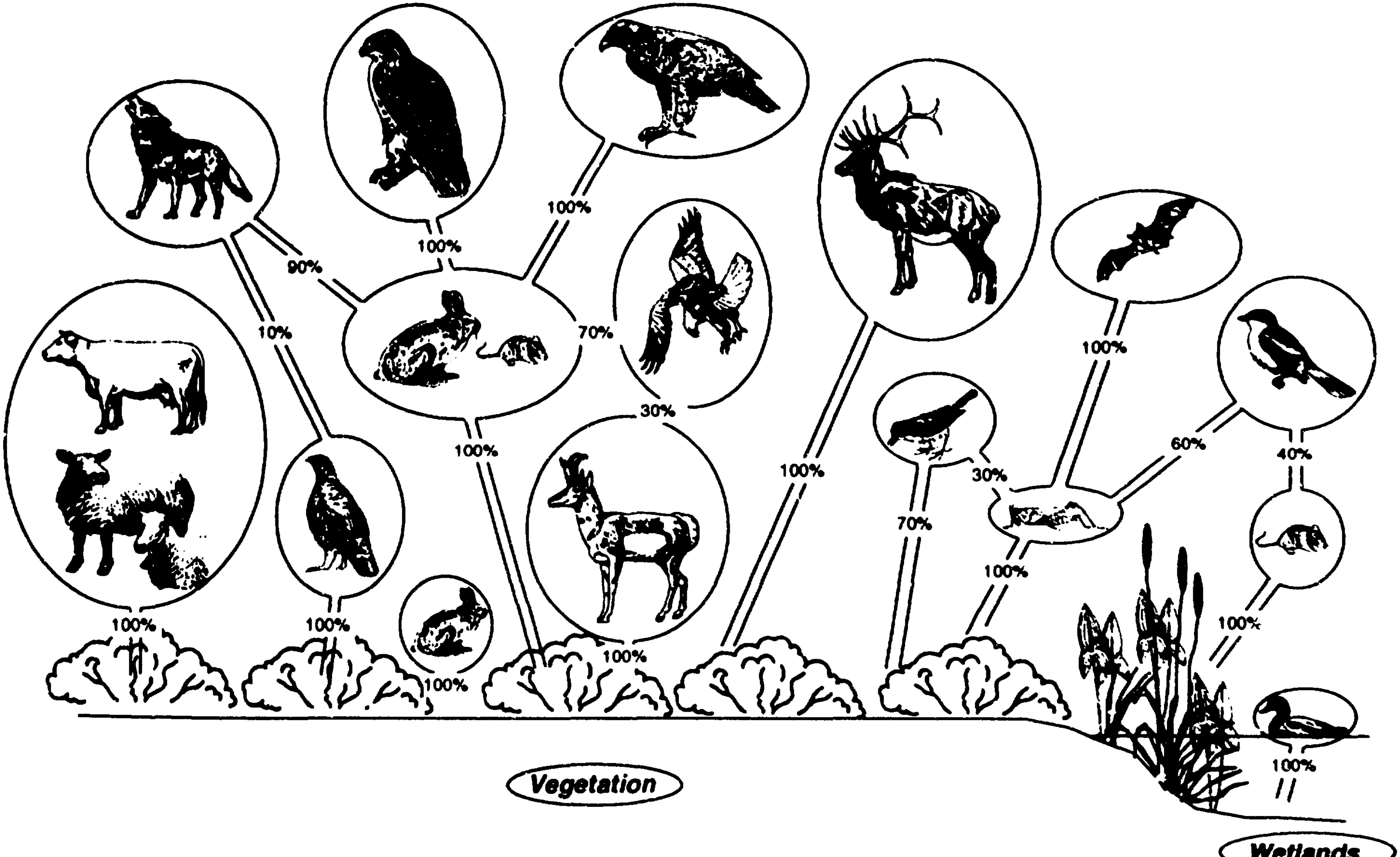

FIGURE 4-2. REPRESENTATION OF THE TERRESTRIAL FOOD WEB OF THE IDAHO NATIONAL ENGINEERING LABORATORY

TABLE 4-3—*Maximum and Average Soil Concentrations on the Idaho National Engineering Laboratory [mg/kg Dry Weight (for Chemical Constituents) or pCi/kg Dry Weight (for Radionuclides)]*

Constituent	Maximum Concentration	Constituent	Average Concentration
Benzene	4.00E-03	Toluene	2.00E-03
BEHP	6.20E-01	Antimony	5.80E+00
Methylene chloride	4.00E-02	Arsenic	4.50E+00
Tetrachloroethene	7.60E-02	Barium	2.17E+03
Toluene	2.00E-03	Cadmium	3.06E+00
Trichloroethene	4.00E-03	Chromium	3.02E+02
Xylene	4.00E-03	Cobalt	4.07E-06
2-butanone	9.00E-02	Lead	1.96E+01
4-methyl-2-pentanone	4.00E-02	Mercury	6.03E+00
Antimony	5.80E+00	Nickel	2.15E+02
Arsenic	9.30E+00	Selenium	7.17E-01
Barium	3.83E+03	Silver	3.74E+00
Beryllium	3.90E+00	Thallium	1.35E+00
Cadmium	3.88E+01	Uranium	5.31E+00
Cesium	6.22E-04	Zinc	1.43E+02
Chromium	3.02E+02	Zirconium	1.05E+04
Cobalt	4.07E-06	Aroclor 1254	9.18E+00
Lead	6.31E+02	Cyanide	9.83E-01
Mercury	1.15E+02	Cesium-134	4.48E+04
Nickel	3.25E+02	Cesium-137	1.14E+07
Selenium	8.70E+00	Cobalt-60	4.60E+06
Silver	1.74E+01	Plutonium-239	1.72E+04
Strontium	4.06E-06	Thorium-232	1.30E+03
Thallium	1.90E+00		
Uranium	4.83E+00		
Zinc	1.43E+02		
Zirconium	1.05E+04		
Aroclor 1254	1.19E+01		
Cyanide	9.83E-01		
Americium-241	7.60E+05		
Cesium-134	4.48E+04		
Cesium-137	4.01E+07		
Cobalt-60	4.61E+06		
Curium-244	6.75E+03		
Europium-152	1.07E+05		
Europium-154	4.70E+06		
Europium-155	9.67E+03		
Potassium-40	1.80E+04		
Plutonium-238	2.80E+06		
Plutonium-239	1.24E+05		
Ruthenium-103			
Ruthenium-106			
Strontium-90	2.80E+06		
Thorium-228	2.72E+04		
Thorium-230	1.42E+04		
Uranium-234	5.52E+03		
Uranium-235	3.00E+06		
Uranium-238	1.66E+03		

NA = no measured soil concentration available.

TABLE 4-4—*Maximum and Average Water Concentrations on the Idaho National Engineering Laboratory [mg/L (for Chemical Constituents) or pCi/L (for Radionuclides)]*

Constituent	Maximum Concentration	Constituent	Average Concentration
Cesium	3.33E–12	Cobalt	2.29E–12
Cobalt	2.29E–12	Cesium-137	2.90E–01
Cesium-137	2.90E–01	Cobalt-60	2.59E+00
Cobalt-60	2.59E+00		

TABLE 4-5—*Maximum and Average Sediment Concentrations on the Idaho National Engineering Laboratory [mg/kg (for Chemicals) or pCi/kg (for Radionuclides)]*

Constituent	Maximum Concentration	Constituent	Average Concentration
Acetone	7.00E–03	Methylene chloride	2.60E+01
Ethylbenzene	1.60E–02	Toluene	4.00E+00
Methylene chloride	2.60E+01	Antimony	1.68E+01
Toluene	4.00E+00	Arsenic	1.16E+01
Xylene	1.00E–02	Barium	2.93E+02
4-methyl-2-pentanone	1.70E–01	Cadmium	3.80E+00
Antimony	1.68E+01	Chromium	3.44E+03
Arsenic	1.16E+01	Cobalt	8.14E+00
Barium	2.93E+02	Lead	4.39E+01
Beryllium	2.20E+00	Mercury	2.80E+00
Cadmium	3.80E+00	Nickel	3.60E+01
Chromium	3.44E+03	Selenium	1.20E+00
Cobalt	8.14E+00	Silver	1.50E+01
Lead	4.39E+01	Vanadium	6.80E+01
Mercury	2.80E+00	Zinc	3.12E+02
Nickel	3.60E+01	Cesium-134	1.48E+13
Selenium	1.20E+00	Cesium-137	2.58E+13
Silver	1.50E+01	Cobalt-60	9.19E+12
Tin	2.17E+01	Plutonium-239	1.59E+08
Vanadium	6.80E+01	Uranium-234	9.86+06
Zinc	3.12E+02		
Cesium-134	1.48E+13		
Cesium-137	2.09E+08		
Cobalt-60	9.19E+12		
Plutonium-239	1.59E+08		
Uranium-234	9.86E+06		

All species are assumed to purposely or incidentally ingest soil while eating, grooming, or preening except for the shrike and other raptors, bat, and coyote for which soil ingestion was assumed to be negligible. Soil ingestion rates (Q_s) were obtained from the literature for the jackrabbit (6.3% of the dry-matter intake; Arthur and Gates 1988), pronghorn (5.4% of the dry-matter intake; Arthur and Gates 1988), cow (7% of the dry-matter intake; Mayland et. al. 1977), mallard duck (8.2% of the dry-matter intake; Beyer et al. 1991), and the mouse (Beyer et al. 1991) (table 4-6). Since published values of soil ingestion rates were not found for the robin or sage grouse, it was conservatively estimated to be 10% of the dry-matter intake. The soil ingestion rate for pygmy rabbits was assumed to be the same as that reported for black-tailed jackrabbits.

The estimated daily rates of food and water consumption (Q_v or Q_h, and Q_w, respectively) for each representative species were calculated from allometric regression equations that are based on

TABLE 4-6—*Body Weights and Consumption Rates[1] for Terrestrial Species[2] on the Idaho National Engineering Laboratories*

Parameter	Mouse	Pygmy Rabbit	Jackrabbit	Pronghorn	Cow	Songbird (Robin)	Sage Grouse	Mallard	Shrike	T.B.E. Bat	F. Hawk	Bald Eagle	Coyote
Body weight, BW (kg)	2.20E−02[3]	4.40E−01[4]	2.27E+00[5]	4.66E+01[6]	4.00E+02[7]	7.50E−02[8]	2.00E+00[9]	1.18E+00[10]	4.55E−02[11]	1.00E−02[12]	1.39E+00[13]	4.50E+00[14]	1.60E+01[15]
Water intake rate, Q_w (L/d)	6.00E−03	5.76E−02	1.83E−01	2.26E+00	1.23E+01	1.43E−02	1.90E−01	1.25E−01	1.00E−02	2.90E−03	1.43E−01	3.59E−01	7.70E−01
Water ingestion fraction, FI_w	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	7.00E−01	6.00E−01	1.00E+00	6.00E−01	5.00E−01	1.00E+00
Soil intake rate, Q_s (kg/d)	8.36E−05[16]	1.25E−03[17]	9.32E−03[18]	4.68E−02[19]	4.86E−01[20]	5.46E−04[21]	1.05E−02[22]	5.64E−03[23]	0.00	0.00	0.00	0.00	0.00
Soil ingestion fraction, FI_s	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	7.00E−01	0.00	0.00	0.00	0.00	0.00
Vegetation intake rate, Q_v (kg/d)	0.00	2.14E−02	1.59E−01 (Ar43)	9.34E−01 (Se68)	7.47E+00	0.00	1.13E−01	0.00	0.00	0.00	0.00	0.00	0.00
Vegetation ingestion fraction, FI_v	0.00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	0.00	1.00E+00	0.00	0.00	0.00	0.00	0.00	0.00
Fruit/seeds intake rate, Q_f (kg/d)	4.50E−03	0.00	0.00	0.00	0.00	5.88E−03[24]	0.00	7.41E−02	0.00	0.00	0.00	0.00	0.00
Fruit/seeds ingestion fraction, FI_f	1.00E+00	0.00	0.00	0.00	0.00	1.00E+00	0.00	7.00E−01	0.00	0.00	0.00	0.00	0.00
Prey 1 intake rate, Q_{1m} (kg/d)	0.00	0.00	0.00	0.00	0.00	2.52E−03 (insects)	0.00	0.00	3.66E−03[25] (insects)	1.70E−03 (insects)	8.44E−02[26] (jackrabbit)	1.50E−01[27] (jackrabbit)	2.63E−01[28] (mice)
Prey 1 ingestion fraction, FI_{1m}	0.00	0.00	0.00	0.00	0.00	1.00E+00	0.00	0.00	6.00E−01	1.00E+00	6.00E−01	5.00E−01	1.00E+00
Prey 2 intake rate, Q_{2m} (kg/d)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.44E−03 (mice)	0.00	0.00	6.42E−02 (pronghorn)	2.63E−01 (jackrabbit)
Prey 2 ingestion fraction, FI_{2m}	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	6.00E−01	0.00	0.00	5.00E−01	1.00E+00
Prey 3 intake rate, Q_{3m} (kg/d)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5.84E−02 (grouse)
Prey 3 ingestion fraction, FI_{3m}	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00E+00

[1] All values are on a wet weight basis. For soils, the wet/dry ratio is 0.98 (Rope et al. 1988), for vegetation the ratio is 0.91 (the lower bound on the range for hay/grasses reported in Suter 1993), and for fruits/seeds, the ratio is 0.17 (Morrison 1991).
[2] Water and food consumption rates were computed by methods in U.S. EPA 1988 (table 8) unless otherwise noted.
[3] Opresko and Suter 1992.
[4] Chapman, et al. 1980.
[5] (Burt and Grossenheider 1976)
[6] (Burt and Grossenheider 1976)
[7] U.S. EPA 1988.
[8] Terres 1980.
[9] Terres 1980.
[10] Terres 1980.
[11] Terres 1980.
[12] (Burt and Grossenheider 1976)
[13] Brown and Amadon 1968.
[14] Brown and Amadon 1968.
[15] (Burt and Grossenheider 1976)
[16] Mouse soil ingestion rate is 2% of dry vegetation intake (Beyer et al. 1991).
[17] Pygmy rabbit is assumed to have the same soil ingestion rate as the jackrabbit (6.3% of dry matter intake).
[18] Jackrabbit soil ingestion rate is about 6.3% of the dry vegetation intake rate (Arthur and Gates 1988).
[19] Pronghorn soil ingestion rate is about 5.4% of the dry vegetation intake rate (Arthur and Gates 1988).
[20] Cattle soil ingestion rate is about 7% of the dry vegetation ingestion rate (Mayland et al. 1977).
[21] The robin is assumed to have a soil ingestion rate equal to 10% of the dry vegetation intake rate.
[22] The sage grouse soil ingestion rate is assumed to be 10% of the dry vegetation intake rate.
[23] The mallard soil intake rate is 8.2% of dry vegetation intake (Beyer et al. 1991).
[24] The robin is assumed to eat 70% fruits/seeds and 30% insects (Terres 1980).[25] The loggerhead shrike is assumed to eat 60% insects and 40% mice (interpreted from information in Terres 1980).
[26] The ferruginous hawk is assumed to eat 100% jackrabbits (interpreted from information in Brown and Amadon 1968).
[27] The bald eagle is assumed to eat 70% jackrabbit carrion and 30% pronghorn carrion (personal communication with T. Reynolds 1993).
[28] The coyote is assumed to eat 45% mice, 45% jackrabbits, and 10% sage grouse (interpreted from data in Burt and Grossenheider 1976).

the weight of the organism (EPA 1988) (appendix A). These equations are based on the combined measurements for laboratory animals, livestock, and selected wildlife and bird species. Measured values for some rates were obtained from the literature for several species and are noted in appendix A.

Because information on the specific habits and behaviors of most of the representative wildlife species is not well known, it is assumed that all species spend 100% of their time on the reservation. The exceptions are the raptors, the mallard duck, and the loggerhead shrike (see discussion in chapter 4.1), whose specific time spent on the INEL reservation has been documented by site ecologists (Reynolds 1993). Therefore, the fraction of contaminated vegetation, fruit, prey, soil, and water consumed (FI_v, FI_f, FI_H, FI_s, and FI_w, respectively) is set at 100%, except for those species noted above, for which the FI values are set accordingly. The bald eagle, for instance, is present 6 months out of the year, so values are set at 50% (table 4-6).

Contaminant concentrations in vegetation, the first level in the food chain, are estimated from source-term concentrations in the soils using published soil-to-plant element- or chemical-specific transfer factors (Baes et al. 1984; Travis and Arms 1988) (table 4-7). Transfer factors for inorganic chemicals are available for both the vegetative and fruiting parts of plants (Baes et al. 1984); however, the transfer factors for organic chemicals do not make this distinction (Travis and Arms 1988). The methodology used to predict contaminant concentrations in vegetation does not make a distinction between different plant types or species. Therefore, all species ingest "generic" vegetation containing contaminant concentrations derived from soil concentrations by the use of transfer factors.

Transfer factors for contaminants of concern are applied to predict concentrations in the tissues of terrestrial mammalian receptors from consumption of vegetation, soil, and water (collectively termed B_b) (Baes et al. 1984; Travis and Arms 1988) (table 4-7). Data on transfer factors from vegetation or soil to insects and earthworms are very limited in the literature. Therefore, the concentration in insects was derived from vegetation concentrations, and a default, conservative one-to-one transfer between vegetation and insects was assumed. The rationale and limitations for applying these transfer factors are discussed in appendix A.

The consumption rates and the benchmark limit or no-observable-adverse-effect level (NOAEL) values are typically reported in wet weights, whereas the vegetation and soil concentrations are typically reported in dry weights. Therefore, conversion factors were applied to account for this difference. The wet- to dry-weight conversion factor for the vegetative parts of plants on INEL was assumed to be 0.91 [the lower end of the range of the percent age of water content for hay and grasses (Suter 1993)]. The wet- to dry-weight conversion factor for the fruiting parts of plants on INEL was assumed to be 0.17 (Morrison 1959). The dry- to wet-weight conversion factor for soils is 0.98; it is the mean for 16 sampling locations in the southwest portion of INEL (Rope et al. 1988).

For the baseline assessment of INEL, the concentrations of radionuclides in animal tissues and the resulting doses were not decay-corrected. The doses are estimated for the current situation and not at some point in the future. The primary radionuclides of concern, ^{137}Cs and ^{60}Co, have relatively long half-lives, so this assumption is reasonable. PNL decay-corrected the radionuclide concentrations in the source terms to the time of disposal or release. To estimate dose to terrestrial receptors, all short-lived daughter products were included.

Aquatic organisms considered in the assessment included benthic macroinvertebrates and, for radiological analyses, emergent vegetation (i.e., cattails) and muskrats. All aquatic organisms, except for benthic macroinvertebrates, are exposed to contaminants in surface water. Benthic macroinvertebrates are assumed to be exposed only to sediment pore-water for calculation of internal radiation dose and exposure to chemicals. The external radiation dose from exposure to surface water was calculated for all organisms.

TABLE 4-7—*Soil to Vegetation and Plant to Beef Transfer Factors for the Constituents of Concern on the Idaho National Engineering Laboratory*

Constituent	Soil to Vegetation Transfer Factor	Vegetation to Beef Transfer Factor
Acetone	5.33E+01	1.45E-08
Benzene	2.37E+00	3.16E-06
BEHP	4.37E-02	3.16E-03
Ethylbenzene	5.48E-01	3.98E-05
Methylene chloride	6.86E+00	5.01E-07
Tetrachloroethene	4.20E-01	6.31E-05
Toluene	1.07E+00	1.26E-05
Trichloroethene	1.59E+00	6.31E-06
Xylene	5.42E-01	3.98E-05
2-butanone	2.63E+01	4.90E-08
4-methyl-2-pentanone	7.84E+00	3.98E-07
Antimony	2.00E-01	1.00E-03
Arsenic	4.00E-02	2.00E-03
Barium	1.50E-01	1.50E-04
Beryllium	1.00E-02	1.00E-03
Cadmium	5.50E-01	5.50E-04
Cesium	8.00E-02	2.00E-02
Chromium	7.50E-03	5.50E-03
Cobalt	2.00E-02	2.00E-02
Lead	4.50E-02	3.00E-04
Mercury	9.00E-01	2.50E-01
Nickel	6.00E-02	6.00E-03
Selenium	2.50E-02	1.50E-02
Silver	4.00E-01	3.00E-03
Strontium	2.50E+00	3.00E-04
Thallium	4.00E-03	4.00E-02
Tin	3.00E-02	8.00E-02
Uranium	8.50E-03	2.00E-04
Vanadium	5.50E-03	2.50E-03
Zinc	1.50E+00	1.00E-01
Zirconium	2.00E-03	5.50E-03
Aroclor 1254	2.24E-02	1.00E-02
Cyanide	5.41E+01	1.41E-08
Americium-241	5.50E-03	3.50E-06
Antimony-125	2.00E-01	1.00E-03
Cerium-141	1.00E-02	7.50E-04
Cesium-134	8.00E-02	2.00E-02
Cesium-137	8.00E-02	2.00E-02
Cobalt-60	2.00E-02	2.00E-02
Curium-244	8.50E-04	3.50E-06
Europium-152	1.00E-02	5.00E-03
Europium-154	1.00E-02	5.00E-03
Europium-155	1.00E-02	5.00E-03
Manganese-54	2.50E-01	4.00E-04
Potassium-40	1.00E+00	2.00E-02
Plutonium-238	4.50E-04	5.00E-07
Plutonium-239	4.50E-04	5.00E-07
Ruthenium-103	7.50E-02	2.00E-03
Ruthenium-106	7.50E-02	2.00E-03
Strontium-90	2.50E+00	3.00E-04
Thorium-228	8.50E-04	6.00E-06
Thorium-230	8.50E-04	6.00E-06
Thorium-232	8.50E-04	6.00E-06
Uranium-234	8.50E-03	2.00E-04
Uranium-235	8.50E-03	2.00E-04
Uranium-238	8.50E-03	2.00E-04
Zirconium-95	2.00E-03	5.50E-03

Source: For organics, the transfer factors are calculated from equations from Travis and Arms using K_{ow} values from the *Superfund Chemical Data Matrix*. For inorganics and radionuclides, the transfer factors were taken from Baes et. al. The K_{ow} for cyanide was taken from MEPAS, and the transfer factors were calculated from equations from Travis and Arms.

4.4 Contaminant Effects Assessment

To quantify risk to terrestrial receptors exposed to organic and inorganic contaminants, the daily consumption rate of contaminated food and water, normalized to body weight (in units of mg/kg/d), was compared with the NOAEL benchmark (mg/kg/d). Ratios more than 1 are considered to pose a potential risk to organisms but do not necessarily indicate the severity of the effect(s). However, it is reasonable to assume that the higher the ratio, the greater the risk of adverse effects. Dose to terrestrial receptors, including vegetation, from internal and external exposure to radionuclides was also determined from calculated tissue concentrations and soil concentrations, respectively. Doses that exceeded 0.1 rad/d were considered to pose a potential risk to terrestrial organisms (IAEA 1992). Methods used to calculate exposure and risk are described in appendix A.

Toxicological benchmarks for terrestrial organisms, excluding vegetation, were obtained from Opresko and Suter (1992) (table 4-8). For representative receptor species that were not listed in the data base, extrapolation techniques were employed to obtain the chronic NOAEL by adjusting for differences in body weight between the receptor and a test organism. If a NOAEL was available for a laboratory test species, the NOAEL for a receptor species could be calculated. Many of the NOAEL benchmarks were derived by extrapolation from small-mammal laboratory data (Opresko and Suter 1992). No wildlife toxicity data were found for a few contaminants. For these cases, wildlife NOAELs were extrapolated from human noncarcinogenic toxicity data (i.e., RfDs) listed in the MEPAS constituent data base, normalized to the "standard man" body weight of 70 kg. Thus, for our purposes, wildlife species that weigh less than 70 kg would have a higher benchmark than humans, and the opposite would be true for wildlife species weighing more than 70 kg.

Literature sources for inorganic terrestrial phytotoxicity benchmarks were summarized and reported by Suter and Futrell (1993) (table 4-8). Where applicable, the lowest source concentration in a soil medium that produced phytotoxically excessive effects was chosen from the data base. Several benchmarks were derived from experiments using nutrient solutions. However, uncertainty values were not applied to these data to account for differences in growth media.

As cited in the *MMR Air National Guard Risk Assessment Handbook* (1992), Eskew and Babb developed a methodology for deriving phytotoxicity benchmarks for organic constituents (table 4-8). Estimated critical concentrations (mg/kg wet weight) for soil were calculated from experimental data on the uptake of compounds from nutrient solution or vapor phase by determining the distribution of a compound between the soil solution and absorption to organic matter with the use of a K_{oc} value. The K_{oc} value was estimated from the chemical-specific K_{ow}. Assumptions used to derive toxicity benchmarks were (1) a soil organic content of 1%, (2) a bulk soil density of 1.3 g/cm^3, and (3) a soil water content of 18%. The organic fraction of the soil is the primary factor in determining bioavailability of organic compounds to plant roots. Use of these assumptions was determined to be applicable since the average soil organic matter at INEL is 1.7% (0.8 – 2.4%) (Rope et al. 1988). Uncertainty factors were applied to adjust the data from acute to chronic effects and from 50% inhibition of growth to lowest toxic effect levels.

Risks to aquatic organisms from exposure to organic and inorganic contaminants in water and sediments (pore water) were calculated through comparison of the water or sediment pore-water concentrations with the chemical-specific aquatic benchmark (Suter et al. 1992) (table 4-8). To determine internal dose to aquatic plants, fish, and muskrats from exposure to radionuclides, the surface-water concentrations were multiplied by radionuclide and organism-specific aquatic (internal) dose conversion factors to produce a daily dose in rads (Killough and McKay 1976). To determine the internal dose to benthic macroinvertebrates and other bottom-dwelling organisms (e.g., fish larvae) from exposure to radionuclides, the sediment pore-water concentrations were multiplied by radionuclide and organism-specific aquatic (internal) dose conversion factors to produce a daily dose. The external dose to all organisms was determined by

TABLE 4-8—*Criteria Benchmarks for Terrestrial[1] and Aquatic[2] Species on the Idaho National Engineering Laboratory (NOAELs Listed in mg/kg/d for Terrestrial Benchmarks or mg/L for Aquatic Benchmarks)*

Constituent	Mouse	Pygmy rabbit	Jackrabbit	Pronghorn	Cow	Songbird	Sage grouse	Mallard
Acetone	2.52E+01	9.27E+00	5.36E+00	1.96E+00	9.56E-01	1.67E+01	5.59E+00	6.67E+00
Benzene	6.29E+00	2.32E+00	1.34E+00	4.90E-01	2.39E-01	4.18E+00	1.40E+00	1.67E+00
BEHP	NA	NA	NA	NA	NA	NA	NA	NA
Ethylbenzene	NA	NA	NA	NA	NA	NA	NA	NA
Methylene chloride	1.47E+01	5.42E+00	3.14E+00	1.15E+00	5.60E-01	9.78E+00	3.27E+00	3.90E+00
Tetrachloroethene	1.55E+00	5.72E-01	3.31E-01	1.21E-01	5.90E-02	1.03E+00	3.45E-01	4.12E-01
Toluene	5.61E+01	2.07E+01	1.20E+01	4.37E+00	2.13E+00	3.73E+01	1.25E+01	1.49E+01
Trichloroethene	1.66E+02	6.13E+01	3.55E+01	1.30E+01	6.33E+00	1.25E+02	4.20E+01	5.00E+01
Xylene	1.26E+03	4.63E+02	2.68E+02	9.79E+01	4.78E+01	8.36E+02	2.80E+02	3.33E+02
2-butanone	2.31E+01	8.52E+00	4.93E+00	1.80E+00	8.80E-01	1.54E+01	5.15E+00	6.14E+00
4-methyl-2-pentanone	1.26E+01	4.63E+00	2.68E+00	9.79E-01	4.78E-01	8.36E+00	2.80E+00	3.33E+00
Antimony	1.25E+04	4.61E+03	2.67E+03	9.73E+02	4.75E+02	8.31E+03	2.78E+03	3.31E+03
Arsenic	1.05E-01	2.26E+00	1.31E+00	8.10E-01	3.96E-01	7.00E-02	1.36E+00	1.63E+00
Barium	1.28E+00	4.73E-01	2.73E-01	9.99E-02	4.88E-02	8.52E-01	2.85E-01	3.40E-01
Beryllium	1.36E+00	5.00E-01	2.90E-01	1.06E-01	5.16E-02	9.02E-01	3.02E-01	3.60E-01
Cadmium	2.42E-02	8.92E-03	5.16E-03	1.89E-03	9.21E-04	1.44E-01	1.98E-03	1.26E-02
Cesium	NA	NA	NA	NA	NA	NA	NA	NA
Chromium	6.04E+00	2.22E+00	1.29E+00	4.70E-01	2.30E-01	4.01E+00	1.34E+00	1.60E+00
Cobalt	NA	NA	NA	NA	NA	NA	NA	NA
Lead	7.29E-03	2.69E-03	1.56E-03	5.68E-04	2.77E-04	1.59E-02	9.85E+00	1.17E+01
Mercury	1.47E+01	2.22E-02	5.58E-03	2.29E-02	1.12E-02	3.19E+00	5.09E-01	2.83E-02
Nickel	6.07E+01	2.24E+01	1.29E+01	4.73E+00	2.31E+00	4.17E+00	1.40E+00	1.67E+00
Selenium	6.32E-02	2.33E-02	1.35E-02	4.92E-03	2.40E-03	2.51E-01	8.39E-02	1.00E-01
Silver	NA	NA	NA	NA	NA	NA	NA	NA
Strontium	6.62E+02	2.44E+02	1.41E+02	5.15E+01	2.52E+01	4.40E+02	1.47E+02	1.75E+02
Thallium	2.52E-02	9.27E-03	5.36E-03	1.96E-03	9.56E-04	1.67E-02	5.59E-03	6.67E-03
Tin	NA	NA	NA	NA	NA	NA	NA	NA
Uranium	1.56E-01	5.74E-02	3.32E-02	1.21E-02	5.93E-03	2.20E+01	7.35E+00	8.77E+00
Vanadium	2.37E-01	8.73E-02	5.05E-02	1.84E-02	9.01E-03	1.57E-01	5.27E-02	6.28E-02
Zinc	2.44E+01	8.99E+00	5.20E+00	1.90E+00	9.28E-01	1.62E+01	5.43E+00	6.47E+00
Zirconium	7.76E-02	2.86E-02	1.65E-02	6.04E-03	2.95E-03	5.16E-02	1.73E-02	2.06E-02
Aroclor 1254?	1.45E-01	6.05E-02	3.50E-02	1.77E-02	8.63E-03	3.19E+00	1.30E+00	1.55E+00
Cyanideion	2.72E+01	1.00E+01	5.79E+00	2.30E-02	1.37E-02	1.80E+01	6.04E+00	7.20E+00

NA = Benchmark not available.

[1] The sourcce for all terrestrial organisms except vegetation was Opresko and Suter (1993). For vegetation, the source was Suter and Futrell (1993), and the Massachusetts Military Reservation Risk Assessment Handbook (1992).

[2] The source for aquatic benchmarks was Suter et al. (1992).

ABLE (cont'd) ***for Terrestrial Species on the Idaho National Engineering Laboratory (NOAELs listed in mg/kg/d)***

Constituent	Shrike	T.B.E. bat	F. Hawk	Bald eagle	Coyote	Aquatic	Vegetation
Acetone	1.97E+01	3.27E+01	6.31E+00	4.27E+00	2.80E+00	2.37E+01	9.65E+01
Benzene	4.94E+00	8.18E+00	1.58E+00	1.07E+00	6.99E-01	2.10E-02	NA
BEHP	NA	NA	NA	NA	NA	3.00E-04	1.40E+01
Ethylbenzene	NA	NA	NA	NA	NA	4.40E-01	NA
Methylene chloride	1.15E+01	1.91E+01	3.69E+00	2.50E+00	1.64E+00	4.10E-01	5.60E+00
Tetrachloroethene	1.22E+00	2.02E+00	3.9[illegible]E-01	2.63E-01	1.73E-01	5.00E-01	1.57E+01
Toluene	4.40E+01	7.29E+01	1.41E+01	9.52E+00	6.24E+00	2.60E-02	9.70E+00
Trichloroethene	1.48E+02	2.16E+02	4.74E+01	3.20E+01	1.85E+01	5.76E+00	6.70E-01
Xylene	9.87E+02	1.64E+03	3.16E+02	2.13E+02	1.40E+02	2.68E+00	2.40E+01
2-butanone	1.82E+01	3.01E+01	5.81E+00	3.93E+00	2.57E+00	1.78E+01	NA
4-methyl-2-pentanone	9.87E+00	1.64E+01	3.16E+00	2.13E+00	1.40E+00	1.59E+00	NA
Antimony	9.81E+03	1.63E+04	3.14E+03	2.12E+03	1.39E+03	1.90E+00	5.00E+00
Arsenic	8.27E-02	1.37E-01	2.61E+00	1.77E+00	1.16E+00	9.32E-01	1.50E+01
Barium	1.01E+00	1.67E+00	3.22E-01	2.18E-01	1.43E-01	2.03E+01	5.00E+02
Beryllium	1.07E+00	1.77E+00	3.41E-01	2.31E-01	1.51E-01	3.80E-03	1.00E+01
Cadmium	1.70E-01	3.15E-02	2.24E-03	1.51E-03	2.69E-03	1.10E-03	3.00E+00
Cesium	NA	NA	NA	NA	NA	NA	NA
Chromium	4.74E+00	7.85E+00	1.52E+00	1.02E+00	6.71E-01	1.10E-02	7.50E+01
Cobalt	NA	NA	NA	NA	NA	4.40E-03	2.50E+01
Lead	1.88E-02	9.49E-03	1.11E+01	7.51E+00	8.11E-04	3.20E-03	1.00E+02
Mercury	3.77E+00	1.92E+01	5.74E-01	3.88E-01	2.91E-03	1.30E-03	3.00E-01
Nickel	4.93E+00	7.90E+01	1.58E+00	1.07E+00	6.75E+00	1.60E-01	1.00E+02
Selenium	2.96E-01	8.22E-02	9.47E-02	6.40E-02	7.03E-03	3.50E-02	5.00E+00
Silver	NA	NA	NA	NA	NA	2.00E-04	2.00E+00
Strontium	5.19E+02	8.61E+02	1.66E+02	1.12E+02	7.36E+01	NA	NA
Thallium	1.97E-02	3.27E-02	6.31E-03	4.27E-03	2.80E-03	6.40E-02	1.00E+00
Tin	NA	NA	NA	NA	NA	NA	NA
Uranium	2.59E+01	2.03E-01	8.30E+00	5.61E+00	1.73E-02	2.70E-02	NA
Vanadium	1.86E-01	3.08E-01	5.95E-02	4.02E-02	2.63E-02	4.10E-02	NA
Zinc	1.91E+01	3.17E+01	6.13E+00	4.14E+00	2.71E+00	1.10E-01	7.00E+01
Zirconium	6.09E-02	1.01E-01	1.95E-02	1.32E-02	8.63E-03	2.51E-01	NA
Aroclor 1254	3.77E+00	1.89E-01	1.47E+00	9.92E-01	2.52E-02	5.20E-04	1.00E+01
Cyanideion	2.13E+01	3.53E+01	6.82E+00	6.11E-02	4.00E-02	5.20E-03	NA

multiplying the surface-water concentration by the external radionuclide-specific dose conversion factor. Combined internal and external doses more than 1 rad/d are considered to pose a potential risk to aquatic organisms (NCRP 1991).

For contaminants and receptors that did not pass the average concentration screening (section 4.3), an attempt was made to further define exposure risks by comparing receptor species' home range sizes with the potential fraction of the home range occupied by contaminants in food and water from waste sites.

Receptor species at INEL have home ranges or territories that range from small [e.g., less than 1 ha (1 acre) for aquatic species in waste ponds] to large [e.g., thousands of hectares (acres) for bald eagles and coyotes (table 4-9)]. Some small species have home ranges small enough to be completely within individual waste sites. Other species have such large home ranges that the waste sites would represent only a small part of the area they would occupy, if the waste sites were used at all. To further interpret the results of the risk analysis, the following assumptions were made about the contaminant exposure to receptors.

1. Burrowing small mammals, insects, and vegetation are known to move radiological contaminants from buried waste where it is presumably redistributed on the surface through the food chain, excrement, and soil dust (Arthur 1982; Markham 1987; Arthur and Markham 1982). The same is probably true for nonradiological contaminants. Because the waste sites are the original sources of contaminants, and data were not provided by PNL for contaminant levels outside the waste sites, the assumption was made that source terms outside waste sites are negligible.

2. The assumption was made that small species with home ranges of 2 ha (5 acres) or less (table 4-9) could receive as much exposure as our average screening indicates.

3. The assumption was made that wide-ranging species with home ranges more than 2 ha (5 acres) but less than the total area within the waste complexes on the reservation could receive at most 25% of the exposure calculated by the average screening if their home range includes as much contaminated area as possible. This assumption is based on the 3600 ha (8800 acres) of waste sites contained within the 14,000-ha (35,000-acre) block where most of the waste sites are located (figure 4-3) (see appendix B). Exposures could be higher if, for instance, the sole source of contaminants is a waste pond used as the only source of drinking water.

4. The assumption was made that species with very large home ranges, greater than the largest waste complex of 14,000 ha (35,000 acres) could receive at most a fraction of exposure comparable to the fraction of its home range contained in the total area of waste sites.

5. Only 4500 ha (11,000 acres) or 2% of the surface area of the INEL reservation is waste sites, which is the only part of the reservation considered for remediation. Biota living in the remaining 98% of the reservation are exposed only to contaminants that have moved from waste sites by dust and by contaminated wildlife and plants. Although this contamination may be measurable, source terms do not exist for them and assume they are negligible compared with the contamination in the waste sites. Because the assumption was made that the entire INEL reservation is similar habitat, only 2% of the area supporting ecological endpoints would be affected by contaminants from the waste sites.

6. Except for threatened and endangered species, for which the loss of an individual is considered a

TABLE 4-9—*Territory Sizes of Receptors Chosen for Analysis on the Idaho National Engineering Laboratory Reservation*[1]

Endpoint	Receptor	<2 ha	2 – 14000 ha
Threatened and Endangered	Pygmy rabbit		X
	Shrike	X	
	Townsend's big-eared bat		X[2]
	Ferruginous hawk		X
	Bald eagle		X
Wetlands	Generic	X	X
Recreational wildlife	Jackrabbit		X
	Pronghorn antelope		X
	Sage grouse		X
	Mallard		X
	Coyote		X
Agricultural	Cow		X
Biodiversity	Mouse	X	
	Songbird	X[3]	X
Correction factor for average HIs[4]		1	0.25

[1] Data sources are discussed in appendix B.
[2] Sizes of feeding territories of bats in general are not known. We assume that Townsend's big-eared bats at INEL have feeding areas of more than 5 acres.
[3] The songbird selected for our risk analyses was the robin, which generally has a territory size of more than 2 ha, but smaller birds can have territories of less than 2 ha.
[4] We assume that this will result in HIs for less than 2% of the populations on the INEL reservation. See appendix B for discussion of correction factors.

significant risk to the population, the assumption was made that other endpoints are at risk only at the small scale represented by the 2% of the INEL reservation that is in waste sites.

7. All contaminated wetlands are waste ponds. The assumption was made thatall aquatic biota receive the average exposure to contaminants if they occur in waste ponds. Similarly, the assumption was made that biota in other wetlands are not exposed to contaminants.

8. Grazing livestock are not allowed into contaminated sites. Risks to livestock would be applicable only if livestock were allowed to graze in waste areas.

4.5 CONTAMINANT HAZARD ASSESSMENTS

4.5.1 Comparison of Modeled Doses with On-Site Measurements

To validate the model assumptions and calculations used in determining contaminant exposure and risk to INEL receptors occupying waste sites, site-measured data were compared with modeled values of risk from exposure to the maximum contaminant concentrations. A literature search of the INEL data provided radiological contaminant concentrations in water and selected organisms and nonradiological concentrations in soils and vegetation. Several comparisons were made to validate different aspects of the model. Contaminant concentrations were measured in mice, cottontail and Nuttall's rabbits, pronghorn, swallows, ducks, coots, arthropods, mourning doves, invertebrates, and sage grouse. Comparisons were made between the modeled hazard indices (HIs) for chemical contaminants or doses for radiological contaminants for the pygmy rabbit and jackrabbit, and the calculated HIs (or doses) for cottontail rabbits; between the modeled values for the songbird and shrike, and the calculated HIs (or doses) for swallows and doves; and between the modeled values for the mallard and the calculated HIs for ducks and coots.

Doses were calculated for receptor species using (1) measured water concentrations for drinking water only, (2) measured soil and vegetation values, (3) measured water and applicable prey tissue concentrations, and (4) measured tissue concentrations in the organism. External dose from exposure to radionuclides was also applied, using measured soil concentrations.

Results of the comparisons indicated that the modeled HIs or doses were similar to the measured values. With few exceptions, the modeled values were generally within one to two orders of magnitude of the measured values. Most modeled values were greater than the measured values, indicating that the model is not underestimating risk. This was to be expected, since the comparison was made with the modeled maximum contaminant concentrations. In general, the model tended to overestimate the risk from exposure to mercury, ^{137}Cs, and ^{60}Co and underestimate the risk from strontium and ^{90}Sr.

4.5.2 Baseline

Baseline HIs for terrestrial receptors exposed to the maximum source concentrations were greater than the criteria limit of 1 for 15 out of 21 inorganic contaminants. There were no exposures to organic contaminants that resulted in HIs greater than 1. Exposure to the maximum concentrations of radionuclides resulted in HIs for all receptors of 30. Radiological exposure was dominated by external exposure to ^{137}Cs in soils.

Exposures to average soil concentrations at the waste sites were calculated for those contaminants whose maximum concentrations resulted in HIs greater than 1 (table 4-10). Compared with the maximum HIs, exposure to the average concentrations at INEL waste sites resulted in a 28% decrease in the number of contaminants with HIs greater than 1. In other words, 72% of the contaminants that resulted in HIs greater than 1 from exposure to the maximum concentrations also had HIs greater than 1 from exposure to average concentrations.

About 90% of the HI values were less than 10, 8% were above 10 but less than 1000, and 2% were still greater than 1000. Exposure to zirconium was responsible for those HIs that exceeded 1000.

Exposure of aquatic organisms to maximum concentrations of nonradiological contaminants in surface water did not result in any HIs over 1 (cesium and cobalt were the only constituents with measured concentrations in surface water). Exposure of benthic macroinvertebrates to the maximum sediment pore-water concentrations (calculated from sediment concentrations) resulted in many HIs greater than 1. Hazard indices resulting from exposure to the average pore-water concentrations were identical to the maximum HIs (table 4-11); this is because there was only one value given in the source terms, and it was not clear whether it represented the maximum or the average concentration

Exposure to both the maximum and average concentrations of radionuclides in the surface water or in the sediment pore water (macroinvertebrates only) resulted in HIs (or doses) greater than 1 for only benthic macroinvertebrates (table 4-12). The primary contributing radionuclide was the gamma emitter ^{134}Cs.

The initial screening using average contaminant values indicated 21 contaminants resulting in HI values greater than 10 (i.e., severe risk from contaminants) or HI values greater than 1 (i.e., moderate risk from contaminants) for various endpoints (tables 4-10, 4-11). Following the assumptions outlined in section 4.4, the approximate home range or territory size of receptors was used to determine the proportion that could potentially be contained within waste sites. Of the receptors included in the analyses, only the shrike and the deer mouse occupy a small enough area (table 4-9) to potentially live entirely within contaminated areas [(e.g., less than 2 ha (5 acres)]. Some small wetlands are less than 2 ha (5 acres) in extent, and vegetation and small songbirds can occupy small areas. All other receptors included in the analyses had territories or home ranges greater than 2 ha (5 acres) and less than the largest waste complex [1400 ha (35,000 acres)] (appendix B). The basis of the assumptions discussed in section 4.3 and appendix B, appropriate correction factors were applied to HIs in table 4-10, 4-11 and 4-12 to determine potential severity of risks to endpoints. For species with home ranges or territories less than 2 ha (5 acres) (e.g., the shrike and the deer mouse), no correction factor was used. For species with home ranges or territories more than 2 ha (5 acres) but less than 1400 ha (35,000 acres), a correction factor of 0.25 was used. No species had home ranges or territories more than 1400 ha (35,000 acres).

Some contaminants may be highly localized, but data do not exist for their areal distribution. Of the contaminants which analyses indicate result in moderate to severe risks, source terms for Zr represent less than 0.004 ha (0.01 acres), and Sb, Ni, and Tl represent less than 0.2 ha (0.5 acres) of contaminated land (appendix A). Except for total radiological contaminants, for which our source terms represent more than 120 ha (300 acres), source terms for all other contaminants represent 1 to 40 ha (3 to 100 acres). Although data for most contaminants were reported for only a small fraction of the total area in waste sites, the data were assumed to be representative. All source terms used in our risk analysis are, therefore, assumed to be present in all 4500 ha (11,000 acres) of waste sites (appendix B). Although this may not be a realistic assumption for all contaminants, it is acceptable for comparison of risks from remediation alternatives.

4.5.2.1 Threatened and Endangered Species

. Risks to some threatened and endangered species would be moderate or severe if individuals a small songbird can occupy waste sites. Potentially severe risks would be present for shrikes (sum of radioactive contaminants) and pygmy rabbits (zirconium). Potentially moderate risks would be present from these and other contaminants to all threatened and endangered species (table 4-13a). Although the analyses indicate potential risks to these species, a site-specific survey of individual waste sites for occurrences of threatened and endangered species would be necessary to determine if there are actual risks.

4.5.2.2 Wetlands

Risks to wetlands receptors (e.g., benthic macroinvertebrates) would be severe from ten contaminants in waste ponds and moderate from nickel and vanadium (table 4-13b). However, because it was assumed that non-waste-pond wetlands are not contaminated, risks to receptors in natural wetlands from contaminants would be negligible.

4.5.2.3 Recreational Species

For some recreational species occupying waste sites, risks from Ba, Zr, and Pb would be severe (table 4-13c). Additional moderate risks would also be possible from Cd, cyanide, Hg, and total radioactive contaminants. Risks to individualsthat do not occupy waste sites would be negligible, and because less than 2% of the reservation is waste sites, overall risks to populations of wildlife on the reservation would be negligible.

4.5.2.4 Agriculture

Barium, Pb, and Zr would pose severe risks to cattle if waste sites were used for grazing (table 4-13d). Similarly, cadmium, cyanide, and total radiological contaminants would pose moderate risks to cattle. However, cattle do not graze in waste areas; therefore, potential risks to livestock are negligible.

4.5.2.5 Public Lands

Because risks to receptor species in the food web would be negligible unless receptors occupy waste sites and because the reservation boundaries adjacent to public lands are more than 10 km (6 miles) from waste sites, risks to public lands would be negligible. Although wide-ranging species (e.g., coyote, hawks, eagles, sage grouse, migratory waterfowl, and pronghorn) are capable of transporting contaminants to public lands, risks to populations of these species would be negligible.

Table 4-10—*Baseline Hazard Indices for Terrestrial Organisms on the Idaho National Engineering Laboratory*

Hazard Indices Calculated Using Average Contaminant Concentrations[1]	Mouse	Pygmy Rabbit	Jackrabbit	Pronghorn	Cow	Songbird	Sage Grouse	Mallard	Shrike	T.B.E. Bat	F. Hawk	Bald Eagle	Coyote	Vegetation
Methylene chloride	2.80E-04	3.43E-04	8.54E-04	6.67E-04	1.28E-03	2.99E-04	6.66E-04	2.37E-04	1.56E-04	3.32E-04	3.01E-11	7.13E-11	3.63E-11	2.73E-03
Toluene	1.44E-06	1.85E-06	4.61E-06	3.54E-06	6.99E-06	1.73E-06	3.83E-06	1.48E-06	7.47E-07	1.59E-06	4.08E-12	9.56E-12	4.96E-12	1.8[illegible]E-04
Antimony	2.07E-06	7.14E-06	1.78E-05	1.30E-05	2.79E-05	6.36E-06	1.74E-05	5.66E-06	1.83E-06	3.88E-06	1.25E-09	2.83E-09	1.55E-09	[illegible]
Arsenic	1.55E-01	6.33E-03	1.58E-02	6.44E-03	1.51E-02	4.54E-01	1.80E-02	8.45E-03	3.36E-02	7.15E-02	1.31E-06	2.85E-06	1.66E-06	2.7[illegible]E-01
Barium	6.46E+00	2.24E+01	5.59E+01	4.05E+01	8.84E+01	2.13E+01	5.64E+01	1.99E+01	4.90E+00	1.06E+01	5.89E-04	1.32E-03	7.34E-04	[illegible]
Cadmium	[illegible]	3.81E+00	[illegible]	7.19E+00	1.46E+01	3.07E-01	2.26E+01	1.00E+00	1.53E-01	2.91E+00	9.96E-04	2.31E-03	4.49E-04	9.11E-01
Chromium	1.79E-01	3.63E-01	9.06E-01	6.11E-01	1.90E+00	5.03E-01	1.09E+00	5.74E-01	7.38E-03	1.57E-02	3.50E-04	7.49E-04	4.47E-04	[illegible]
Cobalt	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	1.47E-07
Lead	[illegible]	2.37E+01	5.91E+01	4.10E+01	9.60E+01	8.79E+00	1.10E-02	5.13E-03	7.23E-01	5.05E+00	2.05E-07	4.48E-07	1.58E-03	1.76E-01
Mercury	4.24E-03	4.40E+00	2.58E+01	1.76E+00	3.40E+00	3.57E-02	2.48E-01	9.60E-01	2.23E-02	1.54E-02	5.18E-03	1.21E-02	5.52E-01	[illegible]
Nickel	1.95E-02	3.35E-02	8.37E-02	5.86E-02	1.35E-01	4.12E-01	8.94E-01	4.47E-01	4.04E-02	8.88E-03	3.41E-04	7.49E-04	4.45E-05	[illegible]
Selenium	4.87E-02	9.07E-02	2.26E-01	1.55E-01	3.71E-01	2.05E-02	4.42E-02	2.29E-02	9.35E-04	1.19E-02	4.00E-05	8.65E-05	3.03E-04	1.2[illegible]E-01
Silver	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	[illegible]
Thallium	1.84E-01	3.82E-01	9.53E-01	6.41E-01	[illegible]	5.33E-01	1.82E+00	6.10E-01	1.69E-02	8.98E-03	2.68E-03	5.72E-03	3.43E-03	[illegible]
Uranium	1.21E-01	2.49E-01	6.21E-01	4.19E-01	[illegible]	1.62E-03	3.52E-03	1.84E-03	2.69E-05	1.21E-02	4.11E-08	8.81E-08	1.11E-05	NA
Vanadium[2]	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	NA
Zinc	2.03E-01	4.12E-01	[illegible]	7.92E-01	[illegible]	3.06E-01	8.36E-01	2.15E-01	1.73E-01	3.68E-01	7.20E-03	1.70E-02	8.75E-03	[illegible]
Zirconium	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	9.17E-01	[illegible]	[illegible]	NA
Aroclor 1254	2.65E-01	4.41E-01	[illegible]	5.44E-01	[illegible]	2.04E-02	3.62E-02	1.88E-02	8.45E-04	5.93E-02	2.17E-05	4.69E-05	7.12E-04	8.2[illegible]E-01
Cyanide	6.83E-02	8.30E-02	2.07E-01	[illegible]	[illegible]	7.14E-02	1.59E-01	5.56E-02	3.86E-02	8.20E-02	2.04E-10	3.66E-08	1.86E-08	NA
Radiological	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

[1] NA = Benchmark is not available; therefore, hazard index could not be calculated.

[2] Vanadium was found only in sediment; therefore, no pathway exists for terrestrial exposure.

TABLE 4-11—*Baseline Chemical Hazard Indices for Aquatic Organisms on the Idaho National Engineering Laboratory*

Constituent	Surface Water Hazard Index	Benthic Macroinvertebrate Hazard Index
Methylene chloride	0.00	[redacted]
Toluene	0.00	[redacted]
Antimony	0.00	1.96E–01
Arsenic	0.00	6.22E–02
Barium	0.00	2.40E–01
Cadmium	0.00	[redacted]
Chromium	0.00	[redacted]
Cobalt	5.20E–10	[redacted]
Lead	0.00	[redacted]
Mercury	0.00	[redacted]
Nickel	0.00	[redacted]
Selenium	0.00	1.14E–01
Silver	0.00	[redacted]
Thallium	0.00	0.00
Uranium	0.00	0.00
Vanadium	0.00	[redacted]
Zinc	0.00	[redacted]
Zirconium	0.00	0.00
Aroclor 1254	0.00	0.00
Cyanide ion	0.00	0.00

[1] NA = Benchmark was not available; therefore, hazard index could not be calculated.

TABLE 4-12—*Average Internal and External Radiological Doses to Aquatic Organisms (rad/d)*[1] *on the Idaho National Engineering Laboratory*

	External Beta and Gamma	Internal Plants	Internal Benthic Macroinvertebrates	Internal Fish	Internal Muskrats
Cesium-134	0.00	0.00	8.53E+04	0.00	0.00
Cesium-137	9.53E–09	6.99E–07	7.79E+04	3.50E–06	4.93E–06
Cobalt-60	3.41E–07	3.97E–05	3.13E+06	3.97E–06	7.81E–06
Plutonium-239	0.00	0.00	9.61E+00	0.00	0.00
Thorium-232	0.00	0.00	0.00	0.00	0.00
Uranium-234	0.00	0.00	5.52E+00	0.00	0.00
Total dose	3.50E–07	4.04E–05	3.30E+06	7.47E–06	1.27E–05

[1] The benchmark for aquatic organisms is 1 rad/d, therefore the total dose equals the hazard index.

4.5.2.6 Biodiversity

Risks to overall biodiversity of the sagebrush-steppe ecosystem on the reservation would be negligible because waste sites occupy only 2% of the total land area. However, as discussed for other endpoints, there would be potential risks to some receptors important to biodiversity in waste sites. In addition to the receptor species discussed previously, Pb, Zr, and total radiological contaminants pose potentially severe risks, and Ba and Cd pose potentially moderate risks to mice or songbirds that could occupy waste sites (table 4-13e). In addition to these contaminants, vegetation is also potentially at severe risk from Hg and at moderate risk from Sb, Cr, Ni, Ag, Tl, and Zn in waste sites. On the basis of calculated risks to Townsend's big-eared bat (table 4-9), risks to bats inhabiting lava tube caves and feeding within waste sites would be moderate for Ba, Pb, Zr, and total radiological contaminants table (4-13a).

4.6 Habitat Disturbance Assessment

As urban and agricultural development increasingly fragments the nation's natural landscape large, undisturbed, and protected blocks of natural landscape are becoming more important for the protection of biodiversity. The INEL reservation is a large block of relatively undisturbed native sagebrush-steppe grassland. Rangeland and lava flow areas in the surrounding counties are similar ecologically. As is clearly seen on aerial photos, much of the surrounding area (table 4-14) is in agricultural use (i.e., farm or rangeland), especially to the north and west of the reservation.

The nine major facilities on the reservation occupy 150 ha (370 acres), and public roads, utility, and railroad rights-of-way occupy an additional 13,349 ha (33,480 acres) (predecisional draft EIS for INEL, September

4.6.1 Baseline

Because no additional disturbance resulting from restoration activities is included in the baseline alternative, no additional disturbance beyond the current 6% of the reservation is expected.

4.7 Cumulative Assessment

4.7.1 On-Site

4.7.1.1 Baseline

For 17 contaminants, HIs suggest potential risks to organisms inhabiting waste sites (table 4-15). Of these contaminants, 4 pose potential risks only to waste pond wetlands and two (antimony and thallium) pose potential risks only to other elements of biodiversity (e.g., vegetation growing on waste sites; table 4-13e). Barium, Cd, Cr, Pb, Hg, Zr, and total radiological contaminants pose potential risks to many endpoints occupying waste sites. Most of the waste sites are highly developed areas that do not provide suitable habitat for most organisms. Actual risks associated with these sites are probably lower than indicated by the HIs. Wildlife and waterfowl probably use waste ponds; therefore, for these organisms current exposures may be substantial. For all of the sites, a future scenario involving closure of the INEL facility without restoration would result in reoccupation of all waste sites by plants and animals; risks similar to those indicated in table 4-15 would then be expected.

Determining cumulative risks to endpoints that do not occupy waste sites is more problematic. Data were not adequate to determine facility-wide contaminant levels. Moreover, many of the inorganic contaminants (e.g., metals) included in our analyses are known to occur in soils throughout the United States at concentrations greater than or equal to concentrations in the INEL source-term data base (table 4-16). For some of these substances, it is possible that the source terms reflect naturally occurring concentrations rather than contamination. Even when background levels are known, interpretation of HIs for inorganic substances is often difficult because most analytical techniques do not distinguish between chemical forms that are available for uptake by organisms (e.g., dissolved in soil pore water or loosely bound to particles) and those that are biologically unavailable (e.g., insoluble salts).

TABLE 4-13A—*Baseline Potential Risks[1] to Threatened, Endangered, and Candidate Species that occupy Waste Sites. Risks to Individuals that do not Occupy Waste Sites are Negligible. Waste Sites Account for 2% of the Surface Area of the Idaho National Engineering Laboratory Reservation*

	Pygmy Rabbit	Shrike	Townsend's Big-Eared Bat	Ferruginous Hawk	Bald Eagle
Barium	M[2]	M	M		
Cadmium	M				
Lead	M		M		
Mercury	M				
Zirconium	S	M	M		
Radiological	M	M	M	M	M

[1] Potential risks based on assumptions discussed in Section 4.4.3.
[2] M = moderate, S = severe.

TABLE 4-13B—*Baseline Potential Risks to Wetlands that are Waste Sites. Risks to Wetlands that are not Waste Ponds are Negligible*

Contaminants	Benthic Invertebrates[1]
Cadmium	S
Chromium	S
Cobalt	S
Lead	S
Methylene chloride	S
Mercury	S
Nickel	M
Silver	S
Toluene	S
Vanadium	M
Zinc	S
Radiological	S

[1]Based on Environmental Protection Agency Water Quality Criteria (Suter et al. 1992). It is assumed that benthic invertebrates are exposed to pore-water concentrations, whereas other wetland (aquatic) organisms are exposed to surface water.

TABLE 4-13C—*Baseline Potential Risks to Recreational Wildlife that occupy Waste Sites. Risks to Individuals that do not Occupy Waste Sites are Negligible, and Overall Risks to Populations of Wildlife on the Reservation are Negligible*

Contaminants	Jackrabbit	Pronghorn	Sage Grouse	Mallard	Coyote
Barium	S	S	S	M	
Cadmium	M	M	M		
Cyanide		M			
Lead	S	S			
Mercury	M				
Zirconium	S	S	S	S	
Radiological	M	M	M	M	M

TABLE 4-13D—*Baseline Potential Risks to Cattle that Occupy Waste Sites. Risks to Individuals that do not occupy waste sites are negligible; hence, risks to cattle are negligible in the areas currently used for livestock grazing*

Contaminants	Cattle
Barium	S
Cadmium	M
Chromium	M
Cyanide	M
Lead	S
Zirconium	S
Radiological	M

TABLE 4-15—*Comparative Summary of Potential On-Site Cumulative Risks[1] to Ecological Endpoints from the Baseline Alternative on the Idaho National Engineering Laboratory Reservation. Risks are for Endpoints that Occupy Waste Sites[2]*

Contaminant	Baseline Risk
Construction[3]	
Antimony	B[4]
Barium	E,R,B
Cadmium	E,W,R,F,B
Chromium	W,F,B
Cobalt	W
Cyanide	R,F
Lead	E,W,R,F,B
Mercury	E,W,R,B
Methylene chloride	W
Nickel	W,B
Silver	W,B
Thallium	B
Toluene	W
Vanadium	W
Zinc	W,B
Zirconium	E,R,F,B
Radiological	E,W,R,F,B

[1] Only those contaminants are listed that our analyses showed could pose severe or moderate risks to some endpoints. Risks could be severe from at least one contaminant for each endpoint (see table 4).
[2] Risks to endpoints that do not occupy waste sites are assumed to be negligible (see Section 4.4.3).
[3] These are short-term risks. Long-term risks could be reduced with successful restoration of appropriate habitat.
[4] Ecological endpoints: E = threatened, endangered, and candidate species; W = wetlands; R = recreational fish and wildlife; F = agriculture and forestry; P = public land; B = biodiversity (only for receptors not included under other endpoints).

TABLE 4-16—*Comparison of Source-Term Concentrations of Contaminants with Naturally Occuring Concentrations in Parts per Million*

Contaminant	Source-Term Conc.	Ave. Background Conc. at INEL[1]	Ave. Conc. for Western US[2]	Range of Naturally Occurring Conc.[2]
Antimony	5.8	NA[3]	0.5	<1 - 2.6
Barium	2170	298	580	70 - 5000
Cadmium	3.1	0.6	NA	NA
Chromium	302	18	41	3 - 2000
Lead	19.6	12	17	<10 - 700
Mercury	6.0	0.24	0.05	<.01 - 4.6
Nickel	215	18	15	<5 - 700
Silver	3.7	NA	NA	NA
Thallium	1.4	NA	NA	NA
Zinc	143	68	55	<10 - 2100
Zirconium	10500	NA	160	<20 - 1500

[1] From Rope et al. (1988).
[2] From Shacklette and Boerngen (1984).
[3] NA = not available.

It was not possible to definitively determine either the fraction of inorganic substances in the source term data base actually attributable to contamination or the fraction of those substances biologically available to organisms living on the reservation. However, evaluation of existing data on regional background levels permits some tentative conclusions. Ranges of concentrations for thallium throughout the United States are higher than our average source-term data for that element (table 4-16). Therefore, risks from thallium due to waste sites are probably negligible. At present, no data characterizing ranges of concentrations of cadmium, thallium, and silver are available. All other inorganics for which data were available range in concentrations from less than those given in source terms to much greater than source terms. However, geometric means for the western United States were much less (e.g., generally less than 1/10) than source terms for Sb, Ba, Cr, Hg, Ni, and Zr. Lead and zinc source term concentrations were somewhat higher than average background concentrations. Because of the high toxicity of lead, and the uncertainty associated with background variability, risks from lead in waste sites may be present. Zinc, however, is an essential element for life, and source-term concentrations were only about three times the average concentration for the western United States. Risks from zinc, which were found to be present only in wetlands and in vegetation growing on waste sites, are probably negligible.

Despite difficulties in interpretation of the HIs, cumulative risks from available source-term and benchmark data are adequate to compare alternatives. Because of the relatively small fraction of the INEL reservation that is contaminated, potential risks to all endpoints except for (1) endangered and threatened species and (2) wildlife using waste ponds appear negligible. Because no restoration activities are included in the baseline case, habitat disturbance/fragmentation risks would also be negligible.

4.7.2 Off-Site

The only currently known mechanism for transport of contaminants from waste sites off the reservation is through ingestion by wide-ranging wildlife (e.g., migratory waterfowl or pronghorn antelope). Of the three classes of contaminants in waste sites (i.e., organics, inorganics, and radionuclides), the only source of radionuclides in the region would be INEL reservation waste sites. Therefore, regional (off-site) cumulative risks for radionuclides would be the same as on-site risks. At the time of our analyses no regional data for organics or inorganics were available, and cumulative risks for the region of influence could not be estimated.

CHAPTER 5: HANFORD RESERVATION

The Hanford Reservation in south-central Washington State is about 148,000 ha (365,700 acres; 560 miles^2) of semiarid sagebrush-steppe vegetation located just north of the confluences of the Snake and Yakima rivers with the Columbia River (figure 5-1). About 6% of the land area has been disturbed and is actively used. Public access to the reservation is restricted (Woodruff and Hanf 1992). The reservation is bordered on the north by the Saddle Mountains. The Columbia River flows through the northern part of the site, and turning south, forms part of the eastern boundary. The Yakima River runs along part of the southern boundary. Rattlesnake Mountain, Yakima Ridge, and Umtanum Ridge form the southwestern and western boundary. Two small east-west ridges, Gable Butte and Gable Mountain, rise above the plateau of the central part of the reservation (Cushing 1991). The Arid Lands Ecology (ALE) Reserve, a protected environmental research area, occupies the southwestern edge of the reservation. Saddle Mountain National Wildlife Refuge and Wahluke Slope Wildlife Refuge Area occupy the portion of the reservation north of the Columbia River.

This semiarid reservation is one of the largest undisturbed tracts of native sagebrush-steppe remaining in the state of Washington. Big sagebrush is the most common shrub species. Additional shrubs include other species of sagebrush, antelope bitterbrush, gray rabbitbrush, greasewood, spiny hopsage, and winterfat. Common grasses are bluebunch wheatgrass, Sandberg's bluegrass, and cheatgrass. In the past, trees were planted for windbreaks and shade, and some have persisted at abandoned farmsteads on the reservation. Wildlife includes 12 species of reptiles and amphibians, almost 187 species of birds, 40 species of mammals, including 6 species of bats (Fitzner and Gray 1991), and 43 species of fish. Most species are characteristic of the semiarid shrub-steppe and river environments of the region. Ecology of the Hanford Reservation is described in detail in Cushing (1991) and Sackschewsky et al. (1992); information is taken from these reports unless noted otherwise.

Contaminated sites are associated with facilities in major operational areas and have been grouped into four aggregated areas using identifiable geographic boundaries (figure 5-1). The four aggregated areas, which have been placed on the U.S. Environmental Protection Agency's (EPA) National Priorities List, are as follows:

- The 100 Area occupies about 11 km^2 (4 mi^2). It lies along the Columbia River in the northern portion of the Hanford Reservation and is the site of eight retired plutonium production reactors and the N Reactor (currently in retired status).
- The 200 West and 200 East Areas cover about 16 km^2 (6 mi^2). They lie in the center of the Hanford Reservation near the basalt outcrops of Gable Mountain and Gable Butte. These areas historically were dedicated to fuel reprocessing and waste processing management and disposal activities.
- The 300 Area covers 1.5 km^2 (0.6 mi^2). It is near the south border of the Hanford Reservation and is the site of nuclear research and development.
- The 1100 Area is a corridor northwest of the city of Richland used for vehicle maintenance and other support activities.

On the basis of information from the Environmental Restoration PEIS source term data base (appendix A), about 870 ha (2150 acres) of the 148,000 ha (365,700 acres) Hanford Reservation are contaminated, including about

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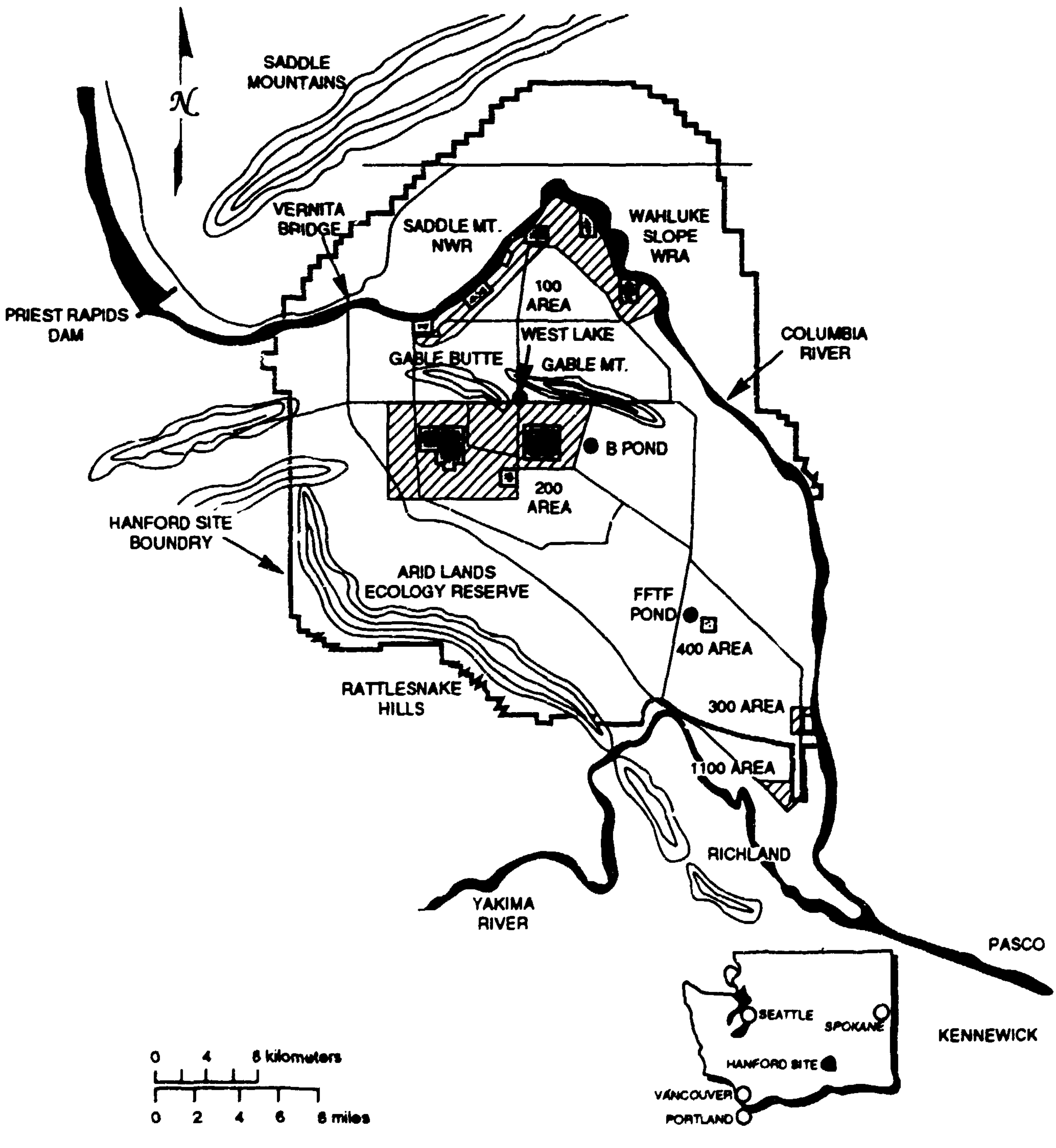

820 ha (2030 acres) of contaminated soil and 45 ha (110 acres) of waste ponds. This is about 0.6% of the total area of the Hanford Reservation and about 10% of the disturbed areas. It was assumed that this is a representative sample of the surface area of all waste sites at Hanford.

5.1 Ecological Endpoints and Species Distribution

Endpoints can be represented by many different receptors. The ecological endpoints and receptors chosen for the Hanford Reservation ecological risk assessment are described in this section of the report. In summary, 11 federally listed threatened and endangered or candidate species of plants and animals occur, visit, or nest on the reservation; wetlands are found along the Columbia River, in the Rattlesnake Hills, at West Lake, and in surface ponds and ditches associated with fuel and waste processing activities; recreational wildlife species are present but hunting is not allowed; no grazing or agricultural activities are allowed, although the reservation is surrounded by range and agricultural land; several public areas lie within the reservation but access is restricted; and finally, the Hanford Reservation is one of the largest relatively undisturbed and protected tracts of sagebrush-steppe in the state of Washington. Because of these important ecological endpoints, the reservation has value for the conservation of biodiversity. Important groups of species include raptors, salmonids, large mammals, and wintering/migratory wildlife.

Determining risks to endpoints requires (1) defining distribution and composition of endpoints and (2) selecting receptor species. The distribution of endpoints must be known in order to determine both exposure pathways for contaminants and risks to endpoints from construction (i.e., habitat disturbance).

For purposes of determining risk of exposure to contaminants, distribution of endpoints is considered to be either ubiquitous (i.e., more or less uniformly distributed throughout the reservation or region), discontinuous (i.e., found in several locations within a limited area or areas), or discrete (i.e., located in one clearly identified location). Risks to ubiquitous endpoints are assumed to be related to the total surface area affected by contaminant exposure or by disturbance from remediation. Risks to discontinuous and discrete endpoints are determined if their locations are known to be within contaminated areas or within areas affected by remedial activities or contaminant exposures.

Although the terrestrial ecology of the reservation is generally uniform, the wetland areas (i.e., rivers, ponds, seeps, and springs) are scattered. Thus, endpoints (e.g., biodiversity) can be both ubiquitous (e.g., shrub-steppe vegetation) and discontinuous (e.g., pelicans) depending on the receptors (table 5-1). Locations of endpoints were determined from existing maps and publications, supplemented by personal communications with ecologists at the Hanford Reservation.

5.1.1 Threatened and Endangered Species

5.1.1.1 Receptors

There are 11 federally listed or candidate species of plants, birds, and mollusks at the Hanford Reservation (table 5-2). Of the federally listed species of birds, the Aleutian Canada goose is a rare visitor, the peregrine falcon is known to reside full-time on the reservation but is listed as rare, and the bald eagle is found during the fall and winter. Of the candidate species of birds, the western sage grouse and loggerhead shrike are year-round residents, and the ferruginous hawk winters off-site (Fitzner and Gray 1991). The plants and mollusk are, of course, full-time residents.

The peregrine falcon feeds almost exclusively on birds, and the Canada goose and bald eagle feed exclusively on vegetation and salmon, respectively. The ferruginous hawk feeds almost exclusively on jackrabbits. The sage grouse has not been observed since the mid-1980s and probably no longer resides at the Hanford site (Fitzner and Gray 1991). The loggerhead shrike eats mostly insects and small mammals. Exposure risk to populations that migrate would be less than to resident populations.

TABLE 5-1—*Distribution of Ecological Endpoints and Receptors at the Hanford Reservation*

Ubiquitous	Discontinuous	Discrete
Resident, breeding federally listed and candidate species (peregrine falcon, western sage grouse, loggerhead shrike)	Wetlands (vegetation, benthic invertebrates, fish, muskrats, and migratory waterfowl)	Public lands (Arid Lands Ecology Reserve, Saddle Mountain Wildlife Refuge, Wahluke Slope Wildlife Refuge Area)
Recreational wildlife (deer, elk, jackrabbits, and upland gamebirds)	Recreational wildlife (salmon)	
Biodiversity (important components not included above- bats, food sources for protected species, sagebrush communities)	Biodiversity (pelican, bald eagle)	

TABLE 5-2—*Rare Species on the Hanford Reservation*

Species	Common Name	Status[a]
Plants		
Artemisia campestris borealis wormskioldii	Northern wormwood	C1
Astragalus columbianus	Columbia milk vetch	C2
Rorippa columbiae	Columbia yellowcress	C2
Lomatium tuberosum	Hoover's desert parsley	C2
Birds		
Branta canadensis leucopareia	Aleutian Canada goose	T
Falco peregrinus	Peregrine falcon	E
Haliaeetus leucoephalus	Bald eagle	T
Buteo regalis	Ferruginous hawk	C2
Centrocercus urophasianus phaios	Western sage grouse	C2
Lanius ludovicianus	Loggerhead shriek	C2
Mollusc		
Fluminicola columbianus	Columbia pebblesnail	C2

[a]Endangered and threatened wildlife and plants, Fed. Regist. 50 CFR 17.11 & 17.12, August 29, 1992; endangered and threatened wildlife and plants: animal candidate review, Fed. Regist. 50 CFR part 17, Nov. 21, 1991; endangered and threatened wildlife and plants: review of plant taxa, Fed. Regist. 50 CFR part 17, August 29, 1992. E = endangered, T = threatened, C1, C2 = under review.

5.1.1.2 Distribution

Most of the federally listed or candidate species are known to have patchy distributions rather than uniform dispersal over the entire reservation. There is no known designated or proposed critical habitat. The plant species are generally found near the Columbia River (Sackschewsky et al. 1992). The mollusk, Aleutian Canada goose, and bald eagle are found in or near the Hanford Reach of the river. For this programmatic analysis, the falcon, hawk, grouse, and shrike are assumed to be uniformly distributed in the Hanford shrub-steppe environment.

5.1.2 Wetlands

5.1.2.1 Receptors

Although the Hanford Reservation is located in a semiarid region, various types of wetlands are on reservation. Benthic macroinvertebrates, fish, muskrats, and aquatic plants are representative species of wetlands for which some toxicity benchmark data are available. Although these biota do not necessarily occur in all wetlands on the reservation, they were selected as receptors in our risk analysis because they cover the range of wetland ecosystem components that could be present. Thus, risks are calculated to these receptors in all wetlands (excluding West Lake which is recharged from groundwater and has not received direct effluents from site activities).

5.1.2.2 Distribution

Wetlands on the Hanford Reservation include the Columbia River; on-site ponds (i.e., West Lake, B Pond, and FFTF Pond); small spring streams and seeps, located mainly on the Arid Lands Ecology Reserve in the Rattlesnake Hills, that disappear into the ground before reaching any major water bodies; artificial ponds and ditches, formed as a result of wastewater disposal practices associated with the operation of the reactors and separation facilities that support aquatic and emergent flora and fauna (Gray and Rickard 1989); and ponds resulting from irrigation runoff in the Saddle Mountain Wildlife Refuge and the Wahluke Slope Wildlife Refuge Area (Cushing 1992).

5.1.3 Recreational Fish and Wildlife

5.1.3.1 Receptors

Many wildlife species having recreational, aesthetic, or commercial importance are present on the reservation, although access to the Hanford Reservation is restricted and the site is closed to hunting and fishing. Determining contaminant risks to aquatic species, including recreational fish, does not require the use of specific receptor species. Risks to fish in general were determined to represent recreational fish in the Columbia River (e.g., salmon). The mule deer, jackrabbit, and coyote were selected as common terrestrial species representative of recreational wildlife that are also important components of the food web on the reservation. All of these species are year-round residents on the reservation. Thus, our analysis estimates potential risks to populations continuously exposed to contaminants. However, it is highly unlikely that Hanford populations of fish, birds, or animals are continuously exposed to contaminants throughout their lifetimes.

5.1.3.2 Distribution

Game animals including deer, elk, jackrabbits, and upland gamebirds were considered to be common and found throughout the Hanford Reservation. Recreational fish are found in the Hanford Reach of the Columbia River which provides valuable spawning habitat for salmon and steelhead trout and is a major resting and feeding area for migratory waterfowl and shorebirds (Fitzner and Gray 1991).

5.1.4 Agricultural or Timber Production

Because of arid conditions, natural productivity on the Hanford Reservation is low. Although closed to agricultural activity, data are available on productivity of native vegetation (see references in Cushing 1991). The reservation is surrounded by range and agricultural land to the west, north, and east.

5.1.5 Parks and Other Public Lands

5.1.5.1 Receptors

Within the Hanford Reservation, there are several public areas with restricted access (figure 5-1). Risks to these receptors were determined by calculating risks to food web components at reservation boundaries. Risks are assumed to be maximal closest to the reservation.

5.1.5.2 Distribution

The Arid Lands Ecology Reserve (ALE) occupies the southwestern section of the reservation, and the Saddle Mountain National Wildlife Refuge and the Washington State Department of Game Wahluke Slope Wildlife Refuge Area occupy the portion of the reservation north of the Columbia River (figure 5-1). Other public lands include the Priest Rapids Wildlife Area on the Columbia River to the northwest, the Columbia National Wildlife Refuge to the north, and the Sacajawea State Park and McNary National Wildlife Refuge to the southeast of the reservation.

5.1.6 Biodiversity

5.1.6.1 Receptors

The Hanford Reservation is a very large, relatively undisturbed, native sagebrush-steppe ecosystem; most of the plant and animal species are characteristic of semiarid and river environments of the region. Conservation of such a large area of natural sagebrush-steppe vegetation contributes to the conservation of biodiversity. Raptors are well represented in our analyses by federally listed or candidate species (e.g., the endangered peregrine falcon, threatened bald eagle, and candidate ferruginous hawk and loggerhead shrike). The common pallid bat (*Antrozous pallidus*), which is ecologically similar to most bats found on the reservation, is a year-round resident and was chosen as a conservative representative of bat species. The robin, which is abundant site-wide and year-round, was chosen as a representative songbird. Other important food web components (figure 5-2) include major food organisms of receptors (e.g., small mammals eaten by raptors and coyotes, and insects eaten by loggerhead shrikes and bats) which were chosen to represent other endpoints. Although very important to ecosystem function and to other species as food, invertebrates were not included in our analyses due to lack of benchmark data for them. Benchmark data were generally not available for reptiles, another important species group at the reservation.

5.1.6.2 Distribution

Rocky Mountain elk inhabit the Arid Lands Ecology Reserve. Mule deer, hawks, upland gamebirds, and other shrub-steppe birds (e.g., sage sparrows, sage thrashers, loggerhead shrikes, and long-billed curlews) find refuge on the reservation from expanding agriculture and urbanization. Eagles, pelicans, and geese benefit from riverine management practices that restrict public access and ensure critical resources such as food, perches, and cover for broods. This large undisturbed expanse of sagebrush-steppe with its associated wetlands provides protected habitat for several species groups whose populations are in general decline. These species groups found on the Hanford Reservation include raptors (26 species), bats (seven species), reptiles and amphibians (12 species), and native Pacific salmonid populations (four species). In addition, the reservation is an important resting area for migrant waterfowl and is within a major sandhill crane flyway.

Invasion of sagebrush-steppe communities on the reservation by nonnative plant species (e.g., cheatgrass, Russian thistle) is an increasing threat to biodiversity. Nonnative species invade disturbed areas, crowd out native species, and inhibit or prevent their reestablishment on fresh disturbances. The abundance of these species is assumed to be inversely proportional to the quality of native sagebrush-steppe habitat and most abundant in and adjacent to disturbed sites and old cultivated fields.

5.2 Contaminants of Potential Concern

The contaminants of potential concern at the Hanford Reservation include radionuclides and inorganic and organic contaminants (table 5-3).

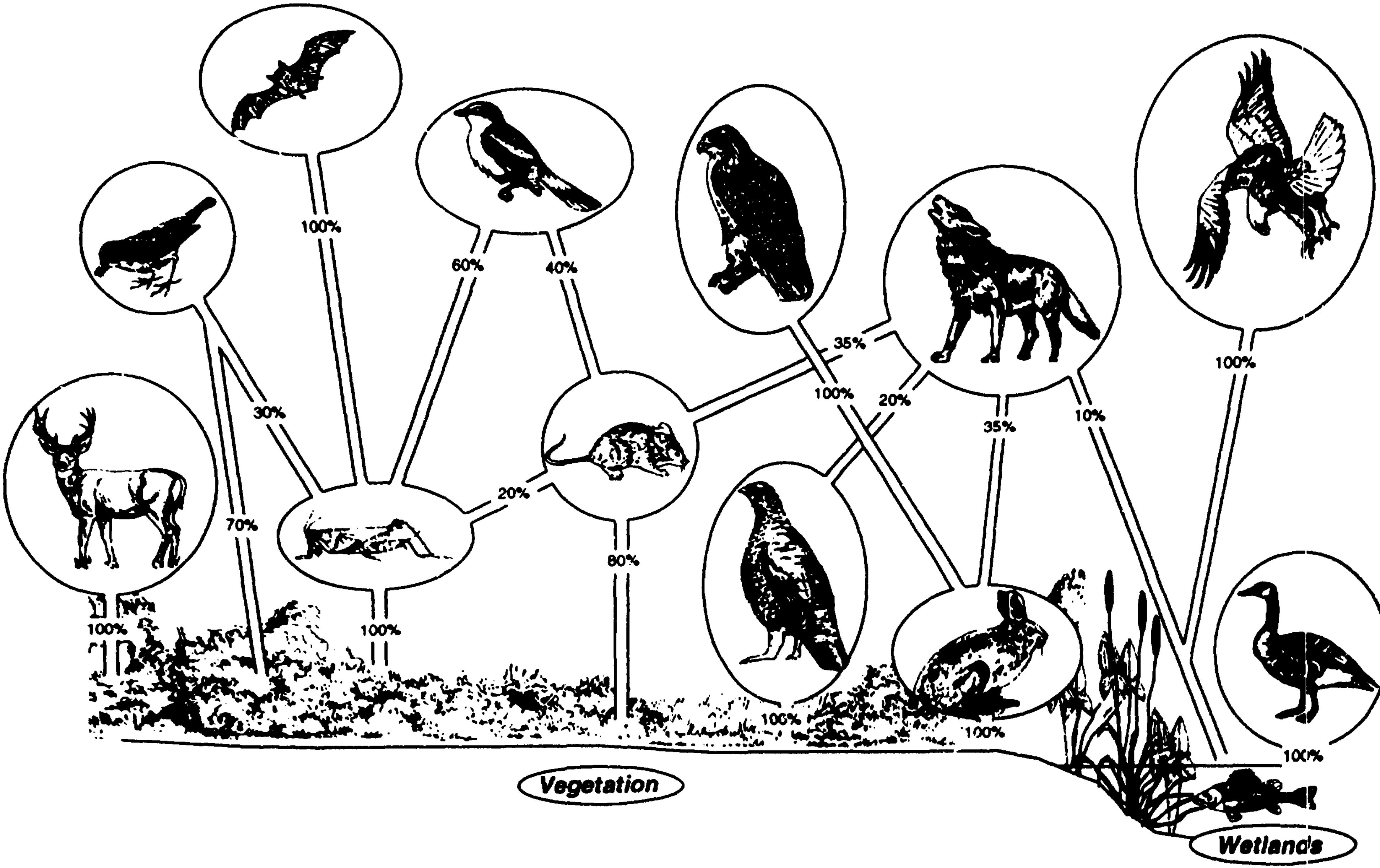

FIGURE 5-2. REPRESENTATION OF THE TERRESTRIAL FOOD WEB OF THE HANFORD RESERVATION

TABLE 5-3—*Maximum and Average Concentrations of Organic, Inorganic, and Radionuclide Contaminants in Soil at the Hanford Reservation*
[mg/kg dry weight (for chemical constituents) or pCi/kg dry weight (for radionuclides)]

Constituent	Maximum Concentration	Constituent	Average Concentration
Ammonia (carbonate)	4.43E+04	Benzo(a)pyrene	1.15e+04
Benzo(a)pyrene	1.80E+04	4-methyl-2-pentanone	2.65e+04
4-methyl-2-pentanone	1.35E+05	Trichloroethene	7.89e+02
Tributyl phosphate (TBP)	2.35E+06	Cadmium	6.25E-01
Trichloroethene	1.05E+03	Chromium	3.51e+01
Aluminum (fluoronitrate)	2.75E+05	Copper	5.07e+02
Beryllium	3.92E+00	Cyanide (iron)	1.12e+03
Cadmium	7.85E+00	Iron (nitrate)	5.23e+04
Chromium	3.92E+02	Lead	4.69e+01
Copper	7.85E+03	Magnesium (nitrate)	2.35e+05
Cyanide (iron)	1.57E+04	Mercury	3.94e+00
Fluoride	1.08E+06	Nickel	8.20e+01
Iron (nitrate)	5.23E+04	Zinc	3.51e+01
Lead	2.35E+02	Cobalt-60	5.82e+05
Magnesium (nitrate)	2.35E+05	Cesium-137	1.58e+07
Mercury	2.94E+04	Europium-152	4.91e+06
Nickel	1.18E+03	Plutonium-239	3.77e+09
Nitrate	4.04E+06	Strontium-90	1.19e+07
Nitric acid	1.18E+05	Uranium-238	3.96e+04
Nitrite	2.88E+05		
Phosphate	6.02E+05		
Potassium (borate)	2.82E+05		
Sodium	2.72E+06		
Sulfate	1.31E+05		
Sulfuric acid	3.00E+03		
Zinc	3.92E+02		
Americium-241	1.57E+05		
Carbon-14	1.62E+08		
Cobalt-60	4.96E+08		
Cesium-134	1.56E+05		
Cesium-137	5.05E+09		
Europium-152	3.32E+07		
Europium-154	5.81E+06		
Europium-155	1.36E+07		
Iodine-129	2.04E+04		
Nickel-63	1.84E+06		
Plutonium-238	7.16E+05		
Plutonium-239	3.07E+12		
Plutonium-240	8.33E+06		
Plutonium-241	8.05E+06		
Promethium-147	8.52E+05		
Ruthenium-106	1.36E+06		
Strontium-90	2.09E+09		
Tin-113	8.41E+02		
Tritium	3.52E+09		
Uranium-235	6.59E+02		
Uranium-238	4.90E+07		

The primary radionuclides, according to relative average concentrations, are ^{60}Co, ^{14}C, ^{137}Cs, ^{239}Pu, ^{3}H, and ^{90}Sr; the primary inorganics that are not essential nutrients (i.e., sodium) are Al, cyanide, Pb, Hg, Ni, and Zn; the primary organics are ammonia, benzo(a)pyrene, tributyl phosphate, trichloroethene, and 4-methyl-2-pentanone.

Maximum and average concentrations of chemical and radiological constituents in soil, surface water, and sediment were determined from the source terms provided by PNL (tables 5-3, 5-4, and 5-5, respectively). Determination of these average and maximum concentrations required that certain assumptions be made with regard to data interpretation and compensation for data gaps.

Appendix B describes the methodology used to develop the source terms for input into the exposure and risk assessment.

5.3 Exposure Assessment

Where available for Hanford, the maximum concentrations of each contaminant in each medium (i.e., soil, water, and sediment) were used to identify the worst-case potential contaminants. Contaminants that did not pose a risk to any of the receptor species from exposure to the maximum values were not considered further. If exposure to the maximum concentrations of contaminants posed a risk to organisms, then the average concentrations of those contaminants were used in the assessment to estimate the most probable and reasonable exposure and risk.

Estimating contaminant exposure for receptor species on the reservation also depends on knowing the amount of time species spend in waste areas and the amount of contaminants ingested. Because specific home ranges and habits of many of the representative species on the Hanford Reservation are not well known, an initial screening assessment for contaminant exposure was conducted using conservative assumptions. Even though only a few species with small home ranges (e.g., small mammals and birds) could reside within contaminated areas for most of their lives and even fewer individuals could contact areas of maximum concentrations (see chapter 5.4 for discussion of home ranges), the conservative assumptions were applied routinely.

The ecological risk assessment (appendix B) estimates the risk to vegetation, terrestrial wildlife, and aquatic organisms from chronic exposure to radiological and nonradiological contaminants. In our exposure analyses, the ecological endpoints and their receptor species were considered. However, due to limited availability of sensitivity data for many species (e.g., threatened and endangered species) and to ecological similarities in exposure risk (e.g., similarly sized raptors feeding on the same prey), a representative organism for each endpoint was chosen for evaluation. A food web was developed which includes receptor species representing the endpoints (figure 5-2). In all cases where data were available, conservative estimates of exposure and risk were made by selecting receptors most sensitive to contaminants or habitat alteration, most likely to experience additional risk due to bioaccumulation or larger body size, or at greatest risk due to rarity. Other abundant species on the reservation were included as important prey components of the foodweb, such as mice and insects (risk estimates were not determined for insects).

The primary exposure routes for terrestrial wildlife species are exposure to external radiation, and ingestion of food (including soils for some species), and water. Table 5-6 lists the body weights and consumption rates for the receptor species. The jackrabbit, sage grouse, and Canada goose are assumed to feed exclusively on the vegetative parts of plants. The mule deer is assumed to eat 80% vegetation and 20% fruits and seeds. On the basis of a review of the literature, the percentage of prey items consumed by omnivores and predators was estimated (table 5-6; figure 5-2). The mouse is assumed to eat 80% fruits and seeds and 20% insects; the robin is assumed to eat 70% fruits and seeds and 30% insects; and the coyote eats 35% mice, 35% jackrabbits, 20% sage grouse, and 10% fish. The loggerhead shrike is assumed to eat 60% insects and 40% mice, the ferruginous hawk eats 100% jackrabbits, and the bald eagle eats 100% fish. The pallid bat is assumed to eat 100% insects, and the insects eat 100% vegetative plant parts.

TABLE 5-4—*Maximum and Average Concentrations of Organic, Inorganic, and Radionuclide Contaminants in Water at the Hanford Reservation*
[mg/L (for chemical constituents) or pCi/L (for radionuclides)]

Constituent	Maximum Concentration	Constituent	Average Concentration
Antimony-125	1.99e+00	Cobalt-60	1.22e+00
Beryllium-7	6.82e+01	Cesium-137	9.64e-01
Cobalt-60	2.64e+00	Strontium-90	5.10e+03
Cerium-144	8.35e+00	Technetium-99	6.49e+12
Cesium-134	7.33e-01		
Cesium-137	9.64e-01		
Europium-154	3.47e+00		
Potassium-40	7.14e+01		
Ruthenium-106	8.34e+00		
Strontium-90	5.10e+03		
Technetium-99	9.87e+12		
Tritium	7.33e+03		
Uranium-234	3.10e-01		
Zirconium-95	1.86e+01		

TABLE 5-5—*Maximum and Average Concentrations of Organic, Inorganic, and Radionuclide Contaminants in Sediment at the Hanford Reservation*
[mg/kg (for chemicals) or pCi/kg (for radionuclides)]

Constituent	Maximum Concentration	Constituent	Average Concentration
Cesium-137	2.45E+03	Cesium-137	2.45e+03
Plutonium-239	5.40E+04	Plutonium-239	5.40e+04
Potassium-40	2.19E+04	Strontium-90	2.94e+02
Strontium-90	1.57E+03	Uranium-238	5.13e+03
Uranium-235	1.91E+02		
Uranium-238	5.13E+03		

TABLE 5-6--*Body Weights and Consumption Rates[1] for Terrestrial Species[2] on the Hanford Reservation*

Parameter	Great Basin Pocket Mouse	Black-tailed Jackrabbit	Pallid Bat	Mule Deer	Robin	Sage Grouse	Canada Goose	Loggerhead Shrike	Ferruginous Hawk	Bald Eagle	Coyote
Body weight, BW (kg)	2.38E-02[3]	2.27E+00[4]	3.30E-02[5]	1.10E+02[6]	7.50E-02[7]	2.00E+00[8]	2.76E+00[9]	4.55E-02[10]	1.39E+00[11]	4.50E+00[12]	1.60E+01[13]
Water intake rate, Q_w (L/d)	6.30E-03	1.83E-01	7.50E-03	4.45E+00	1.43E-02	1.90E-01	2.80E-01	9.70E-03	1.67E-01	4.05E-01	7.73E-01
Water ingestion fraction, FI_w	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	7.00E-01	7.00E-01	5.00E-01	1.00E+00
Soil intake rate, Q_s (kg/d)	3.22E-05[14]	9.32E-03[15]	0.00	2.79E-02[16]	3.56E-04[17]	1.05E-02[18]	1.35E-02[19]	0.00	0.00	0.00	0.00
Soil ingestion fraction, FI_s	1.00E+00	1.00E+00	0.00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	0.00	0.00	0.00	0.00
Vegetation intake rate, Q_v (kg/d)	0.00	1.59E-01[20]	0.00	2.13E+00[21]	0.00	1.13E-01	1.77E-01	0.00	0.00	0.00	0.00
Vegetation ingestion fraction, FI_v	0.00	1.00E+00	0.00	1.00E+00	0.00	1.00E+00	1.00E+00	0.00	0.00	0.00	0.00
Fruit/seeds intake rate, Q_f (kg/d)	3.76E-03[22]	0.00	0.00	5.32E-01	5.80E-03[23]	0.00	0.00	0.00	0.00	0.00	0.00
Fruit/seeds ingestion fraction, FI_f	1.00E+00	0.00	0.00	1.00E+00	1.00E+00	0.00	0.00	0.00	0.00	0.00	0.00
Prey 1 intake rate, Q_{H1} (kg/d)	9.40E-04 (insects)	0.00	4.40E-03 (insects)	0.00	2.50E-03 (insects)	0.00	0.00	3.36E-03[24] (insects)	9.91E-02 (rabbits)	2.67E-01 (fish)	2.04E-01[25] (mice)
Prey 1 ingestion fraction, FI_{H1}	1.00E+00	0.00	1.00E+00	0.00	1.00E+00	0.00	0.00	7.00E-01	7.00E-01	5.00E-01	1.00E+00
Prey 2 intake rate, Q_{H2} (kg/d)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.24E-03 (mice)	0.00	0.00	2.04E-01 (rabbits)
Prey 2 ingestion fraction, FI_{H2}	0.00	0.00	0.00	0.00	0.00	0.00	0.00	7.00E-01	0.00	0.00	1.00E+00
Prey 3 intake rate, Q_{H3} (kg/d)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.17E-01 (grouse)
Prey 3 ingestion fraction, FI_{H3}	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00E+00
Prey 4 intake rate, Q_{H4} (kg/d)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5.84E-02 (fish)
Prey 4 ingestion fraction, FI_{H4}	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00E+00

[1]All values are on a wet weight basis. For soils, the wet:dry ratio is 0.98 (Rope et al. 1988), for vegetation the ratio is 0.91 (the lower bound on the range for hay/grasses reported in Suter 1993) and for fruits/seeds, the ratio 0.17 (Morrison 1959).

[2]Water and food consumption rates were computed by methods in U.S. EPA 1988 (table 4-8) unless otherwise noted.

[3]Whitaker 1988.

[4]Burt and Grossenheider 1976.

[5]Anderson and Wallmo 1984.

[6]Anderson and Wallmo 1984.

[7]Terres 1980.

[8]Terres 1980.

[9]Western Band Birding Association 1984.

[10]Terres 1980.

[11]Brown and Amadon 1968.

[12]Brown and Amadon 1968.

[13]Burt and Grossenheider 1976.

[14]The mouse soil ingestion rate is 2% of dry vegetation intake (Beyer et al. 1991).

[15]The soil ingestion rate of the jackrabbit is 6.3% (Arthur and Gates 1988).

[16]The mule deer soil ingestion rate is 1.35% of dry matter intake (Arthur and Alldredge 1979).

[17]The soil ingestion rate of the robin is assumed to be 10% of dry matter intake.

[18]The sage grouse soil ingestion rate is assumed to be 10% of dry matter intake.

[19]The Canada goose soil ingestion rate is assumed to be 8.2% of dry matter intake (Beyer et al. 1991).

[20]The black-tailed jackrabbit ingestion rate is 159 g/d wet weight (Whitaker 1988).

[21]The mule deer is assumed to eat 80% vegetation and 20% fruit/seeds (Anderson and Wallmo 1984).

[22]The mouse is assumed to eat 80% fruit/seeds and 20% insects.

[23]The robin is assumed to eat 70% fruit/seeds and 30% insects (Terres 1980).

[24]The loggerhead shrike is assumed to eat 60% insects and 40% mice (Terres 1980).

[25]The coyote is assumed to eat 35% mice, 35% rabbits, 20% sage grouse, and 10% fish (Burt and Grossenheider 19

All species are assumed to purposely or incidentally ingest soil while eating, grooming, or preening except for the bat, raptors, and coyote (table 5-6). The soil ingestion rate (Q_s) for black-tailed jackrabbits is said to be 6.3% of the dry matter intake (Arthur and Gates 1988); for mule deer, 1.35% of the dry matter intake (Arthur and Alldredge 1979); and for the mouse and goose, 2% and 8.2% of the dry-matter intake, respectively (Beyer et al. 1991). Since published values of soil ingestion rates were not found for the robin and the sage grouse, they were conservatively estimated to be 10% of the dry matter intake.

The estimated daily rates of food and water consumption (Q_v, Q_f or Q_H, and Q_w, respectively) for each receptor species were calculated from allometric regression equations that are based on the weight of the organism (EPA 1988) (Appendix A). These equations are based on the combined measurements for laboratory animals, livestock, and selected wildlife and bird species. Measured values for some rates were obtained from the literature for several species and are noted in appendix A.

Because information on the specific habits and behaviors of some of the receptors is not well known, it is assumed that all species, except the loggerhead shrike, the ferruginous hawk, and the bald eagle spend 100% of their time on the reservation. Therefore, the fraction of contaminated vegetation, fruit, prey, soil, and water consumed (FI_v, FI_f, FI_H, FI_s and FI_w, respectively) is set at 100% (table 5-6). The loggerhead shrike and the ferruginous hawk are assumed to winter off the reservation; thus, their FI values are set at 70%. The bald eagle is present on the reservation approximately 6 months or less each year (Fitzner and Gray 1991), and its FI value is set at 50%.

Contaminant concentrations in vegetation, the first level in the foodchain, are estimated from source-term concentrations in soils using published element-, or chemical-specific soil-to-plant transfer factors (Baes et al. 1984; Travis and Arms 1988) (table 5-7). Transfer factors for inorganic chemicals are available for both vegetative and fruiting parts of plants (Baes et al. 1984); however, transfer factors for organic chemicals apply only to "vegetation" in general (Travis and Arms 1988). The methodology used to predict contaminant concentrations in vegetation does not distinguish between different plant types or species. Therefore, all species ingest "generic" vegetation containing contaminant concentrations derived from soil concentrations via transfer factors.

Contaminant concentrations in the tissues of terrestrial mammalian receptors are based on transfer factors for consumption of vegetation, soil, and water by beef (collectively termed B_v) (Baes et al. 1984; Travis and Arms 1988) (table 5-7). Data on transfer factors from vegetation or soil to insects and earthworms are very limited in the literature. Therefore, the concentration in insects was derived from vegetation concentrations, and a default, conservative one-to-one transfer between vegetation and insects was assumed. Fish bioconcentration factors (BCF) were applied to estimate the concentrations of contaminants in fish tissue for consumption by the bald eagle (Droppo et al. 1989) (table 5-7). The rationale and limitations for applying these transfer factors are discussed in appendix B.

The consumption rates and the benchmark limit or no-observable-adverse-effect level (NOAEL) values are typically reported in wet weights, whereas the vegetation and soil concentrations are typically reported in dry weights. Therefore, conversion factors were applied to account for this difference. The wet- to dry-weight concentration conversion factor for the vegetative parts of plants on the Hanford Reservation was assumed to be 0.91 [the lower end of the range of percent water content for hay and grasses (Suter 1993)]. The wet- to dry-weight concentration conversion factor for the fruiting parts of plants on the reservation was assumed to be 0.17 (Morrison 1959). The wet- to dry-weight concentration conversion factor for soils was assumed to be 0.98 [this factor is based on the mean for 16 sampling locations in southwest Idaho (Rope et al. 1988)].

For the baseline assessment of the Hanford Reservation, the concentrations of radionuclides in animal tissues and the resulting doses were not decay-corrected. The doses are estimated for the current situation and not at some point in the future. The primary radionuclides of concern

TABLE 5-7—*Fish Bioconcentration Factors and Soil to Vegetation, Soil to Fruit, and Plant to Beef Transfer Factors, for Contaminants of Concern on the Hanford Reservation*

Constituent	Fish Bioconcentration Factor	Soil to Vegetation Transfer Factor	Soil to Fruit Transfer Factor	Vegetation to Beef Transfer Factor
Benzo(a)pyrene	2.38E+04	1.32E-02	1.32E-02	2.51E-02
4-methyl-2-pentanone	2.08E+00	7.86E+00	7.86E+00	3.97E-07
Trichloroethene	3.79E+01	1.59E+00	1.59E+00	6.31E-06
Aluminum (fluoronitrate)	1.00E+00	4.00E-03	6.50E-04	1.50E-03
Beryllium	2.00E+00	1.00E-02	1.50E-03	1.00E-03
Cadmium	2.00E+02	5.50E-01	1.50E-01	5.50E-04
Chromium	2.00E+01	7.50E-03	4.50E-03	5.50E-03
Copper	5.00E+01	4.00E-01	2.50E-01	1.00E-02
Cyanide (iron)	3.79E-01	5.42E+01	5.60E-01	1.41E-08
Iron (nitrate)	1.00E+02	4.00E-03	1.00E-03	2.00E-02
Lead	1.00E+02	4.50E-02	9.00E-03	3.00E-04
Magnesium (nitrate)	5.00E+01	1.00E+00	5.50E-01	5.00E-03
Mercury	2.00E+05	9.00E-01	2.00E-01	2.50E-01
Nickel	1.00E+02	6.00E-02	6.00E-02	6.00E-03
Phosphate	1.00E+05	NA	NA	NA
Potassium (borate)	1.00E+03	1.00E+00	5.50E-01	2.00E-02
Sodium	1.00E+02	7.50E-02	5.50E-02	5.50E-02
Zinc	2.00E+03	1.50E+00	9.00E-01	1.00E-01
Americium-241	2.50E+01	5.50E-03	3.00E-02	3.50E-06
Antimony-125	1.00E+00	2.00E-01	3.00E-02	1.00E-03
Beryllium-7	2.00E+00	1.00E-02	1.50E-03	1.00E-03
Carbon-14	4.60E+03	1.00E+00	1.00E+00	1.00E+00
Cobalt-60	5.00E+01	2.00E-02	7.00E-03	2.00E-02
Cerium-144	1.00E+00	1.00E-02	4.00E-03	7.50E-04
Cesium-134	2.00E+03	8.00E-02	3.00E-02	2.00E-02
Cesium-137	2.00E+03	8.00E-02	3.00E-02	2.00E-02
Europium-152	2.50E+01	1.00E-02	4.00E-03	5.00E-03
Europium-154	2.50E+01	1.00E-02	4.00E-03	5.00E-03
Europium-155	2.50E+01	1.00E-02	4.00E-03	5.00E-03
Iodine-129	1.50E+01	1.50E-01	5.00E-02	7.00E-03
Nickel-63	1.00E+02	6.00E-02	6.00E-02	6.00E-03
Plutonium-238	3.50E+00	4.50E-04	4.50E-05	5.00E-07
Plutonium-239	3.50E+00	4.50E-04	4.50E-05	5.00E-07
Plutonium-240	3.50E+00	4.50E-04	4.50E-05	5.00E-07
Plutonium-241	3.50E+00	4.50E-04	4.50E-05	5.00E-07
Potassium-40	1.00E+03	1.00E+00	5.50E-01	2.00E-02
Promethium-147	NA	1.00E-02	4.00E-03	5.00E-03
Ruthenium-106	1.00E+01	7.50E-02	2.00E-02	2.00E-03
Strontium-90	3.00E+01	2.50E+00	2.50E-01	3.00E-04
Technetium-99	1.50E+01	9.50E+00	1.50E+00	8.50E-03
Tin-113	3.00E+03	3.00E-02	6.00E-03	8.00E-02
Tritium	1.00E+00	1.00E+00	1.00E+00	1.00E+00
Uranium-234	2.00E+00	8.50E-03	4.00E-03	2.00E-04
Uranium-235	2.00E+00	8.50E-03	4.00E-03	2.00E-04
Uranium-238	2.00E+00	8.50E-03	4.00E-03	2.00E-04
Zinc-65	2.00E+03	1.50E+00	9.00E-01	1.00E-01
Zirconium-95	3.30E+00	2.00E-03	5.00E-04	5.50E-03

NA = Transfer factor could not be calculated.

Source: For organics, the transfer factors were calculated from equations in Travis and Arms (1988) using K_{ow} values from the *Superfund Chemical Data Matrix* (1991). For inorganics and radionuclides, the transfer factors were taken from Baes et al. (1984). The K_{ow} for cyanide was taken from MEPAS and the transfer factors were calculated from equations in Travis and Arms (1988).

have relatively long half-lives, so this assumption is reasonable. The radionuclide concentrations in the source terms were decay-corrected by PNL to the time of disposal or release. To estimate dose to terrestrial receptors, all short-lived daughter products were included.

Aquatic organisms considered in the assessment included benthic macroinvertebrates and a generic fish species. For radiological analyses, emergent vegetation (i.e., cattails) and muskrats were included as well. All aquatic organisms, are exposed to contaminants in surface water. However, for this analysis, benthic macroinvertebrates are assumed to be exposed only to the sediment pore water for calculation of internal radiation dose and exposure to chemicals. The external radiation dose from exposure to surface water was calculated for all organisms.

5.4 CONTAMINANT EFFECTS ASSESSMENT

Two pathways are used to determine the *effects* of contaminant exposure (chapter 5.3) on ecological endpoint receptors. For terrestrial receptors, consumption rates of contaminated food and water are compared with toxicological benchmarks. For aquatic receptors, contaminant concentrations in water or sediment pore water are compared with chemical-specific aquatic benchmarks.

To quantify risk to terrestrial receptors exposed to organic and inorganic contaminants, the daily consumption rate of contaminated food and water, normalized to body weight (in units of mg/kg/d), was compared with the NOAEL benchmark (mg/kg/d). Ratios greater than 1 are considered to pose a potential risk to organisms but do not necessarily indicate the severity of the effect(s). However, it is reasonable to assume that the higher the ratio, the greater the risk of adverse effects. Doses to terrestrial receptors, including vegetation, from internal and external exposure to radionuclides was also determined from calculated tissue concentrations and soil concentrations, respectively. Doses that exceeded 0.1 rad/d were considered to pose a potential risk to terrestrial organisms (IAEA 1992). Methods used to calculate exposure and risk are described in appendix A.

Toxicological benchmarks for terrestrial organisms, excluding vegetation, were obtained from Opresko et al. (1993) (table 5-8). For representative receptor species that were not listed in the data base, extrapolation techniques were employed to obtain the chronic NOAEL by adjusting for differences in body weight between the receptor and a test organism. If a NOAEL was available for a laboratory test species, the NOAEL for a receptor species could be calculated. Many of the NOAEL benchmarks were derived by extrapolation from small mammal laboratory data (Opresko et al. 1993). There were a few contaminants for which no wildlife toxicity data were found. For these cases, wildlife NOAELs were extrapolated from human noncarcinogenic toxicity data (i.e., RfDs) listed in the MEPAS constituent data base, normalized to the "standard man" body weight of 70 kg. Thus, for our purposes, wildlife species that weigh less than 70 kg would have a higher benchmark than humans and the opposite would be true for wildlife species weighing more than 70 kg.

Literature sources for inorganic terrestrial phytotoxicity benchmarks were summarized and reported by Suter and Futrell (1993) (table 5-8). Where applicable, the lowest source concentration in a soil medium that produced phytotoxically excessive effects was chosen from the data base. Several benchmarks were derived from experiments using nutrient solutions. However, uncertainty values were not applied to these data to account for differences in growth media. A methodology for deriving phytotoxicity benchmarks for organic constituents was developed by Eskew and Babb [as cited in the MMR Air National Guard Risk Assessment Handbook (1992)] (table 5-8).

Risks to aquatic organisms from exposure to organic and inorganic contaminants in water and sediments (pore water) were calculated by comparing the water or sediment pore-water concentrations with the chemical-specific aquatic benchmark (Suter et al. 1992) (table 5-8). To determine internal dose to aquatic plants, fish, and muskrats from exposure to radionuclides, the surface-water concentrations were multiplied by radionuclide and organism-specific aquatic (internal) dose conversion factors to produce a daily dose in rads (Killough and McKay 1976).

TABLE 5-8—*Criteria Benchmarks for Terrestrial*[1] *and Aquatic*[2] *Species on the Hanford Reservation*

(NOAELs listed in milligrams per kilogram per day for terrestrial benchmarks or milligrams per liter for aquatic benchmarks)

Constituent	G.B.P. Mouse	Blacktailed Jackrabbit	Pallid Bat	Robin	Sage Grouse	Loggerhead Shrike	Canada Geese	Mule Deer	F. Hawk	Bald Eagle	Coyote	Vegetation	Aquatic
Benzo(a)pyrene	2.45E-02	5.36E-03	2.20E-02	1.67E-02	5.59E-03	1.97E-02	5.02E-03	1.47E-03	6.31E-03	4.27E-03	2.80E-03	1.28E-02	2.99E-03
4-methyl-2-pentanone	1.22E+01	2.68E+00	1.10E+01	8.36E+00	2.80E+00	9.87E+00	2.51E+00	7.35E-01	3.16E+00	2.13E+00	1.40E+00	NA	1.59E+00
Trichloroethene	1.62E+02	4.02E+01	1.65E+02	1.11E+02	4.20E+01	1.31E+02	3.77E+01	1.10E+01	4.74E+01	3.20E+01	2.10E+01	6.70E-01	5.76E+00
Aluminum (fluoronitrate)	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	8.00E+00	8.70E-02
Beryllium	1.32E+00	2.90E-01	1.19E+00	9.02E-01	3.02E-01	1.07E+00	2.71E-01	7.94E-02	3.41E-01	2.31E-01	1.51E-01	1.00E+01	3.80E-03
Cadmium	2.36E-02	5.16E-03	2.12E-02	1.44E-01	1.06E-02	1.70E-01	1.78E-03	1.42E-03	2.24E-03	1.51E-03	2.69E-03	3.00E+00	1.10E-03
Chromium	5.88E+00	1.29E+00	5.27E+00	4.01E+00	1.34E+00	4.74E+00	1.21E+00	3.53E-01	1.52E+00	1.02E+00	6.71E-01	7.50E+01	1.10E-02
Copper	1.84E-01	7.51E-01	1.65E-01	6.88E+01	1.86E+01	8.12E+01	1.67E+01	2.06E-01	2.10E+01	1.42E+01	3.92E-01	6.00E+01	1.20E-02
Cyanide (iron)	1.65E+01	5.79E+00	2.37E+01	1.80E+01	6.04E+00	2.13E+01	5.43E+00	2.10E-02	6.82E+00	6.11E-02	4.00E-02	NA	5.20E-03
Iron (nitrate)	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	1.00E+04	1.00E+00
Lead	7.10E-03	1.56E-03	6.37E-03	1.59E-02	9.85E+00	1.88E-02	8.84E+00	4.27E-04	1.11E+01	7.51E+00	8.11E-04	1.00E+02	3.20E-03
Magnesium (nitrate)	4.31E+01	9.44E+00	3.87E+01	2.94E+01	9.85E+00	3.47E+01	8.84E+00	2.59E+00	1.11E+01	7.51E+00	4.92E+00	NA	1.60E-04
Mercury	1.44E+01	5.58E-03	1.29E+01	3.19E+00	5.09E-01	3.77E+00	4.57E-01	1.72E-02	5.74E-01	3.88E-01	3.27E-02	3.00E+[illegible]	1.30E-03
Nickel	5.92E+01	1.29E+01	5.31E+01	4.17E+00	1.40E+00	4.93E+00	1.25E+00	3.55E+00	1.58E+00	1.07E+00	6.75E+00	1.00E+02	1.60E-01
Potassium (borate)	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	1.30E-04
Sodium	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	4.80E-01
Zinc	2.38E+01	5.20E+00	2.13E+01	1.62E+01	5.43E+00	1.91E+01	4.87E+00	1.43E+00	6.13E+00	4.14E+00	2.71E+00	7.00E+01	1.10E-01

[1]The source for all terrestrial benchmarks, except for vegetation is Opresko et al. 1993. For vegetation, the source is Suter and Futrell 1993 and Eskew and Babb 1992.

[2]The source for aquatic benchmarks is Suter et al. 1992.

NA = Benchmark not available.

To determine the internal dose to generic benthic macroinvertebrates and other bottom-dwelling organisms (e.g., fish larvae) from exposure to radionuclides, the sediment pore-water concentrations were multiplied by radionuclide and organism-specific aquatic (internal) dose conversion factors to produce a daily dose. The external dose to all organisms was determined by multiplying the surface-water concentration by the external radionuclide-specific dose conversion factor. Combined internal and external doses greater than 1 rad/d are considered to pose a potential risk to aquatic organisms (NCRP 1991).

For contaminants and receptors that did not pass the average concentration screening (chapter 5.3), an attempt was made to further define exposure risks by comparing receptor species' home range sizes with the potential fraction of the home range occupied by contaminants in food and water from waste sites.

Receptor species at the Hanford Reservation have home ranges or territories that range from small [e.g., less than one hectare (2.5 acres) for mice and robins] to large [e.g., thousands of hectares (acres) for bats and coyotes (table 5-9)]. Some small species have home ranges small enough to be completely within individual waste sites. Other species have such large home ranges that the waste sites would comprise only a small part of the area they would occupy, if the waste sites were used at all. To further interpret the results of this risk analysis, the following assumptions are made about contaminant exposure to receptors.

1. Burrowing small mammals, insects, and vegetation are known to move radiological contaminants from buried waste to the surface where it is presumably redistributed through the food chain, excrement, and soil dust (Arthur 1982; Markham 1987; Arthur and Markham 1983). The same is probably true for nonradiological contaminants. Because the waste sites are the original sources of contaminants, and data are lacking for contaminant levels outside the waste sites, source terms outside waste sites are assumed to be negligible.

2. It is assumed that small species with home ranges of about 5 ha (12 acres) or less (table 5-9) could receive as much exposure as our average screening indicates.

3. It is assumed that wider ranging species could receive at most 30% of the exposure calculated by our average screening. This assumption is based on the approximately 800 ha (2,000 acres) of waste sites contained within the two major waste areas [i.e., 100 and 200 Areas; total area of 2700 ha (6670 acres)]. Exposure could be greater if, for instance, the sole source of contaminants is a waste pond used as the only source of drinking water. Or exposure could be less if the species home range or territory is very large.

4. Waste sites occupy about 800 ha (2,000 acres) or 0.6% of the surface area of the Hanford Reservation; this is the only part of the reservation considered for remediation. Biota living in the remaining 99.4% of the reservation may be exposed to contaminants that have moved from waste sites in dust and that exist in contaminated wildlife and plants. Although this contamination may be measurable, source terms for it are not available and contamination is assumed to be negligible compared with the contamination in the waste sites. Because we assume that the overall habitat at the Hanford Reservation is similar, it is also assumed that only 0.6% of the area supporting ecological

TABLE 5-9—*Home Ranges*[1] *of Hazard Index (HI) Correction Factors (CF)*[2] *for Terrestrial Receptor Species at the Hanford Reservation*

Receptor Species	Home Range (ha)			Correction Factor
	<5	5–800	>800	
Bald eagle			X	1.0[3]
Aleutian Canada goose			X	0.30
Generic vegetation				1.0
Black-tailed jackrabbit		X		0.15
Mule deer			X	0.27
Sage grouse		X		0.15
Canada goose			X	0.30
Coyote			X	0.09
Great Basin pocket mouse	X			1.0[4]
Pallid bat			X[4]	0.004
Robin	X			1.0
Loggerhead shrike		X		0.15
Ferruginous hawk		X		0.11

[1]Data are from Schoener (1968), Terres (1980), Chapman and Feldhamer (1982), Nowak and Paradiso (1983), Anderson and Wallmo (1984), and Fitzner and Gray (1991).

[2]A CF of 1.0 was applied to HIs for each contaminant for each species having a home range ≤5 ha (12 acres); other CFs are based on the ratio of contaminated land and water to the area of the waste complex; CFs for wide-ranging species are based on the ratio of contaminated land and water to the area of their home ranges (see text for discussion of CFs).

[3]A CF of 1.0 was applied to the bald eagle because it is assumed to feed exclusively in the Columbia River.

[4]Sizes of home ranges for bats are generally unknown. Foraging distance ranges between 25 to 97 km. The CF is based on the area of a circle with a 25 km radius.

endpoints is affected by contaminants from the waste sites.

5. Except for threatened and endangered species, for which the loss of an individual is considered a significant risk to the population, it is assumed that other endpoints are at risk only at the small scale represented by the 0.6% of the Hanford Reservation that is in waste sites.

6. Contaminated wetlands are found in B Pond and the FFTF Pond. It is assumed that all aquatic biota receive the average exposure to contaminants if they occur in these waste ponds. Similarly, it is assumed that biota feeding exclusively on fish from the Hanford Reach of the Columbia River receive the average exposure to contaminants.

5.5 CONTAMINANT HAZARD ASSESSMENT

Risk to terrestrial and aquatic receptors from contamination at the Hanford Reservation was modeled. For terrestrial receptors, hazard indices (HIs) were generated for maximum and average contaminant concentrations for chemical constituents, and maximum and average doses were generated for radiological constituents. For aquatic receptors, maximum and average internal and external doses were generated for radiological constituents.

5.5.1 Baseline

The next step in the ecological risk assessment generates HIs that are representative of potential risk and that estimate the level of effects from exposure to contaminants. Baseline HIs for terrestrial receptors exposed to the maximum source concentrations were greater than the criteria limit of 1 for 11 out of 12 inorganic contaminants and for 3 out of 3 organic contaminants for which we had benchmarks. Benchmarks for many of the contaminants could not be obtained. Exposure to the total maximum concentrations of radionuclides resulted in HIs for all receptors of about 2E+04. Radiological exposure was dominated by exposure to ^{239}Pu, ^{90}Sr, ^{99}Tc, ^{60}Co, and ^{137}Cs in soils.

Exposures of terrestrial species to average soil and water concentrations at the site were calculated for those contaminants whose maximum concentrations resulted in HIs greater than 1 (table 5-10). About 18% of the HI values were above 1 but below 10, 61% were above 10 but below 1000, and about 21% were still above 1000. The HIs for all species exposed to the average concentrations of radionuclides were still over 1, as a result of ^{239}Pu and ^{99}Tc exposure (table 5-11).

Concentrations of nonradiological contaminants in surface water and sediment at the Hanford Reservation were not provided in the source terms obtained from PNL. Therefore, risks to aquatic organisms from nonradiological contaminants could not be calculated. Exposure to maximum concentrations of radionuclides in the surface water or in the sediment pore water resulted in HIs (or doses) greater than 1 for all aquatic organisms (except benthic macroinvertebrates) as the result of internal and external exposure to ^{99}Tc in surface water. Exposure to average concentrations did not substantially reduce the HIs because the concentration of ^{99}Tc in the water did not change significantly (table 5-12).

Of the receptors included in these analyses, the Great Basin pocket mouse and robin occupy small enough areas (table 5-9) to potentially live entirely within contaminated areas [e.g., less than 5 ha (12 acres)]. The black-tailed jackrabbit, sage grouse, and loggerhead shrike have home ranges or territories greater than 5 ha (12 acres) and less than the total estimated contaminated areas [i.e., 800 ha (2000 acres)]. Of the remaining receptors, the home territory of the Canada goose was less than the total area of the waste complex [i.e., 2700 ha (6670 acres) for Areas 100 and 200], whereas the home ranges or territories of the pallid bat, mule deer, ferruginous hawk, bald eagle, and coyote exceeded the area of the waste complexes.

On the basis of assumptions discussed in chapter 5.3, appropriate correction factors were applied to the HIs for chemical constituents and radionuclides in tables 5-10, 5-11, and 5-12 to determine potential severity of risks to receptors. (Information for concentrations of nonradiological contaminants in surface water was unavailable; therefore, HIs for aquatic organisms could not be calculated.) For biota with home ranges or territories less than 5 ha (12 acres), no correction factor was applied to the hazard index. For species with home ranges or territories greater than 5 ha (12 acres) but less than 800 ha (2000 acres), a correction factor of 0.15 was used. It was assumed that species with home ranges up to 800 ha (2000 acres) would spend half of their time in one or the other of the aggregated areas but not in both because the 200 Area is about 10 km (6 miles) south of the 100 Area. Thus, the ratio of contaminated area to the area of the waste complex was divided by 2 for a correction factor of 0.15 (i.e., 800/2700 = 0.30/2 = 0.15). For species with home ranges or territories greater than 2700 ha (6670 acres), the correction factor is determined by dividing the total estimated contaminated area by the area the species home range or territory in hectares [i.e., 800/home range].

Some contaminants on the Hanford Reservation may be highly localized; however, there are no data for their areal distribution. Of the contaminants that result in moderate to severe risks (i.e., HI from 1 to 10 and HI greater than 10, respectively), source terms for Mg represent about 0.02 ha (0.05 acre), cyanide and Pb represent about 2 ha (5 acres), and Cd, Cu, and Hg represent about 6 ha (15 acres) of contaminated land (appendix B). Source terms for radionuclides range from 0.4 ha (1 acre) to 36 ha (90 acres). Source terms for all other contaminants range from 0.0002 ha (0.0005 acre)

TABLE 5-10—*Baseline Hazard Indices for Terrestrial Organisms on the Hanford Reservation*

Hazard Indices Calculated Using Average Contaminant Concentrations												
	Great Basin Pocket Mouse	Black-Tailed Jackrabbit	Pallid Bat	Mule Deer	Robin	Sage Grouse	Canada Goose	Loggerhead Shrike	Ferruginous Hawk	Bald Eagle	Coyote	Vegetation
Benzo(a)pyrene	7.38E+02	8.56E+03	2.94E+02	2.51E+03	3.16E+03	[illegible]	[illegible]	1.27+04	2.07E+01	0.00	1.95E+01	1.09E+01
4-methyl-2-pentanone	4.59E+02	1.78E+03	8.09E+02	1.99E+03	6.07E+02	1.38E+03	1.75E+03	3.49+02	6.78E-05	0.00	5.57E-05	NA
Trichloroethene	2.14E-01	7.71E-01	3.24E-01	8.13E-01	3.00E-01	6.26E-01	7.74E+01	1.59E-01	4.68E-07	0.00	3.89E-07	1.06E+03
Cadmium	1.39E-01	1.94E+00	6.93E-01	1.66E+00	5.26E-02	8.65E-01	5.50E+00	3.34E-02	2.79E-04	0.00	8.68E-05	1.88E-01
Chromium	7.99E-03	1.05E-01	2.13E-03	2.77E-02	3.86E-02	1.27E-01	1.33E-01	9.19E-04	5.57E-05	0.00	5.28E-05	4.21E-01
Copper	2.19E+01	8.55E+00	5.25E+01	7.17E+00	8.72E-02	3.26E-01	3.83-01	4.13E-02	3.47E-04	0.00	7.04E-03	7.61E+00
Cyanide (iron)	6.88E-01	2.36E+02	1.09E+02	[illegible]	3.66E+01	[illegible]	2.30E+02	4.71E+01	3.20E-07	0.00	1.96E-05	NA
Iron (nitrate)	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	4.71E+00
Lead	9.63E+00	1.42E+02	1.41E+01	[illegible]	1.44E+01	2.64E-02	2.82E-02	1.86E+00	6.75E-07	0.00	3.78E-03	4.22E-01
Magnesium (nitrate)	8.71E+01	6.50E+02	2.59E+02	[illegible]	[illegible]	[illegible]	6.62E+02	1.12E+02	3.13E-01	0.00	2.61E-01	NA
Mercury	1.81E-03	1.69E+01	1.17E-02	[illegible]	2.04E-02	1.62E-01	1.97E-01	1.56E-02	4.64E-03	0.00	3.01E-02	1.18E+01
Nickel	3.92E-03	3.19E-02	3.96E-03	1.50E-02	1.12E-01	3.41E-01	3.68E-01	1.65E-02	1.78E-04	0.00	1.69E-05	7.38E-01
Zinc	3.75E-02	2.52E-01	1.05E-01	2.52E-01	6.95E-02	2.05E-01	2.53E-01	4.55E-02	2.42E-03	0.00	2.01E-03	4.51E-01

NA = Benchmark not available, therefore hazard index could not be calculated.

TABLE 5-11—*Baseline Average Radiological Doses for Terrestrial Organisms on the Hanford Reservation*

Radiological Doses (rad/d) Calculated Using Average Contaminant Concentrations												
	Great Basin Pocket Mouse	Black-tailed Jackrabbit	Pallid Bat	Mule Deer	Robin	Sage Grouse	Canada Goose	Loggerhead Shrike	Ferruginous Hawk	Bald Eagle	Coyote	Vegetation
Cobalt-60	6.97E-02	6.97E-02	6.97E-02	6.97E-02	6.97E-02	6.97E-02	6.97E-02	6.97E-02	6.97E-02	6.97E-02	6.97E-02	6.80E-04
Cesium-137	5.91E-01	5.91E-01	5.91E-01	5.92E-01	5.91E-01	5.91E-01	5.91E-01	5.91E-01	5.91E-01	5.91E-01	5.91E-01	0.00
Europium-152	2.88E-01	2.88E-01	2.88E-01	2.88E-01	2.88E-01	2.88E-01	2.88E-01	288E-01	2.88E-01	2.88E-01	2.88E-01	0.00
Plutonium-239	1.29E+00	1.29E+00	1.29E+00	1.29E+00	1.29E+00	1.29E+00	1.29E+00	1.29E+00	1.29E+00	1.29E+00	1.29E+00	5.00E-01
Strontium-90	6.19E-01	6.19E-01	6.19E-01	6.19E-01	6.19E-01	6.19E-01	6.19E-01	6.19E-01	6.19E-01	6.19E-01	6.19E-01	5.91E+01
Technetium-99	1.80E+00	5.22E+01	2.14E+00	1.27E+03	4.08E+00	5.41E+01	7.98E+01	1.94E+00	3.33E+01	6.29E+02	5.28E+02	0.00
Uranium-238	1.66E-03	1.66E-03	1.66E-03	1.66E-03	1.66E-03	1.66E-03	1.66E-03	1.66E-03	1.66E-03	1.66E-03	1.66E-03	1.27E-02
Total dose	4.66E+00	5.50E+01	5.00E+00	1.27E+03	6.94E+00	5.70E+01	8.26E+01	4.80E+00	3.61E+01	6.32E+02	5.31E+02	3.58E+00
Radiological HI	4.66E+01	5.50E+02	5.00E+01	1.27E+04	6.94E+01	5.70E+02	8.26E+02	4.80E+01	3.61E+02	6.32E+03	5.31E+03	3.58E+01

TABLE 5-12—*Baseline Average Internal and External Radiological Doses for Aquatic Organisms (rad/d) on the Hanford Reservation*

	External	Internal Plants	Internal Invertebrates	Internal Fish	Internal Muskrats
Cobalt-60	1.60E–07	1.87E–05	0.00	1.87E–06	3.68E–06
Cesium-137	3.17E–08	2.32E–06	7.38E–06	1.16E–05	1.64E–05
Europium-152	0.00	0.00	0.00	0.00	0.00
Plutonium-239	0.00	0.00	3.25E–03	0.00	0.00
Strontium-90	1.40E–04	1.40E–01	4.83E–05	1.40E–03	6.15E–01
Technetium-99	1.60E+04	1.24E+06	0.00	4.62E+05	9.07E+04
Uranium-238	0.00	0.00	2.50E–03	0.00	0.00
Total dose	1.60E+04	1.24E+06	5.81E–03	4.62E+05	9.07E+04

The benchmark for aquatic organisms is 1 rad/d; thus the hazard index is equal to the total dose.

to 32 ha (80 acres). Although data for most contaminants were reported for only a small fraction of the total area in waste sites, it is assumed that the data are representative. All source terms used in this risk analysis are, therefore, assumed to be present in all 800 ha (2000 acres) of waste sites (appendix B).

Threatened and Endangered Species. Risks to some threatened and endangered species would be severe or moderate if individuals occupy waste sites. Potentially severe risks would be present for geese, eagles, and hawks from total radioactive contaminants and for geese from organic contaminants and cyanide and magnesium (table 5-13a). Potentially moderate risks also would be present for the goose (cadmium) and the hawk [benzo(a)pyrene]. Although these analyses indicate potential risks to these species, a site-specific survey of individual waste sites for occurrences of threatened and endangered species would be necessary to determine if there are actual risks.

5.5.2 Wetlands

Risks from total radionuclides to wetlands receptors (e.g., plants, invertebrates, fish and muskrats) if present in waste ponds would be severe based entirely on an elevated source term for ^{99}Tc (table 5-12; the benchmark for aquatic organisms is 1 rad/d; thus for radioactive contaminants the HI equals the total dose). Risks to wetland receptors from nonradiological contaminants were not estimated because source term data were lacking. However, because it is assumed that wetlands that are *not* waste ponds are free of contamination, risks to receptors in natural wetlands from contaminants would be negligible.

5.5.3 Recreational Wildlife

For some recreational species occupying waste sites, risks from organic contaminants, cyanide, lead, magnesium, and total radioactive contaminants would be severe (table 5-13b). Additional moderate risks would also be possible from copper and mercury. Risks to individuals that do not occupy waste sites would be negligible, and because less than 0.6% of the reservation is waste sites, overall risks to populations of wildlife on the reservation would be negligible.

5.5.4 Public Lands

The size, geography, and restricted access to the Hanford Reservation provide buffers to the contaminated waste sites. The Columbia River in particular is a barrier that inhibits wide-ranging wildlife (e.g., deer and elk) from transporting contaminants to public lands north and east of the reservation, whereas the Yakima River and

TABLE 5-13A—*Baseline Potential Risks[1] to Federally Listed Threatened, Endangered, or Candidate Receptor Species[2] That Occupy Waste Sites on the Hanford Reservation*

Contaminant	Receptor		
	Aleutian Canada Goose	Bald Eagle	Ferruginous Hawk
Benzo(a)pyrene	S[3]		M
4-Methyl-2-pentanone	S		
Cadmium	M		
Cyanide ion	S		
Magnesium (nitrate)	S		
Total Radionuclides	S	S	S

[1]Potential risks based on assumptions described in Section 5.4. Risks to individuals that do not occupy waste sites are negligible. Waste sites account for about 0.6% of the surface area of the Hanford Reservation.

[2]See Table 5-2 for complete list of federally listed endangered, threatened, and candidate species.

[3]M = moderate risk, where HI is equal to or greater than 1.0, but less than 10; S = severe risk, where HI is equal to or greater than 10.

TABLE 5-13B—*Baseline Potential Risks[1] to Recreational Wildlife Receptors That Occupy Waste Sites on the Hanford Reservation*

Contaminant	Receptor			
	Black-Tailed Jackrabbit	Mule Deer	Sage Grouse	Coyote
Benzo(a)pyrene	S[2]	S	S	M
4-Methyl-2-pentanone	S	S	S	
Copper	M	M		
Cyanide ion		S	S	
Lead	S	S		
Magnesium	S	S	S	
Mercury	M			
Total Radionuclides	S	S	S	S

[1]Potential risks based on assumptions described in Section 5.4. Risks to individuals that do not occupy waste sites are negligible, and overall risks to populations of wildlife on the reservation are negligible. Waste sites occupy about 0.6% of the surface area of the Hanford Reservation.

[2]M = moderate risk, where HI is equal to or greater than 1.0, but less than 10; S = severe risk, where HI is equal to or greater than 10.

and west. Although other wide-ranging species (e.g., the ferruginous hawk, bald eagle, and coyote) are capable of transporting contaminants, the risk to public lands would be negligible because of the size of home ranges or territories in relation to the size of the reservation. Risks from receptor species in the food web (table 5-13c) would be negligible because the home ranges or territories of these species are small, they are limited by geographic barriers from access to public lands, and/or individuals do not occupy waste sites and thus pose no risk to public lands.

5.5.5 Biodiversity

Risk to overall biodiversity of the sagebrush-steppe ecosystem on the reservation would be negligible because waste sites occupy only about 0.6% of the total land area. However, as discussed for other endpoints, there would be potential risks to some receptors which are important to biodiversity in waste sites (e.g., the mouse as a food source or the robin as an indicator for risk to songbirds). Total radiological contaminants, organic contaminants, and cyanide and magnesium pose potential risks to raptors (e.g., shrikes and hawks) and bats that could feed on prey that occupy waste sites (table 5-13d). In addition to these receptors, vegetation is also potentially at severe risk from uptake of benzo(a)pyrene, trichloroethene, Mg, and total radiological contaminants in waste sites (table 5-13c). Copper and Fe pose moderate risks to vegetation.

5.6 Habitat Disturbance Assessment

As our national natural landscape is increasingly fragmented by agricultural and urban development, large, undisturbed, and protected blocks of natural landscape are becoming more important for protection of biodiversity. The Hanford Reservation is a large block of relatively undisturbed native sagebrush-steppe. Adjoining lands to the west, north, and east are principally range and agricultural land. The cities of Richland, Kennewick, and Pasco (Tri-Cities) located southwest of the reservation are the nearest urban areas.

1450 km^2 (about 560 mi^2). Of this about 665 km^2 (257 mi^2) is dedicated to the Arid Lands Ecology (ALE) Reserve, the U.S. Fish and Wildlife Service Saddle Mountain National Wildlife Refuge, and the Washington State Department of Game Reserve area (Wahluke Slope). About 90 km^2 (36 mi^2) is actively used for facilities operations including roads, utilities, and railroad rights-of-way. These disturbed areas, which are about 6% of the total reservation, are dominated by introduced plant species such as cheatgrass (*Bromus tectorum*), tumble mustard (*Sisymbrium altissimum*), and Russian thistle (*Salsola kali*) that also intrude into surrounding native sagebrush-steppe.

5.6.1 Baseline

Because no additional disturbance due to restoration activities is included in the baseline alternative, no additional habitat disturbance or fragmentation beyond the current 6% of the reservation is expected.

5.7 Cumulative Assessment

5.7.1 On-Site

5.7.1.1 Baseline

For 11 contaminants, including organic and inorganic chemicals and radionuclides, HIs suggest potential risks to organisms inhabiting waste sites (table 5-14). Of these contaminants, six pose potential risks to federally listed threatened, endangered, or candidate species (table 5-13a); only one (^{99}Tc) poses a potential risk to species in wetlands, (no data are available for organic and inorganic contaminants in wetlands); eight pose potential risks to recreational wildlife species (table 5-13b); and ten pose potential risks to important food web components (table 5-13c) and species important to biodiversity (table 5-13d). The waste sites are mostly in highly developed areas that do not provide suitable habitat for many organisms. Thus, actual risks associated with these sites are probably lower than indicated by the HIs. Waste ponds, however, are utilized by wildlife and waterfowl; consequently, exposure may be

TABLE 5-13C—*Baseline Potential Risks[1] to Receptor Species that are Important Food Web Components on Waste Sites on the Hanford Reservation*

Contaminant	Receptor		
	Great Basin Pocket Mouse	Robin	Vegetation
Benzo(a)pyrene	S[2]	S	S
4-Methyl-2-pentanone	S	S	
Trichloroethene			S
Copper	S		M
Cyanide ion		S	
Iron (nitrate)			M
Lead	M	S	
Magnesium (nitrate)	S	S	
Mercury			S
Total Radionuclides	S	S	S

[1]Potential risks based on assumptions described in Section 5.4. Risks to individuals that do not occupy waste sites are negligible and overall risks to populations of wildlife on the reservation are negligible.

[2]M = moderate risk, where HI is equal to or greater than 1.0, but less than 10; S = severe risk, where HI is equal to or greater than 10.

TABLE 5-13D—*Baseline Potential Risks[1] to Receptor Species that are Important for the Conservation of Biodiversity[2] on the Hanford Reservation*

Contaminant	Receptor		
	Pallid Bat	Loggerhead Shrike	Ferruginous Hawk
Benzo(a)pyrene	M[3]	S	M
4-Methyl-2-pentanone	M	S	
Cyanide ion		M	
Magnesium	M	S	
Total Radionuclides		M	S

[1]Potential risks based on assumptions described in Section 5.4. Risks to individuals that do not occupy waste sites are negligible and overall risks to populations on the reservation are negligible.

[2]See Table 5-18c for potential risk to other receptors important for the conservation of biodiversity (e.g., Great Basin pocket mouse, robin, and vegetation).

[3]M = moderate risk, where HI is equal to or greater than 1.0, but less than 10; S = severe risk, where HI is equal to or greater than 10.

Contaminant	Alternatives		
	Baseline		
Benzo(a)pyrene	E[2], R, B		
4-Methyl-2-pentanone	E, R, B		
Trichloroethene	B		
Cadmium	E		
Copper	R, B		
Cyanide	E, R, B		
Iron (nitrate)	B		
Lead	R, B		
Magnesium (nitrate)	E, R, B		
Mercury	R, B		
Radionuclides	E, W[3], R, B		
Habitat Disturbance[4]			

[1]Only those contaminants are listed for which our analyses showed potential moderate or severe risk to endpoint receptors.

[2]Ecological endpoints: E=federally listed threatened, endangered, and candidate species; W=wetlands; R=recreational wildlife; F=agriculture or Timber production; P=parks and other public land; and B=biodiversity.

[3]Risk to aquatic resources from organic and inorganic contaminants is unknown; source terms were provided for radionuclides only.

[4]These are short-term risks; long-term risks could be reduced by successful restoration of appropriate habitat.

substantial for these organisms. For all of the sites, a future scenario involving closure of the Hanford facility without restoration might result in reoccupation of the waste sites by plants and animals; risks similar to those indicated in tables 5-13a, b, c, and d would then be expected.

Determining cumulative risks to receptors and endpoints that do not occur at waste sites is more problematic. Data were not adequate to determine facility-wide contaminant levels. Moreover, many of the inorganic contaminants (e.g., metals) included in our analyses are known to occur in soils throughout the United States at concentrations greater than or equal to concentrations in the Hanford source-term data base (e.g., Fe, Pb, Mg; Shacklette and Boerngen 1984). For some of the substances, it is possible that the source terms reflect naturally occurring concentrations rather than contamination. Even when background levels are known, interpretation of HIs for inorganic substances is often difficult because most analytical techniques do not distinguish between chemical forms that are available for uptake by organisms (e.g., dissolved in soil pore water or loosely bound to particles) and those that are biologically unavailable (e.g., insoluble salts).

Despite difficulties in interpreting the HIs, cumulative risks from available source term and benchmark data are adequate to compare alternatives. Because of the relatively small fraction of the Hanford Reservation that is contaminated, potential risks to all endpoints except for (1) endangered and threatened species and (2) wildlife utilizing waste ponds appear negligible. Because no restoration activities are included in the baseline case, habitat disturbance/fragmentation risks would also be negligible.

5.7.2 Off-Site

The only currently known mechanism for transport of contaminants from waste sites off the reservation is through ingestion of contaminants by wide- ranging wildlife (e.g., migratory waterfowl or mule deer). Of the three classes of contaminants in waste sites (i.e., organics, inorganics, and radionuclides), the only source of radionuclides in the region would be the Hanford Reservation waste sites. Therefore, regional (off-site) cumulative risks for radionuclides would be the same as for on-site risks. At the time of our analyses no regional data for organics or inorganics were available, and cumulative risks for the region of influence could not be estimated.

CHAPTER 6: FERNALD ENVIRONMENTAL MANAGEMENT PROJECT (FEMP) ECOLOGICAL RISK ASSESSMENT

The 425 ha (1050 acres) of the Fernald Environmental Management Project (FEMP) reservation lie in a transition zone where the mixed mesophytic forests of the east give way to oak-hickory forests to the west. Very little of the natural vegetation communities that dominated the region prior to clearing by settlers of European origin, however, survives. The site and immediate environs, moreover, have no virgin forests at all. Most of the remaining reservation area outside the industrial and waste storage areas is dominated by grasses, particularly red fescue, that are regularly mowed or grazed. Agriculture (especially pasture and croplands) is the primary land use in the environs near the reservation, followed by heavy and light industries, and a scattering of individual residences and small villages.

The Great Miami River flows within 1.2 km (0.75 mile) of the eastern boundary of the reservation on its way to the Ohio River, approximately 39 river km (24 river miles) to the southwest. This river averages about 1 m (3 ft) in depth and ranges in width from 40 to 120 m (130–390 ft). Average flow is about 94 m^3/s (3200 cfs), whereas the maximum and minimum discharges were about 3100 m^3/s (110,000 cfs) and 4.4 m^3/s (155 cfs), respectively. A much smaller, first-order, intermittent stream, Paddy's Run, flows southward through the reservation along the western boundary, finally emptying into the Great Miami River about 2.9 river km (1.8 miles) south of the site's southern boundary. Riparian woodland borders most of Paddy's Run and its principal tributary. Both streams support aquatic communities fairly typical of warmwater streams of the region that are slightly to moderately polluted.

The reservation itself (figure 6-1) is characterized by (1) a centrally located (former) production area and waste storage area, totaling only 55 ha (140 acres), that is almost completely devoid of natural ecological communities, (2) small plantations of pine and spruce planted in 1972 in the vicinity of the northeast and southwest corners of the reservation, (3) fairly extensive areas of introduced grassland currently mowed or used for grazing of cattle, (4) relatively small areas of mature riparian woodlands along Paddy's Run and two of its small tributaries, (5) an area of scrub growth as well as young to mature upland woodlands in the northwestern part of the reservation, and (6) fly ash piles towards the southeast corner of the reservation. Although the geographic ranges of at least four federally listed threatened and endangered species encompass the reservation, only one, the Indiana bat, is likely to actually occur on the reservation. One forested wetland of approximately 3.8 ha (9.5 acres) lies in the north central part of the reservation. Other smaller wetlands of the emergent type occupy certain drainage ditches and swales in the vicinity of the waste storage areas. Recreational fish species may occur occasionally in the reach of Paddy's Run that passes along the western boundary of the reservation. Although hunting is not allowed on the reservation, several recreational wildlife species are present. Approximately 60% of the reservation is currently grazed by cattle. Important species groups of concern for conservation of biodiversity at FEMP include songbirds, raptors, deer, fox, other bats, amphibians, fish, and many flowering plants.

6.1 Ecological Endpoints and Species Distribution

The ecological endpoints chosen for the Fernald reservation are described in this chapter. In summary, only one federally listed threatened, endangered, or candidate species is likely to occur on the reservation; wetlands are found along swales, ditches, and streams, and in topographic depressions; recreational wildlife from contaminated species are present but hunting is not allowed; grazing is limited to specific non-contaminated areas; no public areas occur in or adjacent to the reservation; and the vegetation and wildlife (i.e.,

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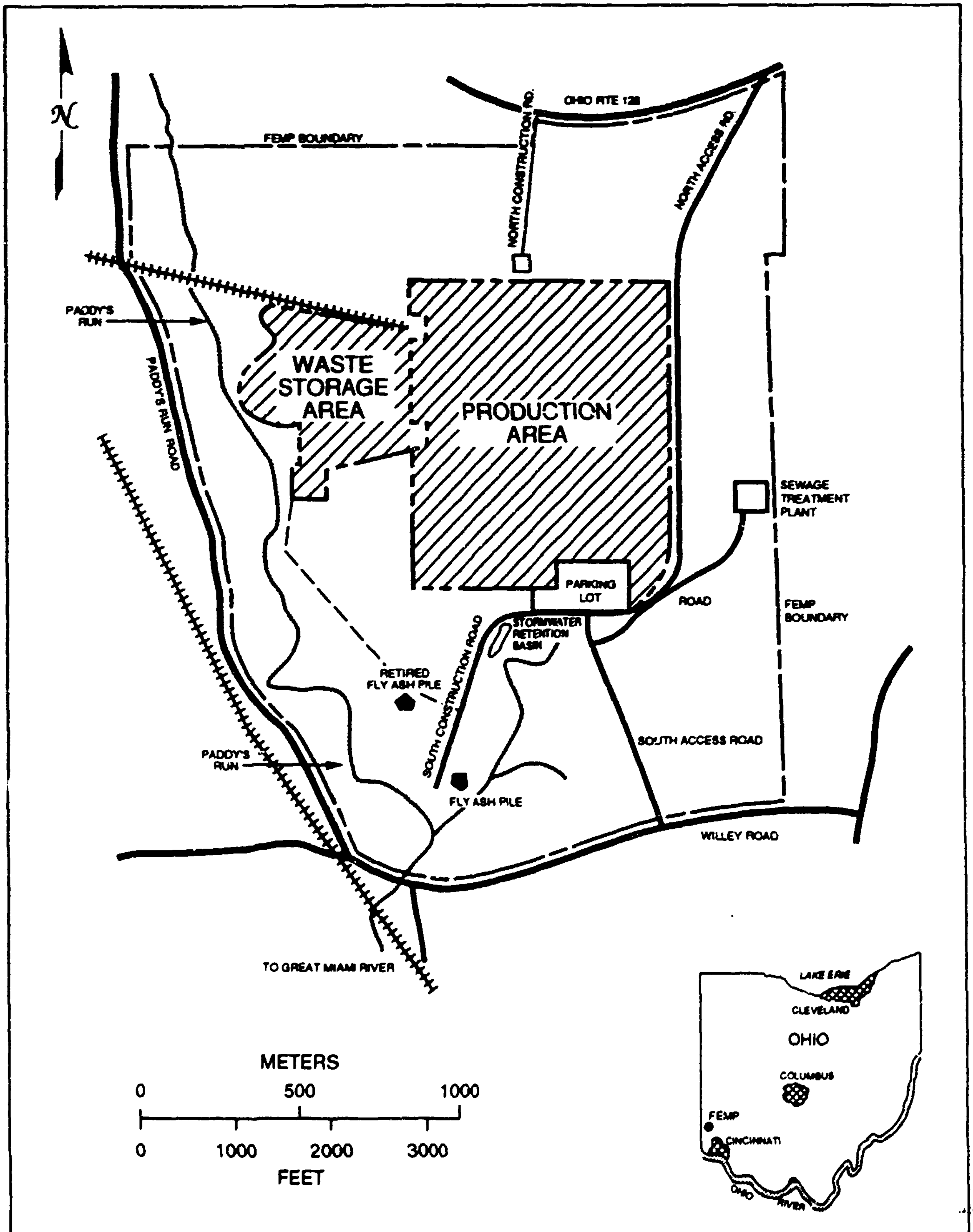


biodiversity) are typical of that found in the surrounding area.

Determining risks to endpoints requires (1) defining distribution and composition of endpoints and (2) selecting representive receptor species. The distribution of endpoints must be known in order to determine both exposure pathways for contaminants and risks to endpoints from construction.

For purposes of determining risk of exposure to contaminants, distribution of endpoints is considered to be either ubiquitous (i.e., more or less uniformly distributed throughout the reservation or region), discrete (i.e., located in one clearly identified location), or discontinuous (i.e., found in several locations within a limited area or areas). Risks to ubiquitous endpoints are assumed to be related to the total surface area affected by contaminant exposure or by disturbance from construction. Risks to discontinuous and discrete endpoints are determined if their locations are known to be within contaminated areas or within areas affected by remediation-related construction or contaminant exposures.

Ubiquitous endpoints on the FEMP reservation include recreational wildlife and certain components of biodiversity (table 6-1). Wetlands, the only federally listed endangered species, and other elements of biodiversity and recreational wildlife, on the other hand, exhibit discontinuous distributions. The distribution of agricultural production and public lands endpoints can best be described as discrete. Locations of endpoints were determined from existing maps and publications.

Endpoints can be represented by many different receptors. The following chapters describe endpoints on the FEMP reservation and endpoint receptors selected for our analyses.

6.1.1 Threatened and Endangered Species

6.1.1.1 Receptors

The geographic ranges of several species listed by the U.S. Fish and Wildlife Service as threatened or endangered theoretically encompass the FEMP reservation, including the threatened northern wild monkshood (an herb, *Aconitum noveboracense*) and the endangered peregrine falcon (*Falco peregrinus*), bald eagle (*Haliaeetus leucocephalus*), and Indiana bat (*Myotis sodalis*). The range of one state-listed endangered species, the cave salamander (*Eurycea lucifuga*), also overlaps the reservation. For reasons stated in the next paragraphs, the Indiana bat was selected as the only receptor representative of federally listed threatened or endangered species on the reservation.

Foraging habitat for one colony of Indiana bats was found to range from 1.5 ha (3.6 acres) in early summer to 4.5 ha (11.2 acres) after young bats are flying (Humphrey et al. 1977). In the summer, these bats forage for insects in the upper woodland canopy (Thomson 1982). They prefer mature riparian woodland containing dead trees for shelter, along small- to medium-sized streams. Winters are generally spent hibernating in caves (October–April).

6.1.1.2 Distribution

Although the northern wild monkshood occurs in northeastern Ohio, it does not occur on or near the reservation (McCance and Burns 1984). Individual peregrine falcons and bald eagles might occur rarely as transients along the Great Miami River, but they do not nest in any of the counties surrounding the reservation. Neither have cave salamanders been found on the reservation. For these reasons, none of these four species will be considered further in this assessment. A survey for threatened and endangered species did not find Indiana bats on the reservation, but eight bats of this species were captured about 5.3 km (3.3 miles) northeast of the FEMP boundary along a tributary creek to the Great Miami River. Moreover, potential Indiana bat habitat along Paddy's Run ranges in quality from poor to excellent. Therefore, the Indiana bat was chosen for this assessment as the only representative of a threatened or endangered species under the Endangered Species Act that may actually reside, or at least forage, on the reservation.

TABLE 6-1—*Distribution of Endpoints and Receptors at Fernald Environmental Management Project*

Ubiquitous	Discontinuous	Discrete
Recreational wildlife (rabbit, deer) Important components of **biodiversity** not included in the above (mice, fox, other bats, robin, hawk, vegetation)	Resident, breeding, or foraging **Federally listed and candidate species** (Indiana bat) **Wetlands** and riparian vegetation along rivers (aquatic plants, benthos) **Biodiversity** (aquatic benthos), **recreational wildlife** (fish)	**Agricultural production** (pine plantations, grazing land) (No **public lands** on or adjacent to FEMP)

6.1.2 Wetlands

6.1.2.1 Receptors

Representative wetland organisms include minnows and other small fish species, benthic invertebrates, and wetland vegetation such as cattails and rushes. For this assessment, benthic invertebrates and vegetation were selected as the receptors representative of reservation wetlands.

6.1.2.2 Distribution

With the exception of approximately 3.8 ha (9.5 acres) of forested wetland near the north-central boundary of the reservation, most (8 ha or 20 acres) of the jurisdictional wetlands on the reservation consist of drainage ditches and swales supporting emergent vegetation such as cattail, sedges, and rushes (DOE 1992). For the purposes of this assessment, at least some of the reservation wetlands are also considered to be within or under the influence of the waste sites. These wetlands, and the receptors chosen to represent them, exhibit discontinuous distributions.

6.1.3 Recreational Fish and Wildlife

6.1.3.1 Receptors

Several recreationally desirable wildlife species occur or may occur on the FEMP reservation, although, with the exception of a few dairy farmers who lease land to graze cattle, the reservation is closed to public access. Fish, particularly those of the catfish and sunfish families, the cottontail rabbit, and the white-tailed deer were selected for this assessment as representative of the recreational fish and wildlife on the reservation. The data available for fish are not specific to species of interest; therefore, the assessment is limited to risks to fish in general.

6.1.3.2 Distribution

For the most part, recreationally desirable fish (mostly of the sunfish family) are limited to the Great Miami River to the east and south of the reservation. Occasionally, a few specimens of catchable size may occur in Paddy's Run or its tributaries within the reservation. None are expected to occur in the waste sites themselves. Game mammals and birds that occur on the reservation include the eastern cottontail rabbit (*Sylvilagus floridanus*), white-tailed deer (*Odocoileus virginianus*), and the bobwhite (*Colinus virginianus*). The fish have a discontinuous distribution, while both mammalian species are considered to be ubiquitous in distribution.

6.1.4 Agricultural or Timber Production

6.1.4.1 Receptors

Although cattle are allowed to graze on the FEMP reservation, under normal circumstances they do not have access to contaminated sites. Therefore, vegetation (representing grass and planted pines), but not cattle, were selected for this assessment as the endpoint receptors representative of agricultural and timber production.

6.1.4.2 Distribution

Approximately 170 ha (430 acres) of grazing land is leased to local dairy owners for cattle grazing. This land, dominated by introduced red fescue (*Festuca rubra*) and Kentucky bluegrass (*Poa pratensis*), exhibits a discontinuous distribution on the reservation. Small pine and spruce plantations have been established in the northeast and southwest corners of the reservation. On the basis of soil classifications, the U.S. Department of Agriculture, has designated much of this land as prime agricultural land. This assessment considers only vegetation on or adjacent to the contaminated sites.

6.1.5 Parks and Other Public Lands

6.1.5.1 Receptors

No likely receptors in terms of parks and public lands were identified for this assessment.

6.1.5.2 Distribution

There are no parks or public lands on or adjacent to the reservation. Nearly all of the land adjacent to the reservation is privately owned agricultural or open land. To the southeast, an industrial area has developed along about 0.37 km (0.23 mile) or 4% of the reservation perimeter's 8.4-km length (5.2 miles). To the northeast lies a Girl Scout camp. Although camp property commences only 0.50 km (0.31 mile) from the nearest reservation boundary, the camp is topographically upgradient of the entire FEMP reservation and consequently is not considered to be subject to contamination from the waste sites.

6.1.6 Biodiversity

6.1.6.1 Receptors

As indicated earlier, the ecosystems of the reservation and its environs began to undergo substantial alterations in structure and function beginning with the arrival of the first European settlers. Virgin forests and the complex plant and animal communities they supported no longer exist in the area. What woodland persists is highly fragmented, and current practices in land management on the reservation, including mowing and grazing, prevent the establishment of truly climax communities. Even so, the fragmented and disturbed terrestrial systems now dominant on the reservation support a variety of plant and animal communities.

Except for cattle, all of the animals and plants used as representative of the other endpoints discussed above are considered as representative elements of area biodiversity and, therefore, are used in this assessment of impacts on biodiversity (i.e., the mouse, rabbit, deer, robin, bat, hawk, fox, vegetation, aquatic invertebrates, and fish). Note that for this assessment aquatic organisms are assumed to be absent from the actual waste sites.

6.1.6.2 Distribution

All but two of the selected receptors representative of the area's biodiversity are considered to have ubiquitous distributions. Fish and benthic invertebrates have discontinuous distributions.

6.2 Contaminants of Potential Concern

The contaminants of potential concern at FEMP include numerous inorganic, organic, and radioactive contaminants (table 6-2). The most prevalent radionuclide, according to relative average concentrations, is ^{238}U; Al, Ba, Cu, U and Zn exhibit the highest concentrations among inorganic contaminants. The concentrations of organic chemicals on the site are fairly low and, thus, are not expected to pose as great a potential hazard as the inorganic and radioactive contaminants.

Maximum and average soil, surface water, and sediment concentrations used in the assessment were determined from the source ter[illegible] provided by F[illegible]L (tables 6-2, 6-3, and 6-[illegible] Development of average and maximum source terms for use in exposure and risk assessment involves certain assumptions concerning interpretations of and compensation for data gaps. Appendix A describes the methodology employed to develop useable source terms for input into the exposure and risk assessment.

6.3 Exposure Assessment

Estimating exposures for all representative species on the reservation accurately is difficult because of the lack of data for numbers of individuals actually exposed to wastes, the amount of time they spend in waste areas, and the actual amounts of contaminant uptake. Site-specific home ranges, behavior, and habitat requirements of many of the representative species at FEMP are not necessarily well known, and only a few species with small home ranges (e.g., small mammals and birds) may reside within contaminated areas for most of their lives. Of these, only a very few individuals may be subject to exposure to maximum concentrations (see chapter 6.4 for discussion of home ranges). Therefore, an initial screening assessment was conducted, using, where available, the maximum concentrations of each contaminant in each medium on-site to identify worst-case potential contaminants. Contaminants that do not pose a risk to any of the receptor species from exposure to the maximum values will not be considered further. If contaminants pose a risk to organisms exposed to the maximum concentrations, however, the average concentrations of those contaminants will be used in the assessment to estimate a more reasonable exposure and risk.

The ecological assessment estimates the risk to vegetation, terrestrial wildlife, and aquatic organisms from chronic exposure to radiological and nonradiological contaminants [appendix A]. It is desirable in exposure analysis to consider all possible ecological endpoints and receptor species within each endpoint. However, due to limited availability of exposure sensitivity data for many species (e.g., threatened and endangered species) and ecological similarities in exposure risks (e.g., similarly sized hawks feeding on the same or similar prey), certain organisms considered representative of each endpoint were chosen fo evaluation. A food web was developed that includes terrestrial receptor species representing all endpoints (figure 6-2). Where data were available, we tried to ensure conservatism in our estimates of exposure and risk by selecting receptors most sensitive to contaminants or habitat

TABLE 6-2—*Constituents of Potential Concern w/Maximum and Average Soil Concentrations [mg/kg dry weight (for chemical constituents) or pCi/kg dry weight (for radionuclides)] on the Fernald Environmental Management Project*

Constituent	Maximum Concentration	Constituent	Average Concentration
1,4 dioxane	1.29E+01	Aroclor 1248	5.65E–01
2-butanone	1.20E–02	Aroclor 1254	9.77E–01
2-methylnapthalene	1.10E+01	Di-n-butyl phthalate	7.30E–02
Acenapthene	2.80E+01	Aluminum	5.85E+03
Acetone	2.30E–01	Antimony	2.53E+01
Aroclor 1242	1.60E+00	Arsenic	4.50E+00
Aroclor 1248	5.65E–01	Barium	5.84E+01
Aroclor 1254	1.10E+00	Beryllium	8.00E–01
Aroclor 1260	6.10E–01	Cadmium	5.10E+00
BEHP	3.10E–01	Chromium	1.45E+01
Dibenzofuran	1.90E+00	Copper	1.52E+02
Diethyl phthalate	8.40E–02	Cyanide ion	1.70E+00
Di-n-butyl phthalate	7.30E–02	Lead	1.99E+01
Di-n-octylphthalate	2.10E–01	Mercury	1.00E–01
Fluoranthene	6.10E–02	Molybdenum	4.80E+00
Methylene chloride	2.40E–01	Nickel	2.62E+01
Napthalene	1.90E+01	Selenium	5.00E–01
Octachlorodibenzo-p-dioxin	7.30E–03	Silver	9.60E+00
Pyrene	5.00E–01	Uranium	2.97E+03
Toluene	1.80E–01	Vanadium	1.75E+01
Aluminum	1.17E+04	Zinc	4.02E+01
Antimony	3.25E+01	Technetium-99	8.90E+03
Arsenic	1.54E+01	Uranium-238	9.51E+05
Barium	2.23E+02		
Beryllium	1.60E+00		
Cadmium	7.70E+00		
Chromium	5.18E+01		
Cobalt	1.70E+01		
Copper	2.01E+01		
Cyanide ion	1.70E+00		
Lead	1.47E+02		
Mercury	2.00E–01		
Molybdenum	1.88E+01		
Nickel	5.02E+01		
Selenium	6.20E–01		
Silver	2.17E+01		
Sodium ion	1.85E+02		
Strontium	5.00E–09		
Thallium	6.80E–01		
Uranium	1.81E+05		
Vanadium	2.69E+01		
Zinc	7.99E+01		
Cesium-137	2.00E+02		

Constituent	Maximum Concentration	Constituent	Average Concentration
Lead-210	4.43E+04		
Neptunium-237	4.00E+03		
Plutonium-238	6.00E+02		
Plutonium-239	2.00E+03		
Radium-224	2.10E+03		
Radium-226	8.76E+05		
Radium-228	1.30E+03		
Strontium-90	8.00E+02		
Technetium-99	3.70E+04		
Thorium-228	1.70E+04		
Thorium-230	4.42E+05		
Thorium-232	1.80E+04		
Uranium-234	1.80E+05		
Uranium-235	4.20E+04		
Uranium-236	7.60E+02		
Uranium-238	6.04E+07		

TABLE 6-3—*Maximum and Average Fernald Water Concentrations [mg/L (for chemical constituents) or pCi/L (for radionuclides)] on the Fernald Environmental Management Project*

Drinking Water[1]				Aquatic Water[2]			
Constituent	**Maximum Conc.**	**Constituent**	**Average Conc.**	**Constituent**	**Maximum Conc.**	**Constituent**	**Average Conc.**
2-butanone	5.00E-02	Aroclor 1248	3.28E-01	Cadmium	5.00E-03	Cadmium	2.80E-03
Acetone	1.92E+00	Aroclor 1254	6.15E-01	Copper	1.47E-02	Copper	1.03E-02
Anthracene	4.77E-01	Benzo(a)pyrene	7.12E-01	Lead	1.40E-02	Uranium-234	3.43E+03
Aroclor 1248	3.28E-01	Di-n-butyl phthalate	1.81E+00	Mercury	1.00E-03		
Aroclor 1254	3.28E-01	Aluminum	1.00E-01	Uranium	1.90E-02		
Benz(a)anthracene	9.46E-01	Antimony	3.70E-02				
Benzo(a)pyrene	7.12E-01	Arsenic	9.25E+00				
Benzo(b)fluoranthene	7.54E-01	Barium	3.32E+03				
Benzo(g,h,i)perylene	2.45E-01	Beryllium	9.67E+00				
Benzo(k)fluoranthene	7.96E-01	Cadmium	1.90E+00				
BEHP	5.95E-01	Chromium	3.69E+01				
Chrysene	1.06E+00	Copper	3.97E+02				
Di-n-butyl phthalate	1.81E+00	Cyanide ion	9.76E+00				
Fluoranthene	3.29E+00	Lead	1.94E+01				
indeno(1,2,3-cd)pyrene	2.29E-01	Mercury	1.55E+00				
Methylene chloride	6.80E-01	Molybdenum	1.80E-02				
Phenanthrene	2.24E+00	Nickel	7.12E+01				
Pyrene	1.49E+00	Selenium	3.95E+00				
Aluminum	9.97E-02	Silver	1.76E+00				
Antimony	3.69E-02	Uranium	7.27E+02				
Arsenic	1.85E+01	Vanadium	1.72E+03				
Barium	6.64E+03	Zinc	9.16E+01				
Beryllium	9.67E+00	Technetium-99	3.28E+05				
Boron	2.43E-01	Uranium-238	2.34E+05				
Cadmium	7.59E+00						
Calcium (oxide)	4.79E+01						
Chromium	7.38E+01						
Cobalt	1.96E+01						
Copper	1.19E+03						
Cyanide ion	9.76E+00						
Iron	3.33E-02						
Lead	7.75E+01						
Magnesium	4.78E+01						
Manganese	1.14E-01						
Mercury	4.65E+00						
Molybdenum	8.13E-02						
Nickel	7.12E+01						

Drinking Water[1]				Aquatic Water[2]			
Constituent	Maximum Conc.	Constituent	Average Conc.	Constituent	Maximum Conc.	Constituent	Average Conc.
Potassium	1.32E+01						
Selenium	3.95E+00						
Silicon	1.04E+00						
Silver	1.13E-02						
Sodium ion	2.72E+02						
Uranium	2.13E+03						
Vanadium	1.72E+03						
Zinc	1.83E+02						
Cesium-137	4.79E+05						
Neptunium-237	2.85E+03						
Plutonium-238	9.59E+01						
Radium-226	3.24E+05						
Radium-228	1.20E+00						
Technetium-99	3.49E+05						
Thorium-228	5.37E+04						
Thorium-230	4.61E+06						
Thorium-232	4.11E+04						
Uranium-234	3.80E+00						
Uranium-235	5.16E+04						
Uranium-238	7.03E+05						

NA = No measured concentration available

[1] Drinking water concentrations at Fernald were used in terrestrial exposure pathways and were derived from all sites, including the Great Miami River and Paddy's Run.

[2] Aquatic water concentrations at Fernald were used in the aquatic organism exposure pathway and were derived from the Great Miami River and Paddy's Run only.

TABLE 6-4—*Maximum and Average Fernald Sediment Concentrations*[1] *[mg/kg (for chemicals) or pCi/kg (for radionuclides)] on the Fernald Environmental Management Project*

Constituent	Maximum Concentration	Constituent	Average Concentration
Aluminum	5.46E+03	Aluminum	3.82E+03
Radium-226	3.70E+03		
Radium-228	8.20E+02		
Thorium-228	1.50E+03		
Thorium-230	1.30E+03		
Thorium-232	6.20E+02		
Uranium-234	2.90E+04		
Uranium-238	3.00E+04		

[1] Sediment concentrations were used only in the aquatic pathway and were derived from the Great Miami River and Paddy's Run values only.

alteration, most likely to experience additional risk due to bioaccumulation or larger body size, or at greatest risk due to rarity. Other abundant species on the reservation were included as important components of the foodweb, such as mice and insects (exposure and risk estimates were not determined for insects).

The primary exposure routes for terrestrial wildlife species at FEMP are ingestion of water (including soils for some species) and food. Table 6-5 lists the body weights and consumption rates for the selected representative species. Cattle are assumed to feed exclusively on the vegetative parts of plants. The cottontail rabbit and white-tailed deer are assumed to eat 50% vegetation and 50% fruits and seeds. Based on a review of the literature, the percentage of prey items consumed by omnivores and predators was estimated (table 6-5; figure 6-1). The mouse and robin are assumed to eat 70% fruit/seeds and 30% insects; the red-tailed hawk to eat 80% mice and 20% rabbits; and the red fox to eat 70% mice and 30% rabbits. Bats are assumed to eat 100% insects, and insects to eat 100% plant material.

All species are assumed to purposely or incidentally ingest soil while eating, grooming, or preening except for the bat, hawk, and red fox (table 6-5). The soil ingestation rate (Q_s) for cottontail rabbits was assumed to be the same as that reported for the jackrabbit (6.3% of the dry-matter intake) (Arthur and Gates 1988). The white-tailed deer soil ingestion rate is assumed to be the same as that reported for the mule deer [1.35% of the dry-matter intake (Arthur and Alldredge 1979)]. The soil ingestion rates for the cow and mouse are 7% and 2% of the dry-matter intake, respectively (Mayland et al. 1977 and Beyer et al. 1991). Because published values of soil ingestion rates were not found for the robin, the rate was conservatively estimated to be 10% of the dry-matter intake.

The estimated daily rates of food and water consumption (Q_f or Q_h, and Q_w, respectively) for each representative species were calculated from allometric regression equations that are based on the weight of the organism (EPA 1988) (table 6-5). These weights, in turn, are based on combined measurements for laboratory animals, livestock, and selected wildlife and bird species (EPA 1988) (appendix A).

Because details of the behavior and habitat requirements of most of the representative wildlife species are not well known, it is assumed that all species spend 100% of their time on the reservation. Thus, all selected representative species are considered to be year-round residents at FEMP. Therefore, the fraction of contaminated food, soil, and water consumed (FI_i) is set at 100% (table 6-5).

Contaminant concentrations in vegetation, the first level in the food chain, are estimated from concentrations measured in soils using published

TABLE 6-5—*Body Weights and Consumption Rates*[1] *for Terrestrial Species*[2] *on the Fernald Environmetnal Management Project*

Parameter	White-footed Mouse	Eastern Cottontail rabbit	Deer	Cow	Robin	Indiana Bat	Red-Tailed Hawk	Red Fox
Body weight, BW (kg)	2.40E-02[3]	1.19E+00[4]	5.65E+01[5]	4.00E+02[6]	7.50E-02[7]	7.30E-03[8]	1.39E+00[9]	6.00E+00[10]
Water intake rate, Q_w (L/d)	6.40E-03	1.14E-01	2.63E+00	1.23E+01	1.43E-02	2.30E-03	1.43E-01	4.51E-01
Water ingestion fraction, FI_w	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00
Soil intake rate, Q_s (kg/d)	4.38E-05[11]	1.28E-03[12]	5.83E-03[13]	1.86E-01[14]	3.87E-04[15]	0.00	0.00	0.00
Soil ingestion fraction, FI_s	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	0.00	0.00	0.00
Vegetation intake rate, Q_v (kg/d)	0.00	3.73E-02[16]	7.93E-01[17]	7.47E+00	0.00	0.00	0.00	0.00
Vegetation ingestion fraction, FI_v	0.00	1.00E+00	1.00E+00	1.00E+00	0.00	0.00	0.00	0.00
Fruit/seeds intake rate, Q_f (kg/d)	3.36E-03[18]	3.73E-02	7.93E-01	0.00	5.80E-03[19]	0.00	0.00	0.00
Fruit/seeds ingestion fraction, FI_f	1.00E+00	1.00E+00	1.00E+00	0.00	1.00E+00	0.00	0.00	0.00
Prey 1 intake rate, Q_{b1} (kg/d)	1.40E-03 (insects)	0.00	0.00	0.00	2.50E-03 (insects)	1.30E-03 (insects)	7.92E-02[20] (mice)	1.88E-01[21] (mice)
Prey 1 ingestion fraction, FI_{b1}	1.00E+00	0.00	0.00	0.00	1.00E+00	1.00E+00	1.00E+00	1.00E+00
Prey 2 intake rate, Q_{b2} (kg/d)	0.00	0.00	0.00	0.00	0.00	0.00	1.98E-02 (rabbits)	8.06E-02 (rabbits)
Prey 2 ingestion fraction, FI_{b2}	0.00	0.00	0.00	0.00	0.00	0.00	1.00E+00	1.00E+00
Prey 3 intake rate, Q_{b3} (kg/d)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Prey 3 ingestion fraction, FI_{b3}	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

[1] All values are on a wet weight basis. For soils, the wet/dry ratio is 0.90 (Clark et al. 1977), for vegetation the ratio is 0.32 and for fruits/seeds, the ratio is 0.17 (Morrison 1959).
[2] Water and food consumption rates were computed by methods in U.S. EPA 1988 (table 8) unless otherwise noted.
[3] Lackey et al. 1985.
[4] Chapman et al. 1980.
[5] Smith 1991.
[6] U.S. EPA 1988.
[7] Terres 1980.
[8] Thomson 1982.
[9] Brown and Amadon 1968.
[10] Opresko and Suter 1992.
[11] Mouse soil ingestion rate is 2% of dry vegetation intake (Beyer et al. 1991).
[12] The eastern cottontail is assumed to have the same soil ingestion rate as the jackrabbit (6.3%) (Arthur and Gates 1988).
[13] The white-tail deer is assumed to have a soil ingestion rate of 1.35% of dry matter intake (Arthur and Alldredge 1979).
[14] Cattle soil ingestion rate is about 7% of dry matter intake (Mayland et al. 1977).
[15] The robin soil ingestion rate is assumed to be 10% of dry matter intake.
[16] The eastern cottontail rabbit is assumed to eat 50% fruit/seeds and 50% vegetation (Whitaker 1988).
[17] The white-tailed deer is assumed to eat 50% vegetation and 50% fruit/seeds (Whitaker 1988).
[18] The mouse is assumed to eat 70% fruit/seeds and 30% insects (Lackey et al. 1985).
[19] The robin is assumed to eat 70% fruit/seeds and 30% insects (Terres 1980).
[20] The red-tailed hawk is assumed to eat 80% mice and 20% rabbits (Terres 1980).
[21] The red fox is assumed to eat 70% mice and 30% rabbits (Whitaker 1988).

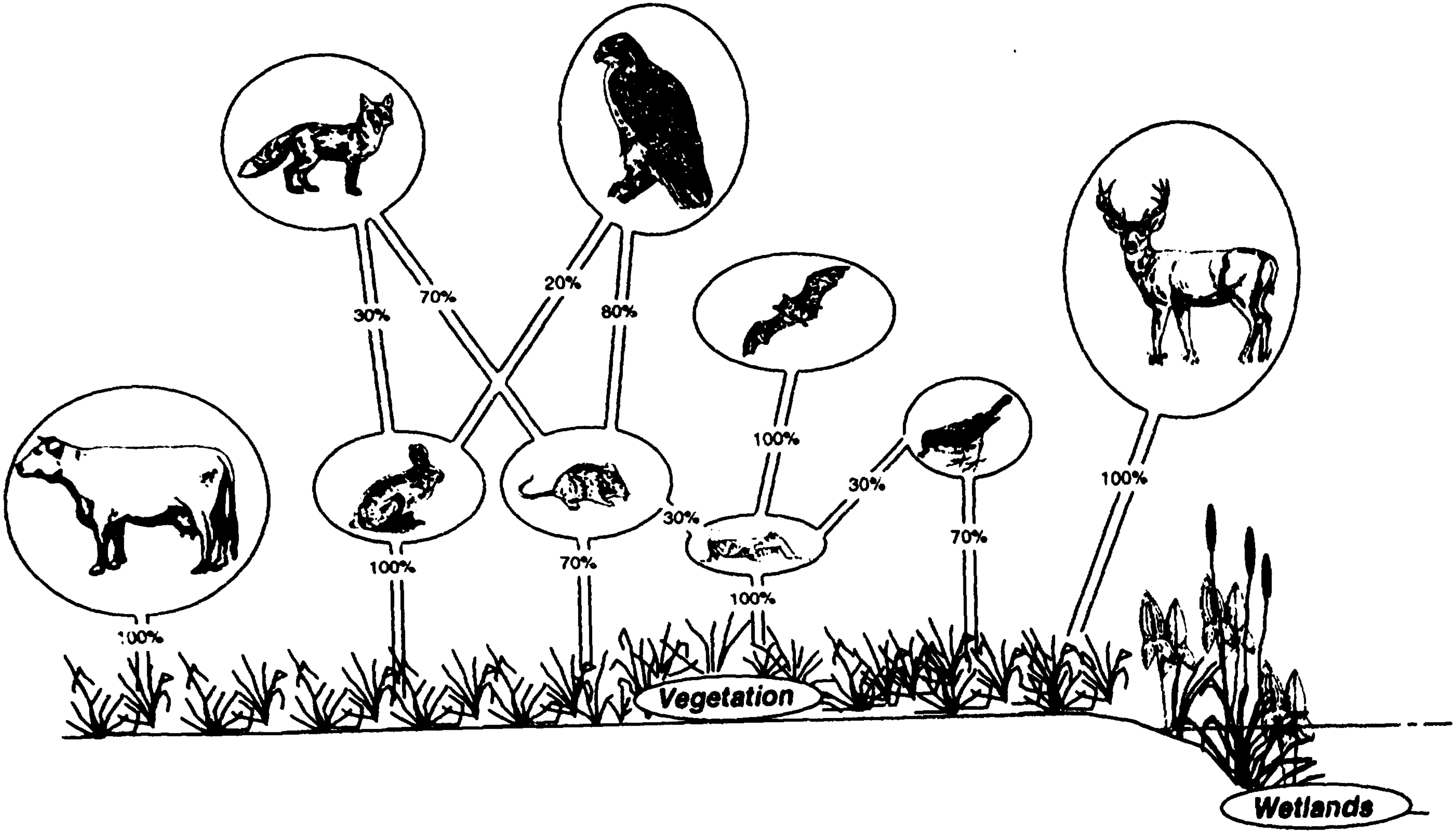


FIGURE 6-2. REPRESENTATION OF THE TERRESTRIAL FOOD WEB OF THE FERNALD RESERVATION

element-specific, soil-to-plant transfer factors (Baes et al. 1984; Travis and Arms 1988) (table 6-6). Transfer factors for inorganic chemicals are available for both the vegetative and fruiting parts of plants (Baes et al. 1984); published transfer factors for organic chemicals, however, do not make this distinction (Travis and Arms 1988). The methodology used to predict contaminant concentrations in vegetation does not make a distinction between different plant types or species. It is assumed, therefore, all species ingest "generic" vegetation containing contaminant concentrations derived from soil concentrations by the use of published transfer factors.

Transfer factors for contaminants of concern are used to predict concentrations in the tissues of terrestrial mammalian receptors from consumption of vegetation, soil, and water (collectively termed B_b) (Baes et al. 1984; Travis and Arms 1988) (table 6-6). The rationale and limitations for applying these transfer factors are discussed in appendix A. Data on transfer factors from vegetation or soil to insects and earthworms are very limited in the literature. Therefore, the concentration in insects was derived from vegetation concentrations, and a default, conservative one-to-one transfer between vegetation and insects was assumed.

The consumption rates and the benchmark limits or no-observable-adverse-effect level (NOAEL) values are typically reported in wet weights, whereas the vegetation and soil concentrations are typically reported in dry weights. Therefore, conversion factors were applied to account for this difference. The wet- to dry-weight conversion factor for the vegetative parts of plants at FEMP was assumed to be 0.32 [the average for meadow fescue, Kentucky bluegrass, wild bromegrass, and orchard grass (Morrison 1959)]. The wet- to dry-weight conversion factor for the fruiting parts of plants on Fernald was assumed to be 0.17 (Morrison 1959). The wet- to dry-weight conversion factor for soils is 0.90.

For the base-line assessment of FEMP, the concentrations of radionuclides in animal tissues and the resulting doses were not decay-corrected. The doses are estimated for the existing conditions and not as some point in the future. The primary radionuclides of concern, ^{234}U and ^{238}U, have a very long half-lives, so this assumption is reasonable. The radionuclide concentrations in the source terms have been decay-corrected by PNL back to the time of disposal or release. Estimated dose to terrestrial receptors was based not only on the radionuclide itself, but on all radioactivity of the short-lived daughter products as well.

Aquatic organisms considered in the assessment include benthic macroinvertebrates and a generic fish species. For radiological analyses, emergent vegetation (i.e., cattails) and muskrats are included as well. All aquatic organisms, except for benthic macroinvertebrates, are assumed to be exposed to contaminants in the surface waters of the Great Miami River and Paddys Run only. For this analysis, benthic macroinvertebrates are assumed to be exposed only to the sediment pore water in the Great Miami River and Paddys Run for calculation of internal radiation dose and exposure to chemicals. The external radiation dose from exposure to surface water was calculated for all organisms. Although contaminant concentration source terms in surface water and sediments were provided by PNL for all sites at FEMP, only those maximum and average source terms corresponding to the Great Miami River and Paddys Run were included in the aquatic exposure scenarios. Surveys indicate there are no year-round aquatic communities living in waste ponds or streams (e.g., lime sludge ponds, the clearwell, or the storm sewer outfall ditch). For the terrestrial drinking water exposure pathway, however, maximum and average source-term concentrations were derived from all sites, including waste ponds and the Great Miami River and Paddys Run.

6.4 Contaminant Effects Assessment

Two pathways are used to determine the effects of contaminant exposure (chapter 6.3) on ecological endpoint receptors. For terrestrial receptors, consumption rates of contaminated food and water are compared with toxicological benchmarks. For aquatic receptors, contaminant concentrations in water or sediment pore water are compared with chemical-specific aquatic benchmarks. To quantify risk to terrestrial

TABLE 6-6—*Soil-to-Vegetation and Plant-to-Beef Transfer Factors for the Constituents of Concern on the Fernald Environmental Management Project*

Constituent	Soil to Vegetation Transfer Factor	Vegetation to Beef Transfer Factor
1,4 dioxane	5.55E+01	1.35E–08
2-butanone	2.63E+01	4.90E–08
2-methylnapthalene	2.27E–01	1.82E–04
Acenapthene	2.16E–01	2.00E–04
Acetone	5.33E+01	1.45E–08
Aroclor 1242	2.24E–02	1.00E–02
Aroclor 1248	2.24E–02	1.00E–02
Aroclor 1254	2.24E–02	1.00E–02
Aroclor 1260	2.24E–02	1.00E–02
BEHP	4.37E–02	3.16E–03
Diethyl phthalate	5.48E–01	3.98E–05
Di-n-butyl phthalate	3.82E–02	3.98E–03
Di-n-octylphthalate	1.86E–04	3.98E+01
Fluoranthene	5.72E–02	1.98E–03
Methylene chloride	6.86E+00	5.01E–07
Napthalene	3.22E–01	1.00E–04
Pyrene	3.35E–02	5.01E–03
Toluene	1.07E+00	1.26E–05
Aluminum	4.00E–03	1.50E–03
Antimony	2.00E–01	1.00E–03
Arsenic	4.00E–02	2.00E–03
Barium	1.50E–01	1.50E–04
Beryllium	1.00E–02	1.00E–03
Cadmium	5.50E–01	5.50E–04
Chromium	7.50E–03	5.50E–03
Cobalt	2.00E–02	2.00E–02
Copper	4.00E–01	1.00E–02
Cyanide ion	5.42E+01	1.41E–08
Lead	4.50E–02	3.00E–04
Magnesium	1.00E+00	5.00E–03
Manganese	2.50E–01	4.00E–04
Mercury	9.00E–01	2.50E–01
Radium-226	1.50E–02	2.50E–04
Radium-228	1.50E–02	2.50E–04
Thorium-228	8.50E–04	6.00E–06
Thorium-230	8.50E–04	6.00E–06
Thorium-232	8.50E–04	6.00E–06
Uranium-234	8.50E–03	2.00E–04
Uranium-238	8.50E–03	2.00E–04

Source: For organics, the transfer factors were calculated from equations in Travis and Arms (1988) using K_{ow} values from the *Superfund Chemical Data Matrix* (1991). For inorganics and radionuclides, the transfer factors were taken from Baes et al. (1984). The K_{ow} for cyanide was taken from MEPAS and the transfer factors were calculated from equations in Travis and Arms (1988).

receptors exposed to organic and inorganic contaminants, the daily consumption rates of contaminated food and water, normalized to body weight (in units of mg/kg/d), is compared to the NOAEL benchmarks (mg/kg/d). These ratios are termed hazard indices (HIs). Ratios greater than 1 are considered to pose a potentially unacceptable risk to organisms but do not necessarily indicate the severity of the effects. However, it is reasonable to assume that the higher the ratio, the greater the risk of adverse effects. Dose to terrestrial receptors, including vegetation, from internal and external exposure to radionuclides was also determined from calculated tissue concentrations and soil concentrations, respectively. Doses that exceed 0.1 rad/d are considered to pose a potentially unacceptable risk (i.e., an HI greater than 1) to terrestrial organisms (IAEA 1992). The "Ecological Risk Assessment Methodology for the PEIS" (1993) and appendix A describes in more detail methods used to calculate exposure and risk.

Toxicological benchmarks for terrestrial organisms, excluding vegetation, were obtained from Opresko et al. (1993) (table 6-7). For representative receptor species that are not specifically listed in the data base, extrapolation techniques were employed to obtain the chronic NOAEL by adjusting for differences in body weight between the receptor and a test organism. If a NOAEL is available for a laboratory test species, a NOAEL for a receptor species can be derived by extrapolation. Many of the NOAEL benchmarks were derived by extrapolation from small-mammal laboratory data, where available (Opresko et al. 1993). There were a few contaminants, however, for which no animal toxicity data was found. For these cases, wildlife NOAELs were extrapolated from human noncarcinogenic toxicity data listed in the EPA IRIS data base based on the "standard man" body weight of 70 kg. In relation to human toxicity values, the wildlife species that weigh less than 70 kg have higher benchmarks than humans; wildlife species weighing more than 70 kg have lower benchmarks.

Literature sources for inorganic terrestrial phytotoxicity benchmarks were summarized and reported by Suter and Futrell (1993) (table 6-7). Where available, the lowest concentrations in a soil medium that produced phytotoxically excessive effects were chosen from the data base. Several benchmarks were derived from experiments using nutrient solutions as the experimental medium. Uncertainty values were not applied to this data to account for differences in experimental growth medium. A methodology for deriving phytotoxicity benchmarks for organic constituents has been developed by Eskew and Babb [in preparation, as cited in the MMR Air National Guard Risk Assessment Handbook (1992)] (table 6-7).

Risks to aquatic organisms from exposure to organic and inorganic contaminants in water and sediments (pore water) were calculated by comparing the water or sediment pore-water concentrations with the chemical-specific aquatic benchmark (Suter et al. 1992) (table 6-7). To determine internal dose to aquatic plants, fish, and muskrats from exposure to radionuclides, the surface water concentrations were multiplied by aquatic (internal), radionuclide-specific dose conversion factors to produce a daily dose in rads (Killough and McKay 1976). To determine the internal dose to benthic macroinvertebrates and other bottom-dwelling organisms (e.g., fish larvae) from exposure to radionuclides, the sediment pore-water concentrations were multiplied by radionuclide and organism-specific aquatic (internal) dose conversion factors to produce a daily dose. The external dose to all organisms was determined by multiplying the surface water concentrations by the external radionuclide-specific dose conversion factors. Combined internal and external doses greater than 1 rad/d are considered to pose a potential risk to aquatic organisms (i.e., HI is equal to or greater than 1) (NCRP 1991).

Although it is reasonable to assume that most species are exposed to contaminants only some of the time and that contaminant concentrations are not as high as maximum values, an initial screening assessment was conducted using the maximum concentrations of each contaminant on-site to identify worst-case potential contaminants. Following this initial screening, average concentrations were used for a more realistic maximum exposure for contaminants and receptors that did not pass the initial screening.

TABLE 6-7—*Criteria Benchmarks for Terrestrial[1] and Aquatic[2] Species (NOAELs listed in mg/kg/d for terrestrial benchmarks or mg/L for aquatic benchmarks) on the Fernald Environmental Management Project*

Constituent	White-Footed Mouse	Eastern Cottontail Rabbit	Indiana Bat	American Robin	Red-Tailed Hawk	White-Tailed Deer	Cow	Red Fox	Aquatic	Vegetation
1,1,2-Trichloro-1,2,2 trifluoroethane	NA	NA	NA	NA	NA	NA	NA	NA	NA	2.60E+00
1,1-dichloroethane	NA	NA	NA	NA	NA	NA	NA	NA	1.59E+00	8.60E-01
2-butanone	2.25E+01	6.12E+00	3.34E+01	1.54E+01	5.81E+00	1.69E+00	8.80E-01	3.57E+00	1.78E+01	NA
2-methylnapthalene	NA	NA	NA	NA	NA	NA	NA	NA	NA	2.10E+01
Acenapthene	NA	NA	NA	NA	NA	NA	NA	NA	1.97E-01	1.28E+02
Acetone	2.44E+01	6.65E+00	3.63E+01	1.67E+01	6.31E+00	1.84E+00	9.56E-01	3.88E+00	2.37E+01	9.65E+01
Anthracene	NA	NA	NA	NA	NA	NA	NA	NA	8.20E-03	1.28E+02
Aroclor 1242	1.16E-01	3.16E-02	1.73E-01	1.59E-01	6.02E-02	8.74E-03	4.55E-03	1.85E-02	2.90E-03	1.00E+01
Aroclor 1248	6.22E-01	6.05E-02	9.25E-01	4.25E-01	5.75E-02	1.67E-02	8.70E-03	3.53E-02	4.00E-04	NA
Aroclor 1254	1.41E-01	4.34E-02	2.10E-01	3.19E+00	1.47E+00	1.73E-02	9.03E-03	3.50E-02	5.20E-04	1.00E+01
Aroclor 1260	1.46E+00	2.92E-03	2.17E+00	9.96E-01	2.77E-03	8.06E-04	4.20E-04	1.70E-03	2.10E-03	NA
Benz(a)anthracene	NA	NA	NA	NA	NA	NA	NA	NA	6.50E-04	1.28E+02
Benzo(a)pyrene	2.44E-02	6.65E-03	3.63E-02	1.67E-02	6.31E-03	1.84E-03	9.56E-04	3.88E-03	2.99E-03	1.28E+02
Benzo(b)fluoranthene	NA	NA	NA	NA	NA	NA	NA	NA	NA	1.28E+02
Benzo(g,h,i)perylene	NA	NA	NA	NA	NA	NA	NA	NA	NA	1.28E+02
Benzo(k)fluoranthene	NA	NA	NA	NA	NA	NA	NA	NA	NA	1.28E+02
BEHP	NA	NA	NA	NA	NA	NA	NA	NA	3.00E-04	1.40E+01
Chrysene	NA	NA	NA	NA	NA	NA	NA	NA	NA	1.28E+02
Chlordane	1.72E-03	4.69E-04	2.56E-03	3.98E-01	1.51E-01	1.30E-04	6.75E-05	2.74E-04	1.70E-04	1.99E+04
Dibenzofuran	NA	NA	NA	NA	NA	NA	NA	NA	2.00E-03	NA
Diethyl phthalate	NA	NA	NA	NA	NA	NA	NA	NA	1.00E+00	NA
Di-n-butyl phthalate	4.56E+01	1.24E+01	6.78E+01	1.41E-02	5.34E-03	3.43E+00	1.78E+00	7.23E+00	2.70E-01	1.48E+04
Di-n-octylphthalate	NA	NA	NA	NA	NA	NA	NA	NA	3.10E-01	NA
Fluoranthene	NA	NA	NA	NA	NA	NA	NA	NA	3.20E-02	1.28E+02
indeno(1,2,3-cd)pyrene	NA	NA	NA	NA	NA	NA	NA	NA	NA	1.28E+02
Methylene chloride	1.43E+01	3.89E+00	2.13E+01	9.78E+00	3.69E+00	1.07E+00	5.60E-01	2.27E+00	4.10E-01	5.60E+00
Napthalene	NA	NA	NA	NA	NA	NA	NA	NA	4.50E-01	1.12E+02
Octachlorodibenzo-p- dioxin	2.44E-02	6.65E-03	3.63E-02	1.67E-02	6.31E-03	1.84E-03	9.56E-04	3.88E-03	NA	NA
Phenanthrene	NA	NA	NA	NA	NA	NA	NA	NA	1.10E-01	1.28E+02
Pyrene	NA	NA	NA	NA	NA	NA	NA	NA	NA	1.28E+02
Toluene	5.45E+01	1.48E+01	8.10E+01	3.73E+01	1.41E+01	4.10E+00	2.13E+00	8.65E+00	2.60E-02	9.70E+00
Aluminum	NA	NA	NA	NA	NA	NA	NA	NA	8.70E-02	8.00E+00
Antimony	1.21E+04	3.31E+03	1.81E+04	8.31E+03	3.14E+03	9.13E+02	4.75E+02	1.93E+03	1.90E+00	5.00E+00

Table 6-7 (cont'd)

Constituent	White-Footed Mouse	Eastern Cottontail Rabbit	Indiana Bat	American Robin	Red-Tailed Hawk	White-Tailed Deer	Cow	Red Fox	Aquatic	Vegetation
Arsenic	1.02E-01	1.62E+00	1.52E-01	7.00E-02	2.61E+00	7.60E-01	3.96E-01	1.60E+00	9.3[illegible]E-01	1.50E+01
Barium	1.25E+00	3.39E-01	1.85E+00	8.52E-01	3.22E-01	9.37E-02	4.88E-02	1.98E-01	2.03E+01	5.00E+02
Beryllium	1.32E+00	3.59E-01	1.96E+00	9.02E-01	3.41E-01	9.92E-02	5.16E-02	2.09E-01	3.80E-03	1.00E+01
Boron	NA	NA	NA	NA	NA	NA	NA	NA	7.00E-03	NA
Cadmium	2.35E-0[illegible]	6.41E-03	3.50E-02	1.44E-01	2.24E-03	1.77E-03	9.21E-04	3.73E-03	1.10E-03	3.00E+00
Calcium (oxide)	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Chromium	5.86E+00	1.60E+00	8.72E+00	4.01E+00	1.52E+00	4.41E-01	2.30E-01	9.31E-01	1.10E-02	7.50E+01
Cobalt	NA	NA	NA	NA	NA	NA	NA	NA	4.40E-03	2.50E+01
Copper	1.83E-01	9.31E-01	2.72E-01	6.88E+01	2.10E+01	2.57E-01	1.34E-01	5.43E-01	1.20E-02	6.00E+01
Cyanide ion	2.64E+01	7.18E+00	3.92E+01	1.80E+01	6.82E+00	2.63E-02	1.37E-02	5.55E-02	5.20E-03	NA
Iron	NA	NA	NA	NA	NA	NA	NA	NA	1.00E+00	1.00E+04
Lead	7.09E-03	1.93E-03	1.05E-02	1.59E-02	1.11E+01	5.33E-04	2.77E-04	1.12E-03	3.20E-03	1.00E+02
Magnesium	2.33E+02	6.34E+01	3.46E+02	1.59E+02	6.02E+01	1.75E+01	9.12E+00	3.70E+01	1.60E-04	NA
Manganese	2.00E+00	5.45E-01	2.97E+00	1.37E+00	5.17E-01	1.50E-01	7.83E-02	3.18E-01	1.10E+00	1.50E+03
Mercury	1.43E+01	6.92E-03	2.13E+01	3.19E+00	5.74E-01	2.15E-02	1.12E-02	4.04E-03	1.30E-03	3.00E-01
Molybdenum	NA	NA	NA	NA	NA	NA	NA	NA	3.60E-01	2.00E+0[illegible]
Nickel	5.90E+01	1.61E+01	8.77E+01	4.17E+00	1.58E+00	4.44E+00	2.31E+00	9.37E+00	1.60E-01	1.00E+02
Potassium	NA	NA	NA	NA	NA	NA	NA	NA	1.30E-04	NA
Selenium	6.14E-02	1.67E-02	9.13E-02	2.51E-01	9.47E-02	4.62E-03	2.40E-03	9.75E-03	3.50E-02	5.00E+0[illegible]
Silver	NA	NA	NA	NA	NA	NA	NA	NA	2.00E-04	2.00E+0[illegible]
Sodium ion	NA	NA	NA	NA	NA	NA	NA	NA	4.80E-01	NA
Strontium	6.43E+02	1.75E+[illegible]	9.56E+02	4.40E+02	1.66E+02	4.83E+01	2.52E+01	1.02E+02	NA	NA
Thallium	2.44E-02	6.65E-03	3.63E-02	1.67E-02	6.31E-03	1.84E-03	9.56E-04	3.88E-03	6.40E-02	1.00E+0[illegible]
Uranium	1.51E-01	4.12E-02	2.25E-01	2.20E+01	8.30E+00	1.14E-02	5.93E-03	2.40E-02	2.70E-02	NA
Vanadium	2.30E-01	6.26E-02	3.42E-01	1.57E-01	5.95E-02	1.73E-02	9.01E-03	3.65E-02	4.10E-02	5.00E+0[illegible]
Zinc	2.37E+01	6.45E+00	3.52E+01	1.62E+01	6.13E+00	1.78E+00	9.28E-01	3.76E+00	1.10E-01	7.00E+0[illegible]

NA = Benchmark not available.

[1] The source for all terrestrial benchmarks except those for vegetation was (Opresko 1993). For vegetation, the source was (Suter 1993) and the Massachusetts Military Reservation Risk Assessment Handbook, 1992.

[2] The source for aquatic benchmarks was (Suter, et al. 1992).

Estimating realistic exposures for all endpoints on the reservation is impossible because data for numbers of individuals actually exposed to wastes, amount of time spent in waste areas, and actual amounts of contaminants ingested are lacking or incomplete. In some cases, for example, benchmarks were lacking; consequently, hazard indices (HIs) could not be calculated and risks could not be assessed. Specific home ranges and habits of many of the representative species at FEMP are not well known or vary widely, and only a few species with small home ranges (e.g., very small mammals and small birds) may reside within a contaminated area for most of their lives.

For contaminants and receptors that did not pass the average concentration screening (see above discussion), an attempt was made to further define exposure risks by comparing the home range sizes of receptor species with the potential fraction of the home range that is contaminated.

Receptor species at FEMP have home ranges or territories that range from small [e.g., 1 ha (about 2.5 acres) or less for very small animals such as the robin, mouse, and certain aquatic species)] to hundreds of hectares for hawks and foxes. Some small species have home ranges small enough to be contained within individual waste sites. Some other species have such large home ranges that the waste sites would comprise only a part of the area they would occupy, if the waste sites were used at all. To further interpret results of this risk analysis, the following assumptions about the contribution of waste sources to receptor exposure are made.

1. For most of the DOE sites assessed in this PEIS, correction factors based on the ratio of the total contaminated area to the home range of terrestrial receptors were developed and applied to the HIs calculated for the average concentrations screening. This is appropriate where contaminant uptake pathways other than drinking water predominate. For most terrestrial endpoint receptors at FEMP, however, results of the exposure assessments indicate that nearly all of the exposure of a receptor to a particular contaminant results from the drinking water pathway (typically 97% or more), although in a very few instances (e.g., uptake of cyanide ion by deer), ingestion of contaminated soil, insects, and/or vegetation rivaled the drinking water pathway in importance. With the exceptions of Cd, Cu, Pb, Hg, and U, all water-borne contaminants for which concentration data are available appear to be associated with the small clear well and sludge ponds of the waste storage area in the northwest quadrant of the reservation. Many contaminants in these waste facilities occur at extremely high levels. Therefore, where the drinking pathway dominates (except for the five metals identified above), it is assumed that the ratio of the length of shoreline of contaminated waters within an animal's home range to the total shoreline of waters available to that animal is the more appropriate correction factor (table 6-8) to apply to the calculated HIs in tables 6-9 through 6-11) to determine the effective HIs used to characterize risk in (tables 6-12a through 6-12e.). Shoreline was determined by measuring the length of streams and the circumference of ponds (including waste ponds) circumscribed by a circle equal in area to the minimum reported range of a given receptor species, and centered on the contaminated sites.

2. Drinking water concentrations of Cd, Cu, Pb, Hg, and U , on the other hand, are based on the average concentrations for a total of 77 ha (190 acres), of surface waters (all water bodies on the reservation including Paddy's Run as well as a reach of the Great Miami River off-site). The resulting HIs for these metals therefore require no correction (i.e., the correction factor is 1.0) since none of the receptor species under consideration have

TABLE 6-5—*Home ranges*[1] *of and Hazard Index (HI) correction factors (CF)*[2] *for terrestrial receptor species at Fernald Environmental Management Project*

Receptor Species	Home Range[3](ha)		Correction Factor
	< 22ha	>22ha	
White-footed mouse	X (0.2 - 0.6)		1.0
Eastern cottontail rabbit	X (1.0 - 2.8)		1.0
Indian bat	X (1.5 - 4.5)		1.0; 0.56
Red fox		X 260 - 520	1.0; 0.35
White-tailed deer		X (60 - 520)	1.0; 0.55
American robin	X (0.1 - 2.0)		1.0
Red-tailed hawk		X (130 - 420)	1.0; 0.42
Vegetation	X (<0.1)		1.0

[1] Burt and Grossenheider 1976; Chapman *et al.* 1980; Smith 1991; Schoener 1966.
[2] A CF of 1.0 was applied to HIs for each contaminant for each species having home range $\leq$ 1.0 ha. Other CFs based on ratio of circumference of contaminated water bodies to total length (shoreline) of water bodies available within home range, except for cadmium, copper, lead, mercury, and uranium, which require a correction factor of 1.0 because of their extensive distribution throughout reservation surface waters.
[3] Where terrestrial sources of contaminant are most important to exposure, 37 ha should be used as the maximum territory size that can result in a correction factor of 1.0.

TABLE 6-9—*Baseline Hazard Indices for Terrestrial Organisms*[1] *on the Fernald Environmental Management Project*

Hazard Indices Calculated Using Average Contaminant Concentrations									
	Mouse	**Rabbit**	**Deer**	**Cow**	**Robin**	**Ind. Bat**	**RT Hawk**	**Red Fox**	**Vegetation**
Aroclor 1248	1.43E-01	5.30E-01	9.22E-01	1.19E+00	1.54E-01	1.12E-01	5.86E-01	6.98E-01	N/A
Aroclor 1254	1.18E+00	1.38E+00	1.66E+00	2.15E+00	3.84E-02	9.28E-01	4.30E-02	1.32E+00	N/A
Benzo(a)pyrene	7.77E+00	1.02E+01	1.80E+01	2.29E+01	8.12E+00	6.17E+00	1.16E+01	1.38E+01	0.00
Chlordane	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Di-n-butyl phthalate	1.06E-02	1.39E-02	2.46E-02	3.12E-02	2.44E+01	8.42E-03	3.48E+01	1.88E-02	4.43E-06
Aluminum	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	6.58E+02
Antimony	9.92E-06	2.51E-05	3.13E-05	8.83E-05	1.97E-05	9.27E-06	1.21E-06	1.44E-06	4.55E+00
Arsenic	2.42E+01	5.43E-01	5.68E-01	7.26E-01	2.55E+01	1.92E+01	3.63E-01	4.33E-01	2.70E-01
Barium	7.11E+02	9.35E+02	1.65E+03	2.09E+03	7.43E+02	5.65E+02	1.06E+03	1.26E+03	1.05E-01
Beryllium	1.96E+00	2.57E+00	4.54E+00	5.76E+00	2.05E+00	1.55E+00	2.91E+00	3.47E+00	7.20E-02
Cadmium	2.40E+01	3.42E+01	5.85E+01	8.40E+01	2.87E+00	1.97E+01	8.71E+01	3.82E+01	1.53E+00
Chromium	1.68E+00	2.22E+00	3.90E+00	4.97E+00	1.77E+00	1.33E+00	2.50E+00	2.98E+00	1.74E-01
Copper	5.88E+02	4.17E+01	7.33E+01	9.43E+01	1.12E+00	4.67E+02	1.94E+00	5.49E+01	2.28E+00
Cyanide ion	2.32E-01	3.27E-01	4.14E+01	6.22E+01	2.12E-01	1.81E-01	1.47E-01	1.32E+01	N/A
Lead	7.36E+02	9.75E+02	1.71E+03	2.20E+03	2.39E+02	5.82E+02	1.79E-0E-	1.29E+03	1.79E-01
Mercury	2.90E-02	2.15E+01	3.38E+00	4.31E+00	9.31E-02	2.31E-02	2.78E-01	2.90E+01	3.00E-01
Molybdenum	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	2.16E+00
Nickel	3.24E-01	4.26E-01	7.50E-01	9.57E-01	3.29E+00	2.56E-01	4.63E+00	5.71E-01	2.36E-01
Selenium	1.72E+01	2.26E+01	3.99E+01	5.06E+01	3.02E+00	1.36E+01	4.28E+00	3.05E+01	9.00E-02
Silver	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	4.32E+00
Uranium	1.32E+03	1.76E+03	3.01E+03	4.01E+03	6.95E+00	1.02E+03	8.99E+00	2.27E+03	N/A
Vanadium	1.99E+03	2.62E+03	4.63E+03	5.87E+03	2.08E+03	1.56E+03	2.97E+03	3.54E+03	3.15E-01
Zinc	1.10E+00	1.49E+00	2.60E+00	3.44E+00	1.14E+00	8.83E-01	1.54E+00	1.83E+00	5.17E-01
Radiological	3.99E-01	3.99E-01	4.00E-01	4.03E-01	3.99E-01	3.99E-01	1.26E-01	1.26E-01	4.09E-01

NA = Benchmark not available, therefore hazard index could not be calculated.

[1] *Shaded numbers are HIs > 1.0.*

TABLE 6-10—*Baseline Chemical Hazard Indices for Aquatic Organisms[1] on the Fernald Environmental Management Project*

Constituent	Average Surface Water HI	Sediment Water HI
Aluminum	0.00	2.93E+01
Cadmium	2.55E+00	0.00
Copper	8.54E-01	0.00
Lead	2.09E+00	0.00

[1] Shaded numbers are HIs > 1.0.

TABLE 6-11—*Average Internal and External Radiological Doses to Aquatic Organisms (rad/d)[1] on the Fernald Environmental Management Project*

	External Beta and Gamma	Internal Plants	Internal Benthic Macroinvertebrates	Internal Fish	Internal Muskrats
Uranium-234	1.50E-06	8.64E+00	4.87E-04	8.64E-02	1.22E-02
Total dose	1.50E-06	8.64E+00	4.87E-04	8.64E-02	1.22E-02

The benchmark for aquatic organisms is 1 rad/d, therefore the total dose equals the hazard index.

[1] Shaded numbers are HIs > 1.0.

TABLE 6-12A—*Baseline potential risks[1, 2] to the endangered Indiana bat, the only endangered species that may reside, feed, or drink in the immediate vicinity of the waste sites or contaminated waters on the Fernald Environmetnal Management Project.*

Contaminant	Risk
arsenic	S
benzo(a)pyrene	M
barium	S
cadmium	S
copper	S
lead	S
selenium	M
vanadium	S
uranium	S

[1] Potential risks based on assumptions discussed in Section 4.4.3; M = moderate risk, where 1.0 ≤HI < 10; S = severe risk, where HI ≥ 10.
[2] Risks to individuals that are not in the immediate vicinity of the waste sites are negligible. Waste sites and contaminated waters account for less than 17% of the surface area of the Fernald Environmental Management Project.

TABLE 6-12B—*Baseline potential risks[1] to wetlands adjacent to waste sites. Risks to wetlands that are not adjacent to waste ponds are negligible at the Fernald Environmental Management Project*

Contaminant	Benthos[2]	Plants
Aluminum	S	-
Cadmium	M	-
Lead	M	-
Radiological dose	-	M

[1] M = moderate risk, where HI is equal to or greater than 1.0, but less than 10; S = severe risk, where HI is equal to or greater than 10.
[2] Based on EPA Water Quality Criteria (Suter et al. 1992). We assume that benthic invertebrates are exposed to surface water or sediment pore water concentrations, whichever are higher (see Section 6.6.2) while other wetland (aquatic) organisms are exposed to surface water.

TABLE 6-12C—*Baseline potential risks[1] to recreational wildlife that occupy or include waste sites or contaminated waters in their home ranges at the Fernald Environmental Management Project*

Contaminant	Cottontail Rabbit	White-tailed Deer	Fish
Benzo(a)pyrene	S	M	
Aroclor 1254	M		
Barium	S	S	
Beryllium	M	M	
Cadmium	S	S	M
Chromium	M	M	
Copper	S	S	
Lead	S	S	M
Mercury	S	M	
Selenium	S	S	
Uranium	S	S	
Vanadium	S	S	
Zinc	M	M	
Cyanide ion		S	

[1] M = moderate risk, where HI is equal to or greater than 1.0, but less than 10; S = severe risk, where HI is equal to or greater than 10.

TABLE 6-12D—***Baseline potential risks[1] to vegetation (grasses and planted pine). Risks to individuals that do not graze or drink in waste sites are negligible; hence, risks to cattle are negligible in the areas currently used for livestock grazing at the Fernald Environmental Management Project***

Contaminant	Vegetation
Aluminum	S
Antimony	M
Cadmium	M
Copper	M
Molybdenum	M
Silver	M

[1] M = moderate risk, where HI is equal to or greater than 1.0, but less than 10; S = severe risk, where HI is equal to or greater than 10.

TABLE 6-12E—***Baseline potential risks[1] to other important food web (biodiversity) components that occupy waste sites on the Fernald Environmental Management Project***

Contaminant	Mouse	Red Fox	Other Bats	Robin	RT Hawk	Vegetation	Aquatic Benthos
Aroclor 1254	M						
Benzo(a)-pyrene	M	M	M	M	M		
Cyanide ion		M					
di-n-butyl phthalate				S	S		
Aluminum						S	S
Antimony						M	
Arsenic	S		S	S			
Barium	S	S	S	S	S		
Beryllium	M	M		M	M		
Cadmium	S	S	S	M	S	M	
Chromium	M	M		M	M		
Copper	S	S	S	M	M	M	
Lead	S	S	S	S			
Mercury		S					
Molybdenum						M	
Nickel				M	M		
Selenium	S	S	M	M	M		
Silver						M	
Uranium	S	S	S	M	M		
Vanadium	S	S	S	S	S		
Zinc	M			M			

[1] M = moderate risk, where HI is equal to or greater than 1.0, but less than 10; S = severe risk, where HI is equal to or greater than 10.

home ranges that would circumscribe more surface water than 77 ha in the vicinity of the reservation. The correction factors as represented by the ratios calculated for each endpoint receptor are presented in table 6-8.

3. The maximum home range (idealized as a circle) that would circumscribe contaminated site waters is only about 22 ha (55 acres). It is assumed, therefore,that small receptor species with minimum home ranges of about 22 ha or less (table 6-8) could receive as much exposure as our average screening indicates. Thus no correction factor was applied to the HIs for these species.

4. For the very few instances in which other (non-drinking water) contaminant uptake pathways are important, the effective HI was determined as follows. It is assumed that the effective exposure (and hence HI) for a given contaminant for wide ranging receptors species with home ranges greater than the total contaminated *land* area of 37 ha [(92 acres; 9% of the total reservation area of 425 ha (1050 acres)] is proportional to the ratio of the contaminated area to the minimum home range of an individual animal whose range is centered on the contaminated area. As described above for the drinking water pathway, this ratio was then applied as a correction factor to the calculated HIs presented in tables 6-9 through 6-11 to determine the effective HI. The contaminated area actually varies with different contaminant species, but lacking sufficient contaminant-specific distribution data, an area of 37 ha is assumed for each contaminant. Exposure of biota living completely outside the 9% of the reservation that is contaminated is limited to contaminants that have moved from waste sites in dust and by contaminated wildlife and plants. Although some contaminants possibly occur in measurable concentrations outside waste sites, for the most part, source terms or measurement data for them are not available, and it is assumed they are minor compared to the concentrations in the waste sites.

5. Although the endangered Indiana bat has not been observed on the reservation itself, its known proximity [approximately 5 km (3 miles) from the northeast boundary] and the identification of potentially suitable habitat along Paddy's Run prompted its inclusion in this assessment.

6. Most wetlands, particularly the wooded wetlands, are probably not subject to contamination by waste sites. For this assessment, it is assumed that only those small emergent wetlands immediately adjacent to or downgradient of waste areas are subject to exposure to contaminants. All aquatic biota receive the average exposure to contaminants if they occur in these small wetlands. Conversely, it is assumed that biota in other wetlands are not exposed to contaminants.

7. Aquatic receptors (fish, invertebrates, and plants) are assumed to be fully exposed to contaminants measured in aquatic habitat (i.e., Paddy's Run and the Great Miami River) outside the primary waste areas, but not in the waste areas themselves, because reported contaminant concentrations and other water quality and habitat conditions in the very small waste ponds would be unlikely to support most aquatic life.

8. Grazing livestock are not allowed into contaminated sites. Risks to livestock, therefore, would only be

applicable if cattle were allowed to graze in waste areas.

6.5 Contaminant Hazard Assessment

6.5.1 Baseline

The next step in the ecological risk assessment generates HIs that are representative of potential risk and that estimate the level of effects from exposure to contaminants. Baseline hazard indices (HIs) for terrestrial receptors exposed to the maximum source concentrations were greater than the criteria limit of 1 for 18 out of 29 inorganic contaminants and 4 out of 33 organic contaminants. Exposure to the maximum concentrations of radionuclides resulted in HIs of about for all receptors 27. Radiological exposure was dominated by exposure to ^{238}U in soils.

Exposure of terrestrial species to average soil and water concentrations at the site were calculated for those contaminants whose maximum concentrations resulted in HIs >1 (table 6-9). About 48% of the HI values for non-radioactive contaminants were above 1 but below 10, 38% were above 10 but below 1000, and about 19% were still above 1000.

Exposure of aquatic organisms to the maximum concentrations of nonradiological contaminants in surface water resulted in HIs over 1, but less than 10, for Cd, Cu, and Pb. Exposure of benthic macroinvertebrates to the maximum sediment pore-water concentrations (calculated from sediment concentrations) resulted in an HI over 1 (41.8) for aluminum only. Hazard indices resulting from exposure to the average surface water concentrations remained over 1 for cadmium and lead (table 6-10). The HI for benthic macroinvertebrates exposed to the average aluminum pore-water concentration was 29.

Exposure to the maximum concentrations of radionuclides in surface water or sediment pore water (macroinvertebrates only) resulted in HIs (or doses) greater than 1 (about 30) only for aquatic plants exposed to ^{234}U. Exposure to the average concentrations in the same media reduced the HI for aquatic plants to about 9 (table 6-11).

From the initial suite of 80 constituents of concern, the two-stage screening process using maximum and then average contaminant values yielded 22 contaminants producing HI values equal to or greater than 1 (i.e., representing at least an intermediate risk from contaminants) for at least one endpoint receptor, as shown in tables 6-9, 6-10, and 6-11). Of these, 13 contaminants produce HI values of 10 or greater (i.e., severe risk) for one or more endpoint receptors. For nearly all combinations of receptor species and contaminants, ingestion of contaminated water accounted for almost 100% of exposure and consequently almost 100% of the calculated HI values. Hazard indices for inorganics (primarily trace elements) most commonly exceeded values of 1, followed by organic compounds, and lastly radionuclides. Following the assumptions outlined in chapter 6.4, the approximate home ranges or territory sizes of receptors were calculated to estimate the proportion of their range that could potentially encompass contaminated lands or surface waters.

Three of the endpoint receptors included in our analyses (the white-footed mouse, the cottontail rabbit, and the American robin) occupy small enough areas (table 6-8) to potentially live their lives entirely within contaminated areas [e.g., less than 37 ha (92 acres)]. The Indiana bat may have home (foraging) areas less than 2 ha (5 acres), but wooded riparian habitat preferences make it likely that only part of the waste areas near Paddy's Run (the clear well area in particular) would be readily accessible to these bats. All of the small wetlands are also less than 37 ha in extent and are considered here because of their proximity downgradient from the waste areas, not because they are immediately within the known contaminated areas. Vegetation self-evidently occupies small areas.

The remaining selected terrestrial receptor species, i.e., the red fox, the white-tailed deer, and the red-tailed hawk, have home ranges generally larger than the waste areas and therefore require application of a correction factor to their average HIs to produce a more meaningful, effective HI. Aquatic receptors (fish, macroinvertebrates, invertebrates, and plants) are assumed to be fully exposed to contaminants measured in aquatic habitat outside the primary waste areas (i.e., Paddy's Run and the Great Miami River) but not in the waste areas themselves. Based on the assumptions discussed here and in chapter 6.4, appropriate correction factors were applied to HIs in table 6-9 to determine potential severity of risks to endpoints. For receptor species with home ranges or territories less than 37 ha (e.g., the mouse), no correction factor was used. For species with larger home ranges or territories, the correction factors shown in table 6-8 were applied to the average HIs to produce an effective HI for each receptor species–contaminant combination.

Note that some contaminants may be fairly localized. Of the contaminants which these analyses indicate present moderate to severe risks, source terms for benzo(a)pyrene, for example, probably represent only 0.28 ha (0.70 acres), and V, Cr, and Ba probably represent less than 10 ha (23 acres) of contaminated land (see appendix B). The qualifier "probably" is used here because, as explained in appendix B, it cannot be certain that larger areas are not contaminated, even though some contaminants such as benzo(a)pyrene almost certainly occur in high concentrations in only a few very small waste sites such as the clear well and sludge ponds. Uranium contaminates the largest area of both land and water at FEMP, 37 ha (92 acres) and 77 ha (190 acres), respectively.

6.5.1.1 Threatened and Endangered Species

As shown in table 6-12a, no less than nine contaminants pose moderate to severe risks to any Indiana bats that may live or forage near the contaminated sites. All but one contaminant, benzo(a)pyrene, are inorganics. Uptake through ingestion of contaminated water accounts for at least 98% of the exposure and HI for each contaminant except cadmium, for which 87% of the HI for this contaminant is due to water ingestion. Ingestion of contaminated insect prey accounts for nearly all of the remaining exposure for these bats. The HIs for five contaminants (Ba, Pb, Cu, V, and U) are each more than 300. Although by these analyses, individuals of this species utilizing contaminated areas face a severe risk, it must remembered that the HI's incorporate a number of conservative assumptions. A site-specific assessment will be required to determine more realistic exposure levels.

6.5.1.2 Wetlands

Risks to wetlands receptors (e.g., benthic macroinvertebrates and aquatic plants) that might receive contamination from the waste sites are shown in table 6-12b. As discussed earlier, wetlands do not occur within the waste site area, but a few small emergent wetlands [probably no more than 3.5 ha (8.5 acres)] occur along drainage ditches and swales immediately downstream of the waste sites. If these small wetlands are contaminated, then wetland plants would incur a moderate risk (doses greater than 1 rad/d) from radionuclides (nearly all of the dose attributable to ^{234}U). Aquatic plants were the only receptors included in the FEMP assessment for which the radiological HI exceeded 1 (HI = 8.7).

Because many benthic invertebrates are exposed to overlying (surface) waters as well as sediment pore water, the HIs are calculated on the basis of either surface water concentrations or sediment water concentrations, whichever are greater. Thus, these calculations indicate that benthic invertebrates would incur moderate risks from Cd and Pb concentrations and severe risks from Al.

6.5.1.3 Recreational Species

Table 6-12c summarizes risks to recreationally desirable species at FEMP. Baseline average HIs for recreational terrestrial species as represented by the cottontail rabbit and white-tailed deer exceeded unity for 14 different contaminants, including trace metals, cyanide ion, benzo(a)pyrene, and Aroclor 1254 [a polychlorinated biphenyl (PCB)]. Moreover, on the basis of this assessment, nine of the contaminants pose severe risks to cottontail rabbits, whereas each of eight contaminants would put deer at severe risk. Fish in contaminated waters would incur moderate risks from cadmium and lead only.

6.5.1.4 Agriculture

Cattle are not allowed to graze in waste areas; therefore, potential risks to livestock are negligible. Vegetation, in the form of grass and planted pines and spruce, would incur a severe risk from exposure to Al and moderate risks from Sb, Cd, Cu, Mo, and Ag (table 6-12d). Potentially adverse effects, however, would be limited to the relatively small areas (totaling less than 37 ha) (92 acres) within and around the waste sites. Some of these values may well be artifacts caused by the analytical techniques used to measure metal concentrationals in soil. With respect to aluminum, it should be noted that the geometric mean concentration for soils in the eastern United States (33,000 mg/kg) reported by Shacklette and Boerngen (1984) is far greater than the 5850-mg/kg average concentration used in this assessment. It is quite likely that the extremely low benchmark (8.0 mg/kg) used in this assessment represents an experimental artifact

6.5.1.5 Public Lands

There are no parks or public lands on or adjacent to the FEMP reservation. A Girl Scout camp lies about 1 km northeast of the reservation boundary, but it is upgradient from the reservation and is therefore unlikely to receive any contamination beyond negligible quantities in the form of occasionally contaminated droppings and scats from birds and wildlife that may encompass both camp and waste sites within their ranges.

6.5.1.6 Biodiversity

As noted earlier, biodiversity on and around the FEMP reservation has suffered under the heavy impact of human activities at least since the arrival of the first European settlers. The original forests have given way to agriculture (crops and cattle), industry, residential developments, a wide variety of introduced organisms, and, here and there, small to medium-sized woodland areas. What is left, nevertheless, supports desirable ecological communities that could be adversely affected by the availability of harmful contaminants on the reservation as indicated in table 6-12e. The mouse, fox, bat, robin, and hawk all would incur moderate or severe risks from each of several contaminants if they inhabited waste sites. Most of the severe risks to these important elements of ecosystem structure and function arise from exposure to As, Ba, and several heavy metals (i.e., Cd, Cu, Pb, U, and V). Both bird species included in this assessment incur severe risks from di-n-butyl-phthalate as well. Aluminum may pose severe risk to vegetation (see discussion under wetlands above), whereas the heavy metals generally pose moderate risks to vegetation. Aluminum is the only contaminant that produces an HI greater than 1 for aquatic invertebrates, but it is sufficiently high that the risk must be rated severe.

6.5.1.7 Conclusions

On the basis of the assumptions and calculations used in this assessment, certain contaminants at a few locations pose moderate to severe risks to selected receptor species. Table 6-13 shows which individual contaminants pose risks to one or more receptor species in the six endpoints.

With respect to the agricultural endpoint, if the contaminated sites were to be used for grazing cattle or planting trees, then those cattle or trees actually using these sites would also incur severe to moderate risks. Otherwise, no adverse effects on agricultural receptor species would be expected.

Most wetlands on the reservation would not be affected under the no-action alternative; however, a few small wetlands in the immediate vicinity of the waste sites could be affected. These analyses indicate that risks to benthic invertebrates and plants in these few wetlands could be severe and moderate, respectively. Finally, public lands and parks do not occur in or adjacent to the reservation; hence, no adverse effects on this endpoint would be expected.

6.6 Habitat Disturbance Assessment

Agricultural, residential, and industrial development long ago began transforming the natural mesophytic and oak-hickory forests (and the ecological communities they supported) that dominated the region around FEMP before the arrival of Europeans. Thus, from a historical perspective, nearly all of the FEMP site and environs already existed in a considerably altered or ecologically "disturbed" state before FEMP was built. The site and environs nevertheless

TABLE 6-13—*Comparative summary of potential risks[1] to ecological endpoints from baseline and ARAR alternatives on the Fernald Environmental Management Project. Risks are for endpoints which occupy or use waste sites or contaminated waters[2]*

Source of Risk	Endpoints[4] - No-action (Baseline)
Construction[3]	
Aroclor 1254	R, B
Benzo(a)pyrene	E, R, B
Cyanide ion	R, B
Di-n-butyl phthalate	B
Alumirum	W, F, B
Antimony	F, B
Arsenic	E, B
Barium	E, R, B
Beryllium	R, B
Cadmium	E, W, R, F, B
Chromium	R, B
Copper	E, R, F, B
Lead	E, W, R, B
Mercury	R, B
Molybdenum	F, B
Nickel	B
Selenium	E, R, B
Silver	F, B
Uranium	E, R, B
Vanadium	E, R, B
Zinc	R, B
Radiological	W

[1] Only those contaminants are listed which our analyses showed could pose severe or moderate risks to some endpoints.
[2] Risks to endpoints which do not include known contaminated areas within their ranges are assumed to be negligible (see Section 4.4.3).
[3] These are short-term risks. Long-term risks could be reduced with successful restoration of appropriate habitat.
[4] Ecological endpoints: E = threatened, endangered, and candidate species; W = wetlands; R = recreational fish and wildlife; F = agriculture or timber production; P = parks and other public lands; B = biodiversity (only for receptors not included under other endpoints)

support fairly rich, if substantially altered, ecosystems typical of this disturbed state, ecosystems that have perhaps come to represent what the layman would characterize today as "normal" in much of Ohio and Kentucky.

6.6.1 Baseline

Outside the 55-ha (136-acres) central production area, another approximately 35–40 ha (90–100 acres), about 9% of the reservation, is highly disturbed physically and therefore possesses little or no habitat value, primarily due to the presence of waste sites and ancillary facilities. The baseline alternative under consideration here does not, by definition, include additional disturbances by restoration activities beyond the 9% of the reservation already disturbed.

6.7 Cumulative Assessment

6.7.1 On-Site

As many as 22 contaminants present at FEMP have been identified on the basis of this analysis as potential hazards (HIs greater than or equal to 1) to the well-being of certain receptor species of local ecosystems, including an endangered bat, recreationally desirable fish and wildlife, and other elements of biodiversity. Moreover, five of these contaminants (Cd, Cu, Pb, Hg, and U) may adversely affect off-site terrestrial and aquatic receptor species that use contaminated reaches of Paddy's Run and the Great Miami River. Some studies of Paddy's Run have reported higher species richness and diversity above the FEMP than adjacent to the FEMP (Facemire et al. 1990; Bauer et al. 1978). Other confounding factors, however, conceivably are the most important causes of reduced species richness and diversity. These factors include the intermittent nature of the stream adjacent to and downstream of the FEMP; natural differences in substrate and other habitat characteristics; past physical disturbances such as stream straightening and dredging; and other sources of pollutants such as agricultural runoff, a small chemical plant, and a steel plant. Although FEMP releases, runoff, or groundwater recharge may have had adverse effects on aquatic communities of Paddy's Run, none of the studies of Paddy's Run to date are adequate for demonstrating cause and effect.

6.7.2 Off-Site

The Great Miami River has a long history of water quality problems related to municipal sewage and industrial outfalls, especially low dissolved oxygen, thermal discharges, and high levels of ammonia and nitrates. Several urban and industrial areas upstream (e.g., the cities of Dayton and Hamilton-Fairfield) discharge pollutants to the river. The Mound Laboratory near Miamisburg, Ohio may release small amounts of radionuclides to the river. Agricultural practices in the watershed have also contributed to problems related to nutrient enrichment, increased suspended solids, and lowered dissolved oxygen. It is not possible to separate the impact of FEMP -derived contaminants from up stream industrial/urban impacts. It should be noted that the reach from the FEMP outfall to well below the confluence with Paddy's Run was described by the Ohio Environmental Protection Agency (OEPA 1982), on the basis of community abundance and diversity, as supporting one of the healthiest fish communities in the lower 150 km (93 miles) of the river.

CHAPTER 7: OAK RIDGE RESERVATION

The ORR is a 15,000-ha (37,500-acre), relatively undisturbed and protected block of mostly native forest ecosystem. It is located in the Ridge and Valley Physiographic Province of east Tennessee, bounded on the south and west by the impounded Clinch River (Melton Hill and Watts Bar reservoirs) (figure 7-1). The Federal government acquired the ORR property, which was primarily in agricultural use, in 1942 for the wartime Manhattan Project (Fielder et al. 1977). At that time, public access to the ORR was restricted except at the Three developed facilities (the Y-12 Plant, the K-25 Site, and X-10). The upper slopes were mostly forested, but there were some clearings for orchards, pastures, and crops. Tillage crops were primarily restricted to lower slopes and bottomlands (Dale et al. 1990). Most of the forest was cut for timber, though not necessarily cleared.

In the late 1940s and early 1950s, extensive loblolly, shortleaf, and white pine plantations were planted in many of the old field areas (Bradburn 1977). Some of these areas were severely eroded prior to establishment of these plantations. From 1965 to 1986, there was an active timber management program. During that time, much of the area was selectively logged. Natural plant communities or pine plantations currently occupy most of the ORR. Within the ORR, 5000 ha (12,500 acres) are designated as the Oak Ridge Research Park. All of the undeveloped area of the ORR is currently under a wildlife management agreement with the Tennessee Wildlife Resources Agency (TWRA) (Parr and Evans 1992). The agreement was initiated in 1984 to reduce deer/vehicle collisions by permitting deer hunting, thus lowering the deer population.

The terrestrial ecology of the ORR has been described in many documents (e.g., Boyle et al. 1982; Saylor et al. 1990; Cunningham et al. 1993). Plant communities are characteristic of those found in the intermountain regions of Appalachia, from the Allegheny Mountains in southern Pennsylvania to the southern extension of the Cumberland Mountains in northern Alabama. The most common forest types are either mixed oak-hickory, pine-hardwood, or pine. In addition to these major forest types, northern hardwoods are found in coves and ravines that are interspersed along the dissected ridge system and on bluffs along Poplar Creek and the impounded river which border ORR. Cedar barrens are also fairly common in small areas on limestone substrate.

The ORR provides habitat for a large number of animal species, including about 60 reptilian and amphibian species, more than 120 species of terrestrial birds (plus 32 species of waterfowl, wading birds, and shorebirds), and about 40 mammalian species (Boyle et al. 1982, Parr and Evans 1992). Habitats dominated support the greatest number of wildlife species. Few wildlife species are found in pine plantations (Parr and Evans 1992).

Contaminated sites are associated with the three main facilities on the ORR. These facilities are ORNL (Oak Ridge National Laboratory, also known as X-10), ORGDP (Oak Ridge Gaseous Diffusion Plant, also known as the K-25 Site), and the the Y-12 Plant weapons production facility. Source terms were provided separately for these three main facilities. According to the Environmental Restoration PEIS source term data base (Appendix B), about 220 ha (550 acres) of the ORR are contaminated areas subject to remediation. This does not include contaminated streams, for which estimates of area were not provided. It was assumed that waste sites and contaminated areas in the source term data base were a representative sample of the surface areas of all waste sites on ORR.

7.1 Ecological Endpoints and Species Distribution

The dominant ecosystem type on the ORR is eastern deciduous forest, some pine plantations and natural pine stands are located primarily in the valleys. Nine federally listed or candidate species are known to visit, breed, winter, or stay

ORNL-DWG 94M-1051

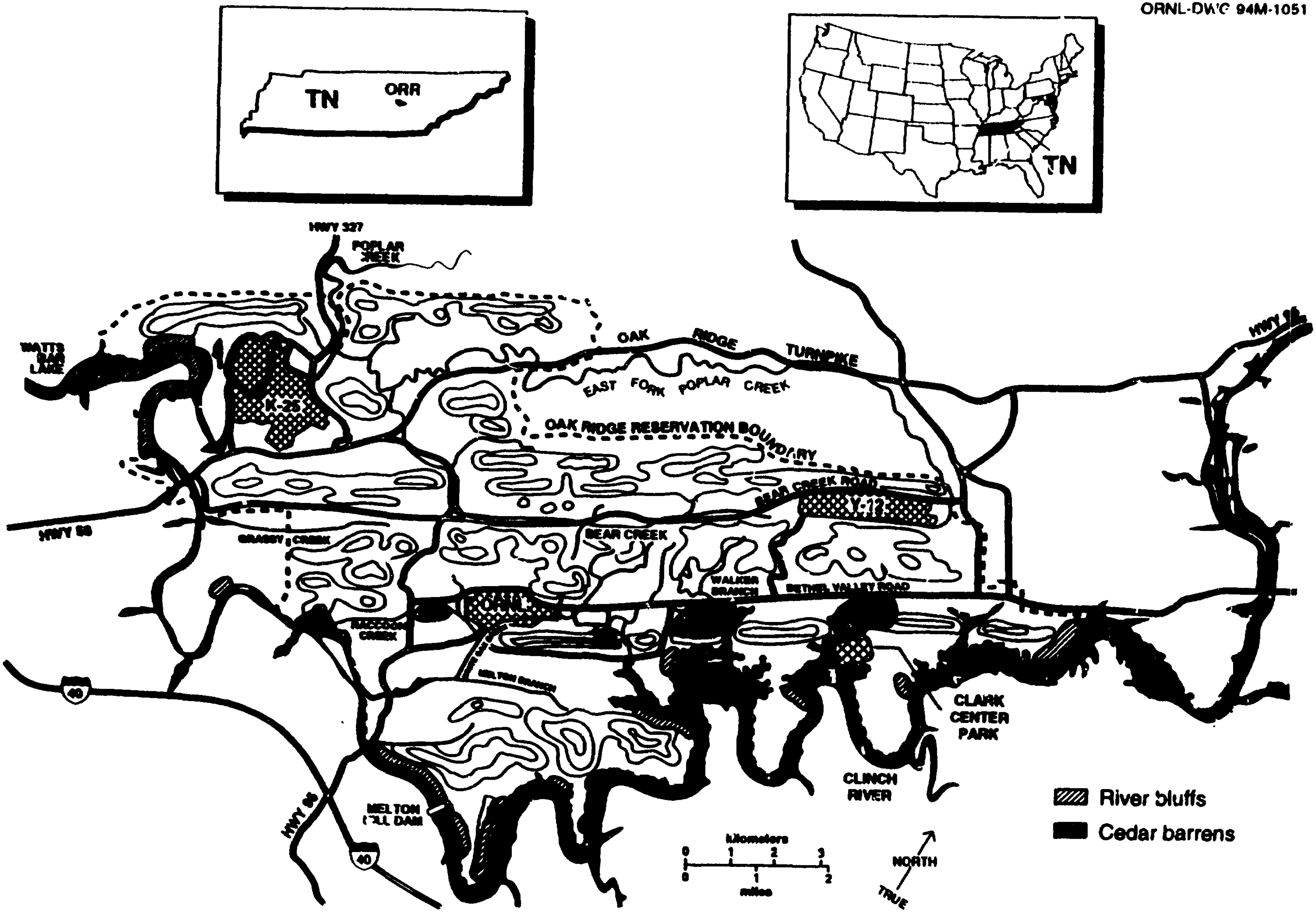


FIGURE 7-1. OAK RIDGE RESERVATION (ORR)

year-round (table 7-1). Natural wetlands are common along the impounded river and along streams. Recreational fish are found in the river and major streams on the reservation. Although only deer hunting is currently allowed, many recreational wildlife species are present. None of the reservation is used for agriculture or commercial forestry, but surrounding lands are used for various forms of agriculture and timber production. Important species groups of concern for conservation of biodiversity on the ORR include bats, raptors, predators, and wintering/migratory wildlife. Sensitive habitats include wetlands providing habitat for state-listed plants and animals, cedar barrens, and river bluffs.

As discussed in Section 4.1, determining risks to endpoints requires (1) selecting receptor species and (2) defining distribution and composition of endpoints. Although ORR is not ecologically homogeneous, it is more or less uniformly heterogeneous so that, for purposes of the analyses, most endpoints are ubiquitous (table 7-2). Exceptions are wetlands and associated species found along the impounded river, recreational fish found in the impounded river and large streams, cedar barrens, and river bluffs, which are discontinuous; and public lands, which are discrete. Locations of endpoints were determined from existing maps and publications, supplemented by personal communications with ecologists at the ORR.

Endpoints can be represented by many different receptors. The following sections describe endpoints on the ORR and receptors selected for the analyses.

7.1.1 Threatened and Endangered Species

Numerous species of plants and animals of special concern have ranges that include the Oak Ridge area, and several occur on the ORR (Kroodsma 1987a; Kroodsma 1992; Cunningham et al. 1993). These species are found in many different habitats throughout the ORR. All federally listed or candidate species were evaluated; state-listed species or species of special concern were beyond the scope of this assessment and were included in discussions of sensitive habitats, wetlands, and biodiversity as only appropriate.

7.1.1.1 Receptors

Nine federally listed or candidate species of plants and animals are known to occur on the ORR (table 7-1). The only listed species known to occur on the ORR, the endangered bald eagle, is an occasional visitor, rarely seen. Although never proven to be present, the endangered eastern cougar has been repeatedly reported on the ORR (Kroodsma 1987a; Parr and Evans 1992). The ORR is also within the range of the endangered Indiana bat, and suitable habitat for this species is present, although the animal is not currently known to be present. Because the Indiana bat is the only listed species that is likely to reside on the ORR, it was the only listed species chosen as a receptor in the analyses.

The candidate Bewick's wren and Bachman's sparrow were represented by a generic songbird receptor (e.g., robin). Because of a lack of benchmark data, vegetation in general serves as a receptor representing the three candidate plant species. Similarly, a generic aquatic receptor represents the aquatic hellbender and paddlefish. The candidate green salamander was not represented by a receptor in the analyses because there were no benchmark data, and this cliff dwelling species was assumed to be unaffected by contaminants.

7.1.1.2 Distribution

Hardwood forest corridors overhanging Poplar Creek and East Fork Poplar Creek are suitable foraging habitat for the endangered Indiana bat (figure 7-1). This species preys on insects as it flies under the forest canopy above streams or rivers.

TABLE 7-1—*Rare species on the Oak Ridge Reservation*

Species	Common Name	Status[1]
	PLANTS	
Aureolaria patula	Spreading false foxglove	C1
Cimicifuga rubifolia	Appalachian bugbane	C2
Delphinium exaltatum	Tall larkspur	C2
	BIRDS	
Haliaeetus leucocephalus	Bald eagle	E
Thryomanes bewickii	Bewick's wren	C2
Aimophila aestivalis	Bachman's sparrow	C2
	REPTILES AND AMPHIBIANS	
Cryptobranchus alleganiensis	Hellbender	C2
Aneides aeneus	Green salamander	C2
	FISH	
Polyodon spathula	Paddlefish	C2

[1] Endangered and threatened wildlife and plants. 50 CFR 17.11 & 17.12, July 15, 1991; Endangered and threatened wildlife and plants: animal candidate review. Fed Reg 50 CFR part 17, Nov. 21, 1991; Endangered and threatened wildlife and plants: review of plant taxa. Fed Reg 50 CFR part 17, Feb. 21, 1990. E=endangered, T=threatened, C1, C2=under review.
Source: Cunningham et al. 1993, Kroodsma 1987a, Kroodsma 1992, Parr and Evans 1992)

TABLE 7-2—*Distribution of Endpoints on the Oak Ridge Reservation*

Ubiquitous	Discontinuous	Discrete
Resident, breeding, and wintering **federal candidate species**[1] **Wetlands** along streams **Recreational wildlife** Important components of **biodiversity** not included in the above (bats, food sources for other species, interior deciduous forest communities)	**Wetlands** and riparian vegetation along the impounded river **Recreational fish** in major streams and the impounded river Sensitive ecosystems important to **biodiversity** and **federally listed and candidate species**[2] (river bluffs, cedar barrens, and Indiana bat foraging habitat)	**Public lands** within the reservation

[1] Birds
[2] Indiana bat and plants

Candidate species (table 7-1) are found on river bluffs and slopes, in cedar barrens, on or near wetlands, in forests, and in old fields(Kroodsma 1987a; Cunningham et al. 1993; Parr and Evans 1992). Species of concern are likely to have patchy distribution rather than uniform distribution over the entire reservation. The hellbender and paddlefish are known only from the impounded river, and the green salamander is known only from one cliff near the river. Appalachian bugbane and spreading false foxglove are known only from bluffs and slopes on the river or major embayments. The tall larkspur is found only in cedar barrens, primarily along Bethel Valley Road (figure 7-1). These species are considered to have discontinuous distribution. The candidate birds could be found in suitable habitat throughout the ORR and are considered ubiquitous.

7.1.2 Wetlands

7.1.2.1 Receptors.

Benthic macroinvertebrates, fish, muskrats, and aquatic plants are representative wetland species for which some toxicity benchmark data are available. Although these biota do not include all wetland species on the reservation, they were selected as receptors in the risk analysis because they cover the range of wetland ecosystem components that could be present. Therefore risks were calculated to these receptors in all wetlands.

7.1.2.2 Distribution.

Wetlands on the ORR include emergent communities in shallow embayments on the impounded river, emergent and aquatic communities in ponds, forested wetlands on low ground along major streams, and wet meadows and marshes associated with streams and seeps (Cunningham and Pounds 1991). Small headwater wetlands, not shown on National Wetland Inventory (NWI) maps, are found throughout the ORR bordering minor stream channels that dissect the hilly terrain. These headwater wetlands are often less than 6 m (20 ft) wide but are often found in and near waste sites. Some provide habitat for sensitive species (e.g., state-listed orchids) (Cunningham et al. 1993).

7.1.3 Recreational Fish and Wildlife

7.1.3.1 Receptors.

Fish and wildlife suitable for recreational use are abundant on the ORR (Boyle et al. 1982; Parr and Evans 1992). Fish suitable for recreational use include gizzard shad; large-mouth, white, striped, and yellow bass; several species of sunfish; sauger; and several species of catfish (Boyle et al. 1982; Parr and Evans 1992). Determining contaminant risks to aquatic species, including recreational fish, does not require the use of specific receptor species. Risks were determined to nonbenthic aquatic biota in general to represent recreational fish in the impounded river and Poplar Creek.

Recreational wildlife include white-tailed deer, which are hunted annually, and wild turkey, which are trapped for release off-site. Other recreational wildlife include coyote, beaver, foxes, bobcat, raccoon, cottontail rabbit, groundhog, opossum, eastern gray squirrel, weasel, mink, woodcock, bobwhite quail, ruffed grouse, mourning and rock dove, and waterfowl. The white-tailed deer, cottontail rabbit, Canada goose, and coyote were selected as common species representative of recreational wildlife which are also important components of the food web on the reservation.

7.1.3.2 Distribution.

Although fish large and abundant enough to be used for recreational purposes are mainly present in the impounded river and its embayments, Poplar Creek, and East Fork Poplar Creek, some recreational species are found in all streams on the ORR. Most recreational wildlife species are year-round residents throughout the ORR. Canada geese, which are also year-round residents on the ORR, are abundant near facilities, especially in grassy areas near ponds.

7.1.4 Agricultural Production

Portions of ORR have been used experimentally for swine, poultry, beef, and dairy cattle; for pasture; for hay production; and for pine and hardwood timber production (Bradburn and Rosenbalm 1984). Timber sales are limited to salvage sales in areas being cleared for other purposes, and agricultural activity is limited to occasional hay harvest in small areas in various locations.

7.1.4.1 *Receptors.*

Generic vegetation was the receptor chosen to represent hay, the agricultural endpoint, and trees, the forestry endpoint in the analyses.

7.1.4.2 *Distribution.*

Most of the ORR is forested, except for facilities, roads and rights-of-way, cedar barrens, some wetlands, very young pine plantations, and fields previously used as pasture, primarily on the eastern end of the ORR.

7.1.5 Parks and Other Public Lands

7.1.5.1 *Receptors.*

Risks to this endpoint were determined by estimating risks to food web components at reservation boundaries adjacent to public access areas. Aquatic receptors are generally the most important ecological components of interest in these public areas (e.g., fishing access), but all food web components were considered.

7.1.5.2 *Distribution.*

Although no parks or public lands are adjacent to the ORR, several public access and recreational areas are located along the impounded river bordering the ORR. Clark Center Park, an employee recreational area located on the ORR on the impounded river upstream from most potential sources of contaminants from the ORR, is also open to the public.

There are several state natural areas on the ORR registered with the state to provide protection to habitat of rare species (Pounds et al. 1993), but these areas are not open to the public and are not considered part of this endpoint.

Because the source term data base does not include source terms for the reservoirs, for purposes of discussion, all public access areas along the impounded rivers, including Clark Center Park, will be considered comparable.

7.1.6 Biodiversity, Including Sensitive Habitats Other Than Wetlands

7.1.6.1 *Receptors.*

The food web developed for the risk assessment was assumed to adequately represent critical components of biodiversity in the mixed forest ecosystems on the ORR. The endangered Indiana bat, whose habitat is restricted to forested large streams, is otherwise similar ecologically to most bats found on the reservation and was chosen as a conservative representative of bat species. Raptors are represented in the analyses by the state endangered Cooper's hawk, and osprey and migratory waterfowl are represented by the resident Canada goose. The robin, which is common across the site was chosen as a representative songbird. Other important food web components (figure 7-2) include major food organisms of receptors chosen to represent other endpoints (i.e., small mammals eaten by coyote, and insects eaten by small mammals, birds, and bats) and other endpoints discussed in the preceding sections. Although very important to ecosystem function and as food for other species, invertebrates were not included in the analyses because of benchmark data were lacking for them. Benchmark data were generally not available for amphibians, another important species group at the site.

7.1.6.2 *Distribution.*

ORR is a large block of relatively natural mixed hardwood and pine forest surrounded by a greatly fragmented urban, suburban, woodlot, and farm landscape. The existence of ORR as a large block of relatively undisturbed forest habitat is a major contribution to its value to biodiversity. In this heterogeneous mixture of upland hardwoods, coves, pine stands, streams, impounded river, and wetlands, amphibians are widespread and diverse (Parr and Evans 1992) as are breeding populations of neotropical migratory warblers (Kroodsma 1987b; Anderson and Shugart 1974), predators, waterfowl, and raptors (Parr and Evans 1992). The ORR is also used as a feeding and resting area by migrating warblers

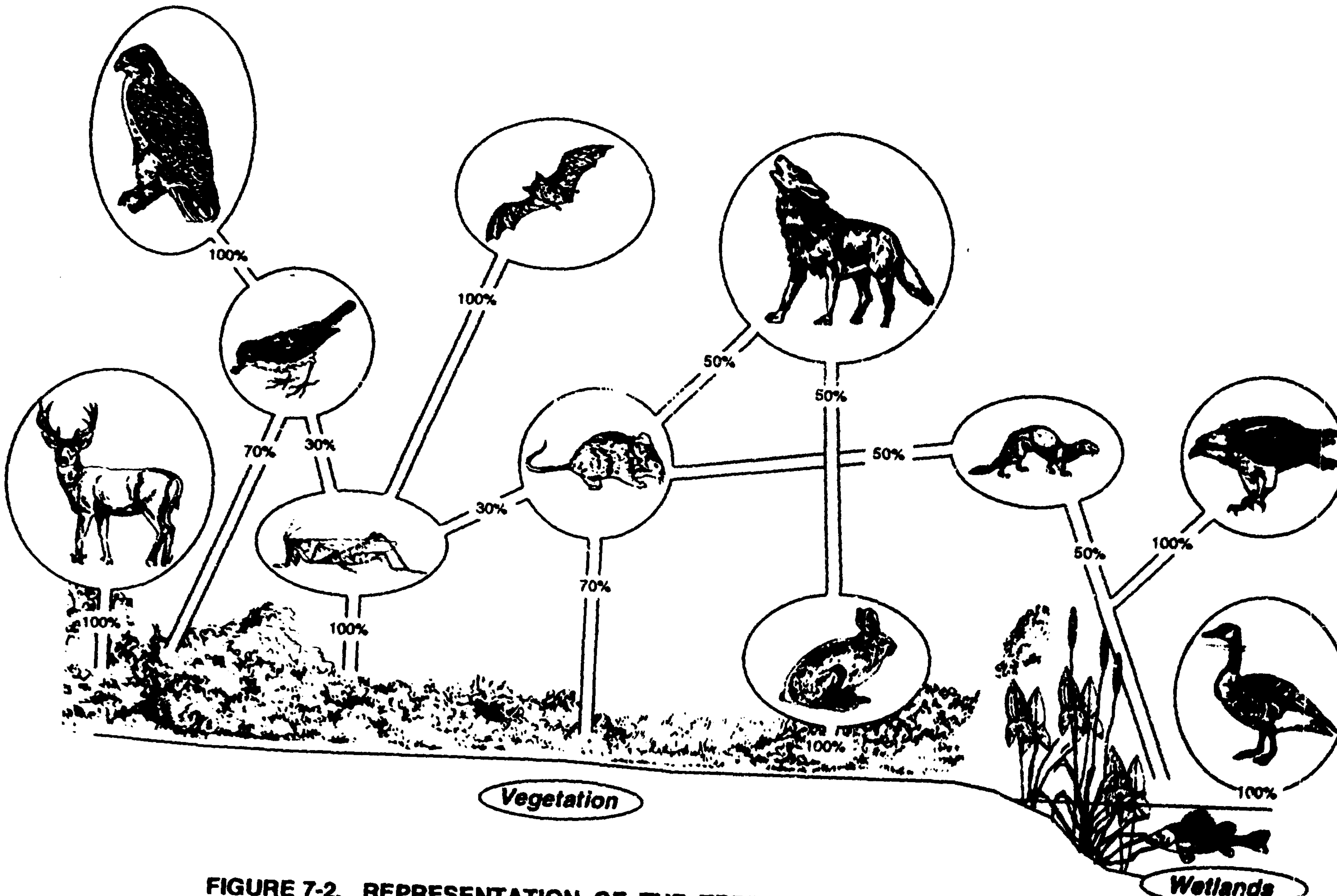


FIGURE 7-2. REPRESENTATION OF THE TERRESTRIAL FOOD WEB OF THE OAK RIDGE RESERVATION

in the spring and fall and is an important source of wildlife for surrounding areas (e.g., white-tailed deer and turkey).

Within the forests of the ORR, sensitive habitats include river bluffs, found in several locations along the impounded river, and cedar barrens, found on shallow limestone soils, mostly in Bethel Valley (figure 7-1). Both of these habitats support federal candidate plant species, and state-protected plant and animal species are found throughout the reservation (Cunningham et al. 1993). Abundant relatively pristine reaches of streams on the ORR are also an important component of biodiversity and contrast with streams in the surrounding area, which are affected by agriculture and urbanization. Although chemical and radiological contaminants are present in some streams, sediment resulting from human activity, which is a great threat to biodiversityin aquatic environments, does not affect most streams on the ORR. Some of these streams are habitat for sensitive species [e.g., the state-listed red-bellied dace).

Because they are found only in certain areas of the ORR, cedar barrens and river bluffs are considered to be discontinuous, and endpoints in these areas would be at risk from contaminants only if located in waste sites or known areas of contamination. Because streams are abundant and found throughout the ORR, they and their associated receptors (e.g., aquatic organisms, mink) were assumed to be uniformly distributed and ubiquitous. Terrestrial receptors (e.g., mouse, rabbit, coyote, bats other than the Indiana bat, and other species not explicitly included in the analyses) are ubiquitous.

Two nonnative plant species dominate certain areas of the ORR. Several hundred acres, primarily along roads in the valleys, have been planted in nonnative loblolly pine (*Pinus taeda*), which is very poor habitat for most native species of plants and animals. Many disturbed areas (e.g., roadsides and rights-of-way) have been planted in fescue (*Festuca elatior*), a nonnative perennial grass, for erosion control. This species is a vigorous cool season grass, which can monopolize terrestrial sites, crowding out native species. Other nonnative plant species are aggressive invaders: kudzu smothers native vegetation in a few areas where it was originally planted for erosion control, Japanese honeysuckle (*Lonicera japonica*) is invasive throughout the ORR, Japanese grass (*Microstegium vimineum*) often blankets the ground in moist woods and headwater wetlands, and water milfoil (*Myriophyllum* spp.) poses problems in reservoir waters. Only abundance of the planted species (fescue and loblolly pine) would be assumed to be related to restoration activities, and these species were assumed to be most abundant in and adjacent to disturbed sites where these agressively competitive species could crowd out natives.

7.2 Constituents of Potential Concern

The constituents of potential and concern on the ORR include radionuclides inorganic and organic contaminants. The primary radionuclides, according to relative average concentrations, are ^{106}Ru, ^{90}Sr, ^{90}Y, ^{99}Tc, ^{137}Cs, ^{244}Cm, ^{241}Am, ^{141}Ce, ^{234m}Pa, ^{238}Pu, ^{228,230,234}Th, and ^{237}Np; the primary inorganics are AL, AS, BA, B, Cd, Co, Cu, Cr, Fe, Mg, Mn, Ni, Si, Pb, Hg, Zn, and V. The primary organic contaminants are (PCBs), flouranthene, phenanthrene, and phenol.

Maximum and average concentrations of chemical and radiological constituents in soil, surface water, and sediment were determined from the source terms provided by PNL (tables 7-3, 7-4, and 7-5,). Determination of these average and maximum concentrations required that certain assumptions be made with regard to data interpretation and compensation for data gaps. Appendix A describes the methodology used to develop the source terms for input into the exposure and risk assessment.

7.3 Exposure Assessment

Where available for the ORR, the maximum concentrations of each contaminant in each medium (i.e soil, water, and sediment) were used to identify the worst case potential contaminants. Contaminants that did not pose a risk to any of the receptor species from exposure to the maximum values were not considered further. If exposure to the maximum concentrations of contaminants posed a risk to organisms, then the average concentrations of those contaminants

TABLE 7-3A—*Maximum and Average Y12 Soil Concentrations*

Constituent	Maximum Concentration	Constituent	Average Concentration
Aroclor 1248	2.56E+02	Aroclor 1248	5.24E+00
Benzene	3.80e-02	Methylene chloride	1.64E+00
Trans-1,2-dichloroethylene	2.70E+00	Phenol	2.90E+01
2,4-dimethylphenol	2.40E+00	Toluene	1.60E+00
Fluoranthene	1.40E+02	Aluminum	1.68E+04
Freon 113	7.74E+00	Antimony	1.35E+01
Methylene chloride	1.64E+00	Arsenic	9.09E+00
Phenanthrene	1.30E+01	Barium	1.32E+02
Phenol	2.90E+01	Beryllium	1.01E+00
Tetrachloroethene	9.17E+00	Cadmium	9.69E+01
Toluene	1.60E+00	Chromium	2.43E+01
1,1,1,-trichloroethane	4.27e-02	Cobalt	1.68E+01
Xylene	5.37e-01	Copper	2.00E+00
Aluminum	8.62+04	Cyanide	1.60e-01
Antimony	1.35+01	Iron	1.65+04
Arsenic	7.30E+01	Lead	3.01E+01
Barium	6.84E+02	Lithium	5.16E+01
Berllium	2.90E+02	Manganese	9.08E+02
Boron	1.89E+02	Mercury	3.43E+02
Cadmium	6.95E+03	Molybdenum	1.12E+00
Calcium	2.04E+05	Nickle	2.17E+01
Chromium	8.80E+01	Potassium	3.16E+03
Cobalt	2.50E+01	Selenium	1.68E+01
Copper	2.40E+01	Silver	3.05E+01
Cyanide ion	1.60e-01	Sodium ion	8.09E+01
Gallium	2.13E+01	Thallium	7.55E+01
Hafnium	8.15E+00	Vanadium	2.39E+01
Iron	6.43E+04	Zinc	4.11E+01
Lanthanum	3.00E+00	Zirconium	4.25E+00
Lead	5.50E+02	Cerium-141	1.97E+15
Lithium	3.70E+01	Curium-244	1.530E+12
Magnesium	7.93E+03	Stontium-90	9.17e-01
Manganese	9.08E+02	Yttrium-90	6.53E+15
Mercury	3.73E+02		
Molybdenum	6.00E+00		
Nickle	3.05E+02		
Niobium	2.00E+01		
Nitrate	2.00E+01		
Phosphorus	2.18E+03		
Potassium	3.87E+04		
Scandium	1.26E+01		
Selenium	1.71E+01		
Silver	3.05E+01		
Sodium ion	3.84E+02		
Thallium	7.55E+01		
Titanium	2.12E+03		

Table 7-3a (con't)

Constituent	Maximum Concentration	Constituent	Average Concentration
Vanadium	2.12E+03		
Zinc	7.60E+01		
Zirconium	5.70E+01		
Cerium-141	1.97E+15		
Cesium-137	3.36E+02		
Curium-244	6.04E+12		
Potassium-40	1.12E+04		
Strontium-90	8.21E+12		
Thorium-232	2.18E+03		
Uranium-235	2.25E+03		
Uranium-238	9.09E+04		
Yttrium-90	6.53E+15		

Note: Measurements for chemical constituents given in milligrams per kilogram, dry weight, measurements for radionuclides given in picocuries per kilogram, dry weight.

TABLE 7-3B—*Maximum and Average K-25 Site Soil Concentrations*

Constituent	Maximum Concentration[a]	Constituent	Average Concentration
Acenapthylene	2.00E+00	Benzo(a)pyrene	1.15E+00
Anthracene	6.70E+00	BEHP	1.24E+00
Aroclor 1016	1.00E–01	Di-n-butyl phthalate	1.32E+00
Aroclor 1232	1.00E–01	Aluminum	1.90E+04
Aroclor 1242	1.00E–01	Antimony	4.65E+01
Aroclor 1248	1.00E–01	Arsenic	1.08E+01
Aroclor 1254	6.70E+00	Barium	1.92E+02
Aroclor 1260	2.80E–01	Beryllium	6.41E–01
Benzo(a)anthracene	2.50E+00	Boron	2.01E+00
Benzo(a)pyrene	4.70E+00	Cadmium	1.75E+00
Benzo(b)fluoranthene	4.20E+00	Chromium	7.94E+01
Benzo(g,h,i)perylene	3.50E+00	Cobalt	9.72E+00
Benzo(k)fluoranthene	4.50E+00	Copper	1.07E+02
Benzoic acid	9.60E+00	Iron	4.91E+04
BEHP	3.80E+00	Lead	3.84E+01
Chloride IC	1.00E+03	Lithium	2.04E+01
Chloroform	8.00E+00	Magnesium	2.10E+03
Chrysene	2.70E+00	Manganese	5.63E+02
Dibenzo(a,h)anthracene	1.90E+00	Mercury	1.20E+00
3,3-dichlorobenzidine	4.00E+00	Molybdenum	2.22E+00
Diethyl phthalate	1.30E+01	Nickel	3.13E+01
Dimethyl phthalate	2.00E+00	Potassium	1.57E+03
Di-n-butyl phthalate	5.30E+00	Selenium	6.95E+00
Di-n-octylphthalate	2.00E+00	Silver	1.63E+00
2,4-dinitrophenol	9.60E+00	Vanadium	6.44E+01
Fluoranthene	4.00E+00	Zinc	1.06E+02
Fluoride	3.96E+02	Zirconium	9.59E+00
indeno(1,2,3-cd)pyrene	3.50E+00	Americium-241	1.96E+09
2-methylnapthalene	2.00E+00	Cesium-137	1.54E+10
Napthylene	2.00E+00	Plutonium-238	5.33E+09
2-nitroaniline	9.60E+00	Protactinium-234M	1.900E+19
3-nitroaniline	9.60E+00	Strontium-90	1.10E+12
4-nitroaniline	9.60E+00	Technecium-99	1.20E+05
4-nitrophenol	9.60E+00	Thorium-228	1.79E+12
n-nitrosodium-n-propylamine	1.20E+00	Thorium-230	1.46E+07
Pentachlorophenol	9.60E+00	Thorium-234	1.710E+14
Phenanthrene	2.10E+00		
Pyrene	4.60E+00		
Sulphate	5.43E+03		
2,4,5-trichlorophenol	9.60E+00		
Aluminum	2.40E+04		
Antimony	5.00E+01		
Arsenic	1.77E+02		
Barium	7.20E+02		
Beryllium	1.00E+02		

Table 7-3b (con't)

Constituent	Maximum Concentration[a]	Constituent	Average Concentration
Boron	8.90E+00		
Cadmium	2.90E+01		
Calcium	3.10E+05		
Chromium	3.70E+02		
Cobalt	5.90E+01		
Copper	3.00E+03		
Iron	1.24E+05		
Lead	4.20E+02		
Lithium	2.50E+01		
Magnesium	2.70E+04		
Manganese	2.70E+04		
Mercury	2.90E+01		
Molybdenum	1.00E+01		
Nickel	1.90E+03		
Niobium	3.60E+00		
Nitrate	8.56E+01		
Phosphorus	3.10E+02		
Potassium	5.70E+03		
Selenium	1.45E+02		
Silicon	1.10E+03		
Silver	6.75E+02		
Sodium	1.30E+02		
Thallium	1.00E+00		
Titanium	1.00E+02		
Vanadium	3.25E+02		
Zinc	1.31E+03		
Zirconium	1.10E+01		
Americium-241	2.29E+09		
Cesium-137	1.37E+11		
Neptunium-237	1.04E+06		
Plutonium-238	2.59E+10		
Plutonium-239	4.86E+04		
Protactinium-234M	4.83E+19		
Strontium-90	2.04E+13		
Technecium-99	3.79E+08		
Thorium-228	6.65E+12		
Thorium-230	6.54E+07		
Thorium-232	2.19E+04		
Thorium-234	4.710E+14		
Uranium-235	6.21E+04		
Uranium-238	4.32E+05		

[a]Chemical constituents measured in milligrams per kilogram; radionuclides in picocuries per kilogram.
NA = No measured soil concentration available.

TABLE 7-3C—*Maximum and Average X10 Soil Concentrations*

Constituent	Maximum Concentration[a]	Constituent	Average Concentration[a]
Aroclor 1248	1.31E–01	Aluminum	NA
Aluminum	5.88E+04	Barium	5.24E+00
Barium	2.62E+02	Lead	1.64E+00
Cadmium	1.13E+01	Lithium	2.90E+01
Calcium	4.04E+04	Manganese	1.60E+00
Chromium	2.72E+02	Nickel	1.68E+04
Hafnium	6.33E+01	Potassium	1.35E+01
Lithium	5.88E+01	Selenium	9.09E+00
Magnesium	5.21E+03	Silver	1.32E+02
Manganese	3.41E+02	Sodium ion	1.01E+00
Mercury	3.20E+02	Zinc	9.69E+01
Nickel	2.83E+02	Zirconium	2.43E+01
Phosphorus	2.23E+02	Cerium-141	2.22E+08
Potassium	1.72E+04	Curium-244	2.30E+06
Sodium ion	2.60E+03	Strontium-90	1.35E+09
Titanium	3.11E+03	Yttrium-90	7.69E+07
Vanadium	6.07E+01		
Zinc	6.00E+01		
Zirconium	9.15E+01		
Americium-241	4.47E+05		
Carbon-14	1.39E+05		
Cerium-141	3.47E+06		
Cesium-134	8.36E+04		
Cesium-137	3.73E+11		
Chromium-51	3.83E+02		
Cobalt-60	2.43E+09		
Curium-244	4.47E+05		
Europium-152	1.39E+01		
Europium-154	4.47E+05		
Europium-155	1.39E+01		
IodinE–131	3.79E+03		
Neptunium-237	4.02E+03		
Plutonium-238	4.47E+05		
Plutonium-239	4.47E+05		
Radium-226	1.70E+03		
Ruthenium-106	6.31E+09		

Table 7-3c (con't)

Constituent	Maximum Concentration[a]	Constituent	Average Concentration[a]
Strontium-90	7.76E+09		
Technecium-95	8.45E+03		
Technecium-99	2.01E+03		
Thorium-228	7.90E+03		
Thorium-232	1.50E+03		
Uranium-234	1.13E+00		
Uranium-235	1.77E-01		
Uranium-238	1.20E+03		

[a]Chemical constituents measured in milligrams per kilogram; radionuclides in picocuries per kilogram.
NA = No measured soil concentration available.

TABLE 7-4A—*Maximum and Average Y12 Water Concentrations*

Constituent	Maximum Conc.[a]	Constituent	Average Conc.[a]
Aroclor 1016	2.50E–03	Aroclor 1016	2.50E–03
Aroclor 1232	2.50E–03	Aroclor 1242	2.50E–03
Aroclor 1242	2.50E–03	Aroclor 1248	2.50E–03
Aroclor 1248	2.50E–03	Aroclor 1254	2.50E–03
Aroclor 1254	2.50E–03	Aroclor 1260	2.50E–03
Aroclor 1260	2.50E–03	Benzene hexachloride (gamma)	2.50E–04
Benzene	1.20E–02	4,4'-DDE	2.50E–04
Benzene hexachloride (gamma)	2.50E–04	4,4'-DDT	2.50E–04
Carbon tetrachloride	1.10E–02	Methylene chloride	4.10E–03
Chloroform	2.50E–02	Phenol	3.00E–02
Chloromethane	5.00E–03	Tetrachloroethene	4.81E–03
2,4-D	2.50E–03	Toluene	1.10E–03
4,4'-DDD	2.50E–04	Vinyl chloride	3.16E–03
4,4'-DDE	2.50E–04	Aluminum	2.69E–02
4,4'-DDT	2.50E–04	Arsenic	2.10E–03
1,1-dichloroethane	5.00E–02	Barium	1.30E–03
1,2-dichloroethane	1.00E–02	Copper	8.90E–03
1,1-dichloroethene	2.50E–02	Iron	1.36E–03
Trans-1,2-dichloroethylene	8.31E–01	Lead	8.00E–04
Dieldrin	2.00E–04	Magnesium	1.47E+01
Di-n-octylphthalate	2.70E–02	Manganese	1.09E+00
Endosulfan	2.50E–04	Potassium	4.94E–03
Endosulfan II	2.50E–04	Sodium ion	3.16E+00
Endrin	2.50E–04	Zinc	1.53E–02
Endrin ketone	2.50E–04		
Methoxychlor	2.50E–04		
Methylene chloride	6.50E–02		
Phenol	3.00E–02		
2,4,5-T	5.00E–04		
2,4,5-TP (Silvex)	5.00E–04		
Tetrachloroethene	1.02E–01		
Toluene	6.30E–02		
Toxaphene	5.00E–04		
1,1,1-trichloroethane	6.80E–02		
1,1,2-trichloroethane	5.00E–03		
Trichloroethene	4.43E–03		
Vinyl chloride	9.20E–02		
Aluminum	2.69E–02		
Arsenic	2.10E–03		
Barium	1.30E–03		
Calcium	9.36E–02		
Copper	8.90E–03		
Iron	5.80E–03		
Lead	8.00E–04		
Magnesium	1.47E+01		

Table 7-4a (con't)

Constituent	Maximum Conc.[a]	Constituent	Average Conc.[a]
Manganese	1.09E+00		
Niobium	9.50E-03		
Nitrate	1.00E+00		
Potassium	2.00E+00		
Sodium ion	3.16E+00		
Zinc	1.53E-02		
Americium-241	8.80E-02		
Neptunium-237	6.41E-01		
Radium-226	5.68E-01		
Thorium-230	3.90E-01		
Uranium-234	1.11E+02		
Uranium-235	1.65E+01		
Uranium-238	2.35E+02		

[a]Chemical constituents measured in milligrams per kilogram; radionuclides in picocuries per kilogram.
NA = No measured concentration available.

TABLE 7-4B—*Maximum and Average X10 Water Concentrations*

Measurements in milligrams per liter (for chemical constituents) or picocuries per liter (for radionuclides)

Constituent	Maximum Concentration	Constituent	Average Concentration
Benzene	6.80E–03	Benzene hexachloride (gamma)	2.50E–03
Benzene hexachloride (gamma)	2.00E–03	Aluminum	2.50E–03
Chloroform	4.70E–02	Barium	2.50E–03
2,4-D	1.00E–02	Beryllium	2.50E–03
Dichlorobromomethane	5.00E–03	Boron	2.50E–03
1,2-dichloroethane	3.00E–03	Chromium	2.50E–04
trans-1,2-dichloroethylene	2.10E–03	Copper	2.50E–04
Endrin	2.00E–03	Iron	2.50E–04
Methoxychlor	8.00E–03	Lead	4.10E–03
Methylene chloride	6.40E–03	Lithium	3.00E–02
2,4,5-TP (Silvex)	1.00E–02	Magnesium	4.81E–03
Toxaphene	5.00E–03	Manganese	1.10E–03
Trichloroethene	1.90E–03	Mercury	3.16E–03
Aluminum	4.80E+00	Nickel	2.69E–02
Antimony	7.40E–02	Selenium	2.10E–03
Arsenic	1.00E–01	Silver	1.30E–03
Barium	1.30E–01	Cerium-141	3.00E+03
Beryllium	1.00E–02	Curium-244	5.10E+03
Boron	8.00E–02	Yttrium-90	2.60E–02
Cadmium	2.00E–02		
Calcium	3.10E+01		
Chromium	5.00E–02		
Cobalt	6.10E–03		
Copper	5.00E–02		
Fluoride	1.00E+00		
Iron	5.30E+00		
Lead	2.00E–01		
Lithium	1.50E+01		
Magnesium	1.40E+01		
Manganese	9.70E–01		
Molybdenum	4.00E–02		
Nickel	5.00E–02		
Nitrate	1.00E+01		
Phosphorus	3.00E–01		
Selenium	2.00E–01		
Silicon	8.40E+00		
Silver	5.00E–02		
Sodium ion	5.00E+00		
Sulfate ion	5.00E+00		
Tin	5.00E–02		
Titanium	4.50E–02		
Vanadium	8.50E–03		
Zinc	5.00E–02		
Zirconium	2.00E–02		
Americium-241	1.09E+02		
Cesium-137	2.11E+04		
Cobalt-60	5.10E+03		
Europium-152	1.31E+03		
Europium-154	7.07E+02		

Table 7-4b (con't)

Constituent	Maximum Concentration	Constituent	Average Concentration
Europium-155	2.69E+02		
Plutonium-238	1.85E+02		
Plutonium-239	2.92E+02		
Plutonium-240	2.92E+02		
Strontium-90	1.00E+03		
Tritium	2.00E+06		

NA = No measured water concentration available.

TABLE 7-5A—*Maximum and Average Y-12 Plant Sediment Concentrations*

Measurements in milligrams per kilogram (for chemicals) or pCi/kg (for radionuclides)

Constituent	Maximum Concentration
Acenapthene	7.90E-02
Acenapthylene	1.60E-01
Aldrin	1.10E-03
Anthracene	8.50E-01
Aroclor 1254	4.20E-01
Aroclor 1260	2.70E-01
Benzo(a)anthracene	3.90E+00
Benzene	1.55E-02
Benzene hexachloride (alpha)	2.00E-04
Benzene hexachloride (beta)	1.60E-03
Benzene hexachloride (gamma)	1.00E-03
Benzene hexachloride (delta)	2.70E-03
3,4-benzfluoranthene	5.00E-04
Benzo(a)pyrene	3.50E+00
Benzo(g,h,i)perylene	5.00E-04
Benzo(k)fluoranthene	4.60E-01
Benzoic acid	1.80E-01
BEHP	1.20E+00
Butyl benzyl phthalate	2.30E-01
Carbezol	7.80E-02
Chlordane (alpha)	4.60E-03
Chlordane (gamma)	7.80E-03
Chlorobenzene	1.55E-02
Chloroethane	5.00E-03
Chloride IC	2.00E+00
Chloroform	2.10E-02
Chloromethane	2.90E-02
Chrysene	3.70E+00
4,4'-DDD	4.80E-03
4,4'-DDE	6.00E-03
4,4'-DDT	4.70E-03
Dibenzo(a,h)anthracene	5.80E-01
1,1-dichloroethane	1.60E-02
1,2-dichloroethane	9.00E-03
1,1-dichloroethene	1.20E-02
Trans-1,2-dichloroethylene	4.20E-01
Dieldrin	1.20E-03
Diethyl phthalate	6.00E-02
Di-n-butyl phthalate	9.70E-01
Di-n-octylphthalate	2.50E-01
Endosulfan	1.00E-03
Endosulfan II	1.30E-03
Fluoranthene	7.10E+00
Fluorene	1.40E-0[illegible]
Fluorotrichloromethane	2.10E-0[illegible]
Heptachlor	3.00E-04
Heptachlor epoxide	8.00E-05
indeno(1,2,3-cd)pyrene	2.20E+00
Methylene chloride	1.30E-01

Constituent	Average Concentration
Aroclor 1254	8.52E-02
Aroclor 1260	2.20E-02
Benzo(a)anthracene	4.14E-01
Benzene hexachloride (gamma)	4.67E-04
BEHP	1.71E-01
4,4'-DDE	3.75E-04
4,4'-DDT	9.74E-04
Methylene chloride	1.66E-02
Phenol	NA
Tetrachloroethene	8.81E-03
Toluene	1.04E-03
Vinyl chloride	4.62E-04
Aluminum	8.10E+03
Antimony	7.39E+01
Arsenic	1.66E+01
Barium	1.20E+02
Beryllium	1.78E+01
Boron	3.16E+03
Cadmium	5.32E+00
Chromium	4.95E+01
Cobalt	1.76E+01
Copper	2.45E+01
Iron	3.79E+04
Lead	6.56E+01
Lithium	NA
Magnesium	5.10E+03
Manganese	1.24E+03
Mercury	1.31E+01
Molybdenum	1.69E+01
Nickel	3.26E+01
Potassium	6.80E+02
Selenium	1.26E+02
Silver	1.65E+01
Sodium ion	3.19E+03
Thallium	1.59E+03
Vanadium	3.30E+01
Zinc	9.62E+01
Zirconium	6.40E+00
Curium-244	3.03E+01
Strontium-90	4.77E+00

Table 7-5a (con't)

Constituent	Maximum Concentration	Constituent	Average Concentration
Phenanthrene	5.00E-02		
Pyrene	7.90E+00		
Tetrachloroethene	2.70E-01		
Toluene	3.15E-02		
1,1,1-trichloroethane	3.80E-03		
Trichloroethene	5.90E-03		
Vinyl chloride	1.30E-02		
Aluminum	7.80E+04		
Antimony	2.10E+02		
Arsenic	2.20E+02		
Barium	1.50E+03		
Beryllium	5.15E+01		
Boron	1.14E+04		
Cadmium	7.00E+01		
Calcium	1.05E+05		
Chromium	1.40E+02		
Cobalt	6.70E+02		
Copper	1.10E+03		
Gallium	3.90E+01		
Germanium	1.00E+00		
Iron	8.42E+04		
Lanthanum	1.80E+01		
Lead	9.84E+02		
Lithium	2.10E+02		
Magnesium	2.72E+04		
Manganese	1.60E+04		
Mercury	9.56E+01		
Molybdenum	5.15E+01		
Nickel	5.20E+02		
Potassium	6.80E+02		
Selenium	1.98E+03		
Silicon	5.90E+03		
Silver	5.15E+01		
Sodium ion	9.50E+03		
Thallium	3.41E+04		
Tin	1.90E+04		
Titanium	2.60E+03		
Uranium oxyfluoride	1.20E+02		
Vanadium	6.60E+02		
Zinc	8.70E+02		
Zirconium	6.40E+00		
Americium-241	2.00E+02		
Cesium-137	2.05E+03		
Cobalt-60	2.22E+02		
Curium-242	2.00E+01		
Curium-244	2.40E+02		
Neptunium-237	2.54E+03		
Plutonium-238	1.70E+02		
Plutonium-239	4.40E+01		
Protactinium-233	7.42E+02		
Strontium-90	1.41E+13		

Table 7-5a (con't)

Constituent	Maximum Concentration	Constituent	Average Concentration
Thorium-228	1.17E+03		
Thorium-230	1.21E+03		
Thorium-232	1.45E+03		
Uranium-234	3.85E+04		
Uranium-235	3.56E+03		
Uranium-238	1.05E+05		

NA = No measured sediment concentration available.

TABLE 7-5B—*Maximum and Average K-25 Site Sediment Concentrations*

Measurements in milligrams per kilogram (for chemicals) or pCi/kg (for radionuclides)

Constituent	Maximum Concentration	Constituent	Average Concentration
Acetone	1.00E-03	BEHP	3.20E+00
Aroclor 1254	1.00E+00	Aluminum	3.63E+04
Aroclor 1260	1.00E+00	Arsenic	1.39E+01
BEHP	3.50E+00	Barium	3.23E+01
Bromoform	1.00E-03	Beryllium	1.20E+00
Carbon tetrachloride	3.00E-03	Boron	8.00E+01
Chlorobenzene	1.00E-03	Cadmium	4.46E-01
1,1-dichloroethene	1.00E-03	Chromium	1.31E+03
trans-1,2-dichloroethylene	3.00E-03	Cobalt	2.50E+01
1,2-dichloropropane	1.00E-03	Copper	1.27E+02
cis-1,3-dichloropropene	1.00E-03	Iron	4.94E+04
trans-1,3-dichloropropene	1.00E-03	Lead	2.38E+01
Ethyl benzene	1.00E-03	Lithium	2.90E+01
Fluoranthene	1.60E+00	Magnesium	5.07E+03
Freon 113	1.00E-03	Manganese	8.12E+02
Freon 114	1.00E-03	Mercury	7.74E-01
Freon 123	1.00E-03	Molybdenum	1.00E+01
Methyl chloroform	2.50E-02	Nickel	4.50E+02
Methyl ethyl ketone	1.00E-03	Potassium	4.75E+03
Phenanthrene	1.10E+00	Selenium	6.00E+01
Phosphate	8.40E+02	Silver	1.25E+00
Pyrene	1.40E+00	Vanadium	4.40E+01
1,1,2,2-tetrachloroethane	1.00E-03	Zinc	4.32E+02
Toluene	1.00E-03	Cesium-137	6.63E+03
Toxaphene	3.00E-03	Plutonium-238	2.16E+03
1,1,2-trichloroethane	1.00E-03	Strontium-90	7.50E+12
Trichloroethene	6.90E-02	Technecium-99	2.38E+06
Trichlorofluoromethane	1.00E-03	Thorium-234	NA
Aluminum	3.63E+04		
Arsenic	2.50E+02		
Barium	6.30E+02		
Beryllium	3.10E+00		
Boron	1.90E+02		
Cadmium	5.60E+00		
Calcium	2.28E+04		
Chromium	3.30E+03		
Cobalt	6.10E+01		
Copper	1.70E+03		
Iron	4.94E+04		
Lead	2.20E+02		
Lithium	5.30E+01		
Magnesium	1.60E+05		
Manganese	5.40E+03		
Mercury	9.50E+00		

Table 7-5b (con't)

Constituent	Maximum Concentration	Constituent	Average Concentration
Molybdenum	4.90E+01		
Nickel	9.70E+03		
Niobium	7.00E-01		
Phosphorus	2.10E+03		
Potassium	1.10E+04		
Selenium	2.80E+02		
Silver	8.90E+01		
Sodium	3.10E+03		
Titanium	4.60E+02		
Vanadium	7.60E+01		
Zinc	1.30E+03		
Cesium-137	9.01E+03		
Cobalt-60	2.13E+02		
Neptunium-237	7.66E+03		
Plutonium-238	8.56E+03		
Strontium-90	2.58E+13		
Technecium-99	6.76E+06		
Thorium-232	6.34E+03		
Uranium-235	8.54E+04		
Uranium-238	4.74E+05		

NA = No measured sediment concentration available.

TABLE 7-5C—*Maximum and Average X10 Sediment Concentrations*

Measurements in milligrams per kilogram (for chemicals) or pCi/kg (for radionuclides)

Constituent	Maximum Concentration	Constituent	Average Concentration
Barium	6.93E+02	Barium	NA
Beryllium	NA	Beryllium	8.52E-02
Boron	NA	Boron	2.20E-02
Cadmium	NA	Cadmium	4.14E-01
Calcium	NA	Chromium	4.67E-04
Chromium	NA	Cobalt	1.71E-01
Cobalt	NA	Copper	3.75E-04
Copper	NA	Iron	9.74E-04
Lead	2.62E+02	Lead	1.66E-02
Magnesium	NA	Magnesium	8.81E-03
Manganese	NA	Manganese	1.04E-03
Mercury	2.19E+01	Mercury	4.62E-04
Nickel	6.50E+01	Nickel	8.10E+03
Potassium	NA	Potassium	7.39E+01
Selenium	NA	Selenium	1.66E+01
Silver	NA	Silver	1.20E+02
Sodium ion	NA	Sodium ion	1.78E+01
Vanadium	NA	Vanadium	3.16E+03
Zinc	NA	Zinc	5.32E+00
Zirconium	NA	Zirconium	4.95E+01

NA = No measured sediment concentration available.

were used in the assessment to estimate the most probable and reasonable exposure and risk.

Contaminant exposure of species on the reservation depends on the amount of time spent in waste areas and the amount of contaminants ingested. Only species with small home range such as small mammals and birds would reside within contaminated areas for most of their lives, and very few individuals would contact areas of maximum concentrations (see Appendix B for discussion of home ranges).

The risk assessment estimates the risk to vegetation, terrestrial wildlife, and aquatic organisms from chronic exposure to radiological and nonradiological contaminants. In the exposure analyses, the ecological endpoints and their corresponding species were considered. However, because the availability of sensitivity data for many species (e.g., threatened and endangered species) is limited and because those are similarities in exposure risk (e.g., similarly sized raptors feeding on the same prey), representative organisms for each endpoint were chosen for evaluation. A food web was developed which included receptor species representing the endpoints (figure 7-2). In all cases where data were available, conservative estimates of exposure and risk were made by selecting receptors most sensitive to contaminants or habitat alteration, most likely to experience additional risk due to bioaccumulation or larger body size, or at greatest risk due to rarity. Other abundant species on the reservation were included as important prey components of the food web, such as mice and insects (risk estimates were not determined for insects).

The primary exposure routes for terrestrial wildlife species are exposure to external radiation, ingestion of food (including soils for some species), and water. Table 7-6 lists the body weights and consumption rates for the representative species on the ORR. The Canada goose feeds exclusively on the vegetative parts of plants. The cottontail rabbit and white-tailed deer were assumed to eat 50% vegetation and 50% fruits and seeds. On the basis of on a review of the literature, the percentage of prey items consumed by omnivores and predators was estimated (table 7-6; Figure 7-2). The mouse and robin were assumed to eat 70% fruit and seeds and 30% insects; the osprey and Cooper's hawk to feed exclusively on fish and songbirds (robin), respectively; the mink to eat 50% fish and 50% mice; and the coyote to eat 50% mice and 50% rabbits. The bat was assumed to eat 100% insects, and the insects were assumed to eat 100% vegetative plant parts.

All species were assumed to purposely or incidentally ingest soil while eating, grooming, or preening except for the bat, mink, coyote, and the raptors for which soil ingestion was assumed to be negligible (table 7-6). The soil ingestion rate (Q_s) for cottontail rabbits was assumed to be the same as that reported for the jackrabbit, 6.3% of the dry matter intake (Arthur and Gates 1988). The white-tailed deer soil ingestion rate was assumed to be the same as that reported for the mule deer, 1.35% of the dry matter intake (Arthur and Alldredge 1979). The soil ingestion rate for the mouse was assumed to be 2% of the dry matter intake (Beyer et. al., 1991). The soil ingestion rate of the Canada goose was assumed to be the same as that for the mallard, 8.2% (OHEA 1991). Since published values of soil ingestion rates were not found for the robin, it was conservatively estimated to be 10% of the dry matter intake.

The estimated daily rates of food and water consumption (Q_v, Q_f or Q_H, and Q_w, respectively) for each representative species were calculated from allometric regression equations that were based on the weight of the organism (EPA 1988) (appendix A). These equations are based on the combined measurements for laboratory animals, livestock, and selected wildlife and bird species.

Because information on the specific habits and behaviors of most of the representative wildlife species is not well known, it is assumed that all species spend 100% of their time on the reservation or within the vicinity of contaminated areas. Therefore, the fraction of contaminated vegetation, fruit, prey, soil, and water consumed (FI_v, FI_f, FI_H, FI_s and FI_w, respectively) is set at 100% (table 7-6).

Contaminant concentrations in vegetation, the first level in the food chain, are estimated from source term concentrations in the soils using published soil-to-plant element- or chemical-specific transfer factors (Baes et al. 1984; Travis and Arms 1988) (table 7-7). Transfer factors for inorganic chemicals are available for both the vegetative and fruiting parts of plants (Baes et al. 1984); however, the transfer factors for organic chemicals do not make this distinction (Travis and Arms 1988). The methodology used to predict contaminant concentrations in vegetation does not make a distinction between different plant types or species. Therefore, all species ingest "generic" vegetation containing contaminant concentrations derived from soil concentrations by the use of transfer factors (appendix A).

Transfer factors for contaminants of concern were applied to predict concentrations in the tissues of terrestrial mammalian receptors from consumption of vegetation, soil, and water (collectively termed B_b) (Baes et al. 1984; Travis and Arms 1988) (table 7-7). Data on transfer factors from vegetation or soil to insects and earthworms are very limited in the literature. Therefore, the concentration in insects was derived from vegetation concentrations, and a default, conservative one-to-one transfer between vegetation and insects was assumed. Fish bioconcentration factors (BCF) were applied to estimate the concentrations of contaminants in fish tissue for consumption by the osprey and mink (Droppo et al., 1989) (table 7-7). The rationale and limitations for applying these transfer factors are discussed in Appendix A.

The consumption rates and the benchmark limit or no-observable-adverse-effect level (NOAEL) values are typically reported in wet weights, whereas the vegetation and soil concentrations are typically reported in dry weights. Therefore, conversion factors were applied to account for this difference. The wet- to dry-weight concentration conversion factor for the vegetative parts of plants on the ORR was assumed to be 0.32 [the average for meadow fescue, Kentucky bluegrass, wild bromegrass, and orchard grass (Morrison 1959)]. The wet- to dry-weight concentration conversion factor for the fruiting parts of plants on the ORR was assumed to be 0.17 (Morrison 1959). The wet- to dry-weight concentration conversion factor for soils was assumed to be 0.90 (Clark and Maisel 1977).

For the baseline assessment of the ORR, the concentrations of radionuclides in animal tissues and the resulting doses were not decay-corrected. The doses are estimated for the current situation and not at some point in the future. The primary radionuclides of concern (except for ^{90}Y) have sufficiently long half-lives, so this assumption was reasonable. PNL decay-corrected the radionuclide concentrations in the source terms to the time of disposal or release. To estimate dose to terrestrial receptors, all short-lived daughter products were included.

Aquatic organisms considered in the assessment included benthic macroinvertebrates and generic aquatic biota. For radiological analyses, emergent vegetation (i.e., cattails) and muskrats were included as well. All aquatic organisms, except for benthic macroinvertebrates, were assumed to be exposed to contaminants in surface water. Benthic macroinvertebrates were assumed to be exposed only to contaminants in the sediment pore water for calculation of internal radiation dose and exposure to chemicals. The external radiation dose from exposure to surface water was calculated for all organisms.

7.4 Contaminant Effects Assessment

Two pathways were used to determine the effects of contaminant expousure on ecological endpoint receptors. For terrestrial receptors, consumption rates of contaminated food and water were compared with toxicological benchmark. For aquatic receptorscontaminanat concentrations in water and sediment pore water were compared with chemical-specific aquatic benchmarks.

To quantify risk to terrestrial receptors exposed to organic and inorganic contaminants, the daily consumption rate of contaminated food and water, normalized to body weight (in units of mg/kg/d), was compared with the NOAEL benchmark (mg/kg/d). Ratios greater than 1 were considered to pose a potential risk to organisms but do not necessarily indicate the severity of the effect(s). However, it is reasonable to assume that the higher the ratio, the greater the risk of adverse effects. Dose to terrestrial receptors, including vegetation, from internal and

TABLE 7-6—*Body Weights and Consumption Rates*[1] *for Oak Ridge Terrestrial Species*[2]

Parameter	White-footed Mouse	Eastern Cottontail Rabbit	White-tailed Deer	Indiana Bat	Robin	Canada Goose	Cooper's Hawk	Osprey	Mink	Coyote
Body weight, BW (kg)	2.40E−02[3]	1.19E+00[4]	5.65E+01[5]	7.30E−03[6]	7.50E−02[7]	2.76E+00[8]	4.39E−01[9]	1.49E+00[10]	1.15E+00[11]	1.60E+01[12]
Water intake rate, Q_w (L/d)	6.40E−03	1.14E−01	2.63E+00	2.30E−03	1.43E−02	2.80E−01	5.75E−02	1.75E−01	1.23E−01	9.76E−01
Water ingestion fraction, FI_w	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00
Soil intake rate, Q_s (kg/d)	4.38E−05[13]	1.28E−03[14]	5.83E−03[15]	0.00	3.87E−04[16]	6.29E−03[17]	0.00	0.00	0.00	0.00
Soil ingestion fraction, FI_s	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	0.00	0.00	0.00	0.00
Vegetation intake rate, Q_v (kg/d)	0.00	3.73E−02[18]	7.93E−01[19]	0.00	0.00	1.77E−01	0.00	0.00	0.00	0.00
Vegetation ingestion fraction, FI_v	0.00	1.00E+00	1.00E+00	0.00	0.00	1.00E+00	0.00	0.00	0.00	0.00
Fruit/seeds intake rate, Q_f (kg/d)	3.36E−03[20]	3.73E−02	7.93E−01	0.00	5.80E−03[21]	0.00	0.00	0.00	0.00	0.00
Fruit/seeds ingestion fraction, FI_f	1.00E+00	1.00E+00	1.00E+00	0.00	1.00E+00	0.00	0.00	0.00	0.00	0.00
Prey 1 intake rate, Q_{M1} (kg/d)	1.40E−03 (insects)	0.00	0.00	1.30E−03 (insects)	2.50E−03 (insects)	0.00	3.39E−02 (meadowlarks)	1.05E−01 (fish)	3.63E−01[22] (mice)	2.92E−01[23] (fish)
Prey 1 ingestion fraction, FI_{M1}	1.00E+00	0.00	0.00	1.00E+00	1.00E+00	0.00	1.00E+00	1.00E+00	1.00E+00	1.00E+00
Prey 2 intake rate, Q_{M2} (kg/d)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.63E−01	2.92E−01
Prey 2 ingestion fraction, FI_{M2}	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00E+00	1.00E+00
Prey 3 intake rate, Q_{M3} (kg/d)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Prey 3 ingestion fraction, FI_{M3}	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

1 All values are on a wet weight basis. For soils, the wet/dry ratio is 0.90 (Clark and Maisel 1977), for vegetation the ratio is 0.32 for fruit/seeds, the ratio is 0.17 (Morrison 1959).
2 Water and food consumption rates were by methods in U.S. EPA 1988 (Table 4-8) unless otherwise noted.
3 Lackely et al. 1985.
4 Chapman et al. 1980.
5 Smith 1991.
6 Thomson 1982.
7 Terres 1980.
8 Terres 1980.
9 Terres 1980.
10 Terres 1980.
11 Whitaker 1988.
12 Burt and Grossenheider 1976.
13 Mouse soil ingestion rate is 2% of dry vegetation intake (Beyer et al. 1991).
14 The eastern cottontail is assumed to have the same soil ingestion rate as the jackrabbit (6.3%)(Arthur and Gates 1988.)
15 The white-tail deer is assumed to have soil ingestion rate of 1.35% of dry matter intake (Arthur and Alldredge 1979).
16 The robin soil ingestion rate is assumed to be 10% of dry matter intake.
17 The goose soil ingestion rate is assumed to be 8.2% of dry matter intake.
18 The rabbitt is assumed to eat 50% fruit and seeds and 50% vegetation (Whitaker 1988).
19 The white-tail deer is assumed to eat 50% fruit and seeds and 50% vegetation (Whitaker 1988).
20 The mouse is assumed to eat 70% fruit and seeds and 30% insects (Lackery et al. 1985).
21 The robin is assumed to eat 70% fruit and seeds and 30% insects (Terres 1980).
22 The mink is assumed to eat 50% mice and 50% fish (Whitaker 1988).
23 The coyote is assumed to eat 50% mice and 50% rabbits (Whitaker 1988).

TABLE 7-7—*Soil to Vegetation, Soil to Fruit, and Plant to Beef Transfer Factors, and Fish Bioconcentration Factors for the Oak Ridge Reservation Constituents of Concern*

Constituent	Fish Bioconcentration Factor	Soil to Vegetation Transfer Factor	Soil to Fruit Transfer Factor	Vegetation to Beef Transfer Factor
Acenapthene	6.46E+02	2.16E-01	2.16E-01	2.00E-04
Acenapthylene	3.01E+02	2.16E-01	2.16E-01	2.00E-04
Aldrin	3.14E+03	7.14E-01	7.14E-01	2.51E-05
Anthracene	1.42E+03	9.71E-02	9.71E-02	7.94E-04
Aroclor 1016	1.70E+04	2.24E-02	2.24E-02	1.00E-02
Aroclor 1232	1.60E+02	2.24E-02	2.24E-02	1.00E-02
Aroclor 1242	7.84E+02	2.24E-02	2.24E-02	1.00E-02
Aroclor 1248	1.40E+04	2.24E-02	2.24E-02	1.00E-02
Aroclor 1254	2.30E+04	2.24E-02	2.24E-02	1.00E-02
Aroclor 1260	1.60E+05	2.24E-02	2.24E-02	1.00E-02
Benzo(a)anthracene	1.17E+04	1.97E-02	1.97E-02	1.26E-02
Benzene	2.41E+01	2.37E+00	2.37E+00	3.16E-06
Benzo(b)fluoranthene	2.38+04	2.37+00	1.19e-02	2.14e-04
Benzene hexachloride (alpha)	5.17E+02	2.46E-01	2.46E-01	1.58E-04
Benzene hexachloride (beta)	5.42E+02	2.16E-01	2.16E-01	1.98E-04
Benzene hexachloride (gamma)	1.80E+02	1.65E-01	1.65E-01	3.16E-04
Benzene hexachloride (delta)	7.70E+02	1.62E-01	1.62E-01	3.27E-04
3,4-benzfluoranthene	6.94E+04	5.93E-03	5.93E-03	1.00E-01
Benzo(a)pyrene	2.38E+04	1.32E-02	1.32E-02	2.51E-02
Benzo(g,h,i)perylene	6.70E+04	6.09E-03	6.09E-03	?.55E-02
Benzo(k)fluoranthene	2.38E+04	1.19E-02	1.19E-02	3.02E-02
Benzoic acid	1.55E+01	3.09E+00	3.09E+00	2.00E-06
BEHP	1.19E+07	4.37E-02	4.37E-02	3.16E-03
Butyl benzyl phthalate	3.54E+03	5.70E-02	5.70E-02	2.00E-03
Carbon tetrachloride	1.70E+01	9.32E-01	9.32E-01	1.58E-05
Chlordane (alpha)	3.22E+02	2.56E-02	2.56E-02	7.94E-03
Chlordane (gamma)	3.22E+02	2.56E-02	2.56E-02	7.94E-03
Chloride IC	NA	1.19r-02	NA	8.00e-04
Chlorobenzene	6.45E+02	9.32E-01	9.32E-01	1.58E-05
Chloroethane	7.19E+00	5.76E+00	5.76E+00	6.78E-07
Chloroform	1.85E+01	2.70E+00	2.70E+00	2.51E-06
Chloromethane	3.10E+00	1.15E+01	1.15E+01	2.04E-07
Chrysene	1.08E+04	1.97E-02	1.97E-02	1.26E-02
2,4-D	8.05E+01	9.17E-01	9.17E-01	1.63E-05
4,4'-DDD	2.71E+03	1.32E-02	1.32E-02	2.51E-02
4,4'-DDE	8.45E+03	1.97E-02	1.97E-02	1.26E-02
4,4'-DDT	2.98E+04	7.74E-03	7.74E-03	6.31E-02
Dibenzo(a,h)anthracene	1.13E+05	6.78E-03	6.78E-03	7.94E-02
1,1-dichloroethane	1.35E+01	3.53E+00	3.53E+00	1.58E-06
1,2-dichloroethane	2.00E+00	5.26E+00	5.26E+00	7.94E-07
1,1-dichloroethene	1.47E+01	2.37E+00	2.37E+00	3.16E-06
Trans-1,2-dichloroethylene	1.36E+00	2.37E+00	2.37E+00	3.16E-06
Dieldrin	4.87E+03	8.50E-02	8.50E-02	1.00E-03
Diethyl phthalate	4.36E+01	5.48E-01	5.48E-01	3.98E-05
2,4-dimethylphenol	1.50E+02	1.39E+00	1.39E+00	7.94E-06
3,3-dishlorobenzidine	2.69E+02	NA	3,65-01	2.00e-02
Dimethyl phthalate	5.70E+01	2.70E+00	4.88E+00	5.00e-03

Table 7-7 (cont'd)

Constituent	Fish Bioconcentration Factor	Soil to Vegetation Transfer Factor	Soil to Fruit Transfer Factor	Vegetation to Beef Transfer Factor
Di-n-butyl phthalate	1.07E+04	3.82E-02	3.82E-02	3.98E-03
Di-n-octylphthalate	1.87E+07	1.86E-04	1.86E-04	3.98E+01
2,4-dinitorphenol	8.12E+00	9.17e-01	5.22E+00	6.00e-03
Endosulfan	2.94E+02	3.22E-01	3.22E-01	1.00E-04
Endosulfan II	3.32E+02	3.22E-01	3.22E-01	1.00E-04
Endrin	1.48E+03	2.24E-02	2.24E-02	1.00E-02
Fluoranthene	3.12E+03	5.70E-02	5.70E-02	2.00E-03
Fluorene	7.13E+02	1.44E-01	1.44E-01	4.02E-04
Fluoride	1.00E+01	7.74e-03	NA	5.50e-02
Fluorotrichloromethane	5.60E+01	1.34E+00	1.34E+00	8.51E-06
Freon 113	1.90E+02	4.79E-01	4.79E-01	5.02E-05
Heptachlor	1.30E+03	1.27E-01	1.27E-01	5.01E-04
Heptachlor epoxide	6.73E+01	1.05E+00	1.05E+00	1.28E-05
indeno(1,2,3-cd)pyrene	5.13E+04	2.37E+00	6.69e-03	3.00e-03
indeno(1,2,3-cd)pyrene	5.13E+04	6.69E-03	6.69E-03	8.13E-02
Methoxychlor	8.30E+03	6.51E-02	6.51E-02	1.58E-03
Methylene chloride	5.74E+00	6.86E+00	6.86E+00	5.01E-07
2-methylnapthalene	5.05E+02	NA	2.28e-01	8.00e-02
Napthylene	1.68E+02	5.48e-01	5.26e-01	3.00e-02
2-nitroaniline	NA	1.39E+00	NA	2.50e-03
3-nitroaniline	NA	3.82e-02	NA	1.00e-01
4-nitroaniline	NA	1.86e-04	NA	5.50e-03
4-nitrophenol	1.26E+02	3.22e-01	3.05+00	NA
a-nitrosodium-n-propylamine	7.22E+00	3.22e-01	6.34E+00	NA
Pentachlorophenol	3.72E+03	2.24e-02	4.99e-02	NA
Phenanthrene	1.44E+03	9.71E-02	9.71E-02	7.94E-04
Phenol	7.57E+00	5.26E+00	5.26E+00	7.94E-07
Protactinium-234M	1.10E+01	2.50e-03	2.50e-04	1.00e-05
Pyrene	2.80E+03	3.35E-02	3.35E-02	5.01E-03
Sulphate	NA	1.34E+00	NA	NA
2,4,5-T	1.90E+03	6.25E-01	6.25E-01	3.16E-05
2,4,5-TP (Silvex)	5.71E+02	2.07E-01	2.07E-01	2.14E-04
Technecium-99	1.50E+01	9.50E+00	1.50E+00	8.50e-03
Tetrachloroethene	5.57E+01	4.20E-01	4.20E-01	6.31E-05
Toluene	6.99E+01	1.07E+00	1.07E+00	1.26E-05
Toxaphene	1.90E+02	6.51E-02	6.51E-02	1.58E-03
1,1,1-trichloroethane	9.00E+00	1.39E+00	1.39E+00	7.94E-06
1,1,2-trichloroethane	3.90E+01	2.07E+00	2.07E+00	3.98E-06
2,4,5-trichlorophenol	1.90E+03	9.71e-02	2.73e-01	NA
Trichloroethene	3.79E+01	1.59E+00	1.59E+00	6.31E-06
Vinyl chloride	6.59E+00	6.01E+00	6.01E+00	6.31E-07
Xylene	1.77E+02	5.48E-01	5.48E-01	3.98E-05
Aluminum	1.00E+00	4.00E-03	6.50E-04	1.50E-03
Antimony	1.00E+00	2.00E-01	3.00E-02	1.00E-03
Arsenic	1.00E+00	4.00E-02	6.00E-03	2.00E-03
Barium	4.00E+00	1.50E-01	1.50E-02	1.50E-04
Beryllium	1.90E+01	1 [illegible]0E-02	1.50E-03	1.00E-03
Boron	2.20E-01	4.00E+00	2.00E+00	8.00E-04

Table 7-7 (cont'd)

Constituent	Fish Bioconcentration Factor	Soil to Vegetation Transfer Factor	Soil to Fruit Transfer Factor	Vegetation to Beef Transfer Factor
Cadmium	2.00E+02	5.50E-01	1.50E-01	5.50E-04
Calcium	0.00	3.50E+00	3.50E-01	7.00E-04
Chromium	2.00E+01	7.50E-03	4.50E-03	5.50E-03
Cobalt	5.00E+01	2.00E-02	7.00E-03	2.00E-02
Copper	5.00E+01	4.00E-01	2.50E-01	1.00E-02
Cyanide ion	3.79E-01	5.42E+01	5.60E-01	1.41E-08
Gallium	1.00E+02	4.00E-03	4.00E-04	5.00E-04
Germanium	4.00E+03	4.00E-01	8.00E-02	7.00E-01
Hafnium	4.00E+01	3.50E-03	8.50E-04	1.00E-03
Iron	1.00E+02	4.00E-03	1.00E-03	2.00E-02
Lanthanum	3.00E+01	1.00E-02	1.00E-02	3.00E-04
Lead	1.00E+02	4.50E-02	9.00E-03	3.00E-04
Lithium	5.00E-01	2.50E-02	4.00E-03	1.00E-02
Magnesium	5.00E+01	1.00E+00	5.50E-01	5.00E-03
Manganese	4.00E+02	2.50E-01	5.00E-02	4.00E-04
Mercury	2.00E+05	9.00E-01	2.00E-01	2.50E-01
Molybdenum	1.00E+01	2.50E-01	6.00E-02	6.00E-03
Nickel	1.00E+02	6.00E-02	6.00E-02	6.00E-03
Niobium	3.00E+04	2.00E-02	5.00E-03	2.50E-01
Phosphorus	1.00E+05	3.50E+00	3.50E+00	5.50E-02
Potassium	1.00E+03	1.00E+00	5.50E-01	2.00E-02
Scandium	1.00E+02	6.00E-03	1.00E-03	1.50E-02
Selenium	1.70E+02	2.50E-02	2.50E-02	1.50E-02
Silicon	2.00E+01	3.50E-01	7.00E-02	4.00E-05
Silver	2.30E+00	4.00E-01	1.00E-01	3.00E-03
Sodium ion	1.00E+02	7.50E-02	5.50E-02	5.50E-02
Thallium	1.00E+04	4.00E-03	4.00E-04	4.00E-02
Tin	3.00E+03	3.00E-02	6.00E-03	8.00E-02
Titanium	1.00E+03	5.50E-03	3.00E-03	3.00E-02
Uranium oxyfluoride	2.00E+00	NA	NA	NA
Vanadium	1.00E+01	5.50E-03	2.50E-03	2.50E-03
Zinc	2.00E+03	1.50E+00	1.00E-01	1.00E-01
Zirconium	3.30E+00	2.00E-03	5.00E-04	5.50E-03
Americium-241	2.50E+01	5.50E-03	3.00E-02	3.50E-06
Cerium-141	1.00E+00	1.00E-02	4.00E-03	7.50E-04
Cesium-137	2.00E+03	8.00E-02	3.00E-02	2.00E-02
Cobalt-60	5.00E+01	2.00E-02	7.00E-03	2.00E-02
Curium-242	2.50E+01	8.50E-04	1.50E-05	3.50E-06
Curium-244	2.50E+01	8.50E-04	1.50E-05	3.50E-06
Neptunium-237	1.00E+01	1.00E-01	1.00E-02	5.50E-05
Potassium-40	1.00E+03	1.00E+00	5.50E-01	2.00E-02
Plutonium-238	3.50E+00	4.50E-04	4.50E-05	5.00E-07
Plutonium-239	3.50E+00	4.50E-04	4.50E-05	5.00E-07
Protactinium-233	1.10E+01	2.50E-03	2.50E-04	1.00E-05
Radium-226	5.00E+01	1.50E-02	1.50E-03	2.50E-04
Strontium-90	3.00E+01	2.50E+00	2.50E-01	3.00E-04
Thorium-228	3.00E+01	8.50E-04	8.50E-05	6.00E-06
Thorium-230	3.00E+01	8.50E-04	8.50E-05	6.00E-06

Table 7-7 (cont'd)

Constituent	Fish Bioconcentration Factor	Soil to Vegetation Transfer Factor	Soil to Fruit Transfer Factor	Vegetation to Beef Transfer Factor
Thorium-232	3.00E+01	8.50E-04	8.50E-05	6.00E-06
Uranium-234	2.00E+00	8.50E-03	4.00E-03	2.00E-04
Uranium-235	2.00E+00	8.50E-03	4.00E-03	2.00E-04
Uranium-238	2.00E+00	8.50E-03	4.00E-03	2.00E-04
Yttrium-90	2.50E+01	1.50E-02	6.00E-03	4.00E-04

NA = Transfer factor could not be calculated.
Source: For organics, the transfer factors were calculated from equations in Travis and Arms (1988) using K_{ow} values from the *Superfund Chemical Data Matrix* (1991). For inorganics and radionuclides, the transfer factors were taken from Baes et al. (1984). The K_{ow} for cyanide was taken from MEPAS and the transfer factors were calculated from equations in Travis and Arms (1988).

external exposure to radionuclides was also determined from calculated tissue concentrations and soil concentrations, respectively. Doses that exceeded 0.1 rad/d were considered to pose a potential risk to terrestrial organisms (IAEA 1992). Methods used to calculate exposure and risk are described in Appendix A.

Toxicological benchmarks for terrestrial organisms, excluding vegetation, were obtained from Opresko et al. (1993) (table 7-8). For representative receptor species that were not listed in the data base, extrapolation techniques were employed to obtain the chronic NOAEL by adjusting for differences in body weight between the receptor and a test organism. If a NOAEL was available for a laboratory test species, the NOAEL for a receptor species could be calculated. Many of the NOAEL benchmarks were derived by extrapolation from small mammal laboratory data (Opresko et al. 1993). There were a few contaminants for which no wildlife toxicity data was found. For these cases, wildlife NOAEL's were extrapolated from human non-carcinogenic toxicity data (i.e. RfD's) listed in the MEPAS constituent database, normalized to the "standard man" body weight of 70 kg. Thus, wildlife species that weigh less than 70 kg would have a higher benchmark than humans, and the opposite would be true for wildlife species weighing more than 70 kg.

Literature sources for inorganic terrestrial phytotoxicity benchmarks were summarized and reported by Suter and Futrell (1993). Where applicable, the lowest source concentration in a soil medium that produced phytotoxically excessive effects was chosen from the data base. Several benchmarks were derived from experiments using nutrient solutions. However, uncertainty values were not applied to these data to account for differences in growth media. A methodology for deriving phytotoxicity benchmarks for organic constituents was developed by Eskew and Babb (as cited in the MMR Air National Guard Risk Assessment Handbook (1992).

Risks to aquatic organisms from exposure to organic and inorganic contaminants in water and sediments (pore water) were calculated by comparing the water or sediment pore-water concentrations (for benthic macroinvertebrates only) with the chemical-specific aquatic benchmark (Suter et al. 1992) (table 7-8). To determine internal dose to aquatic plants, fish, and muskrats from exposure to radionuclides, the surface water concentrations were multiplied by radionuclide and organism-specific aquatic (internal) dose conversion factors to produce a daily dose in rads (Killough and McKay 1976). To determine the internal dose to benthic macroinvertebrates and other bottom-dwelling organisms (e.g., fish larvae) from exposure to radionuclides, the sediment pore-water concentrations were multiplied by radionuclide and organism-specific aquatic (internal) dose conversion factors to produce a daily dose. The external dose to all organisms was determined by multiplying the surface water concentration by the external radionuclide-specific dose conversion factor. Combined internal and external doses greater than 1 rad/d are considered to pose a potential risk to aquatic organisms (NCRP 1991).

For contaminants and receptors that did not pass the average concentration screening (section 7.3), an attempt was made to further define exposure risks by comparing the home range sizes of receptor species with the potential fraction of the home range occupied by contaminants in food and water from waste sites and other contaminated areas.

Receptor species on the ORR have home ranges or territories that range from small [e.g., less than 1 hectare (1 acre) for aquatic species in small wetlands] to large [e.g., thousands of hectares (acres) for coyotes (appendix B)]. Some small species have home ranges small enough to be completely within individual waste sites. Other species have such large home ranges that the waste sites would represent only a small part of the area the species would occupy, if the waste sites were used at all. To further interpret the results of the risk analysis, assumptions similar to those described in section 4.4 were made. Because the ORR is different from the INEL reservation in ecological characteristics and distribution of endpoints/receptors, in distribution and area of waste sites, and in having three sets of source terms (e.g., Y-12, K-25, X-10), some assumptions for the ORR were different from those for the INEL reservation.

1. As for the INEL reservation, it was assumed that source terms outside of contaminated areas in the PNL data base are negligible. Although floodplain soils contain measurable levels of contaminants along some contaminated streams (SAIC 1994), source terms were assumed to be negligible for the rest of the ORR compared with source terms for waste sites.

2. The average size of terrestrial waste sites is about 4 ha (10 acres)at Y-12; about 20 ha (50 acres)at the K-25 Site; and about 2 ha (5 acres) or less at X-10. It was assumed that small terrestrial species with home ranges less than or equal to the area of a typical waste sites at each facility (table 7-9 a, b, c) could receive as much exposure as the average screening indicates (appendix B).

3. It was assumes that wide-ranging terrestrial species with home ranges greater than the average waste site but less than the total waste complex at each facility could receive at most about 20% and 15% for the Y-12 Plant and X-10, respectively, of the exposure calculated by the average screening if their home range includes as much contaminated area as possible (see appendix B). This assumption was derived from the approximate proportion of area of waste sites contained within the waste complex or within an area containing a representative group of waste sites at the Y-12 Plant (figure 7-3) and X-10 (figure 7-4). The waste complexes at Y-12 and X-10 were estimated to occupy about 690 ha (700 acres) and 445 ha (1100 acres) respectively.

The waste complex at the K-25 Site is very large relative to the total area in waste sites [e.g., 20 ha (50 acres)] more than 80% of which is in one location. Receptor species home ranges were either less than the area in a representative waste site or many times larger than all waste sites (appendix B). Therefore, for the K-25 Site it was assumed that all species with home ranges greater than the representative waste sites could receive at most a fraction of exposure comparable to the fraction of its home range contained in the total of all waste sites. At all three sites, exposures could be higher if, for instance, the sole source of contaminants is a waste pond or contaminated stream used as the only source of drinking water, or if waste sites are preferred feeding areas.

TABLE 7-8—*Criteria Benchmarks for ORR Terrestrial[1] and Aquatic[2] Species*

(NOAELs listed in milligrams per kilogram per day for terrestrial benchmarks or milligrams per liter for aquatic benchmarks)

Constituent	W.F. Mouse	E.Cotton. Rabbit	Whitetail Deer	Indiana Bat	Robin	Canada Geese	Cooper's Hawk	Osprey	Mink	Coyote	Vegetation	Aquatic
Acenapthene	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	1.28E+02	1.97E–01
Acenapthylene	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	1.7.3E+02	NA
Anthracene	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	1.28E+02	8.20E–03
Aroclor 1016	4.51E+00	1.25E–02	3.44E–03	6.70E+00	3.08E+00	9.41E–03	1.74E–02	1.16E–02	1.26E–02	5.24E–03	NA	NA
Aroclor 1232	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	1.60E–02
Aroclor 1242	1.16E–01	3.16E–02	8.74E–03	1.73E–01	1.59E–01	4.79E–02	8.84E–02	5.89E–02	3.20E–02	1.33E–02	1.28E+02	2.90E–03
Aroclor 1248	6.22E–01	6.05E–02	1.67E–02	9.25E–01	4.25E–01	4.57E–02	2.36E–01	5.62E–02	6.12E–02	2.55E–02	NA	4.00E–04
Aroclor 1254	1.41E–01	4.34E–02	1.73E–02	2.10E–01	3.19E+00	1.17E+00	1.77E+00	1.44E+00	7.00E–02	2.52E–02	1.00E+01	5.20E–04
Aroclor 1260	1.46E+00	2.92E–03	8.06E–04	2.17E+00	9.96E–01	2.21E–03	4.07E–03	2.71E–03	2.95E–03	1.23E–03	NA	2.10E–03
Benzo(a)anthracene	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	1.28E+02	6.50E–04
Benzene	6.11E+00	1.66E+00	4.59E–01	9.08E+00	4.18E+00	1.26E+00	2.32E+00	1.54E+00	1.7E+00	6.99E–01	NA	2.10E–02
Benzene hexachloride (alpha)	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	2.40E–04
Benzene hexachloride (beta)	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	2.40E–04
Benzene hexachloride (gamma)	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	8.00E–05
Benzo(a)pyrene	2.44E–02	6.65E–03	1.84E–03	3.63E–02	1.67E–02	5.02E–03	9.27E–03	6.18E–03	6.73E–03	2.80E–03	1.28E+02	2.99E–03
Benzo(g,h,i)perylene	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	1.28E+02	NA
Benzo(k)fluoranthene	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	1.28E+02	NA
Benzoic acid	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	1.26E+00
BEHP	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	1.40E+01	3.00E–04
Carbon tetrachloride	1.73E–01	4.72E–02	1.30E–02	2.58E–01	1.19E–01	3.57E–02	6.58E–02	4.39E–02	4.78E–02	1.99E–02	5.60E+01	6.50E–02
Chlordane (gamma)	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	1.99E+04	1.70E–04
Chlorobenzene	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	1.65E–01
Chloride IC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Chloroform	2.20E+01	5.99E+00	7.84E–01	3.27E+01	1.50E+01	2.15E+00	8.35E+00	2.64E+00	6.1E+00	1.19E+00	NA	8.40E+00
Chrysene	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	1.28E+02	NA
4,4'-DDD	4.15E+02	1.13E+02	3.12E+01	6.17E+02	2.84E+02	8.53E+01	1.58E+02	1.05E+02	1.1E+02	4.75E+01	NA	6.10E–04
4,4'-DDE	4.15E+02	5.80E–03	1.60E–03	6.17E+02	7.97E–01	4.38E–03	1.93E–01	5.39E–03	5.87E–03	2.44E–03	NA	NA
4,4'-DDT	3.53E–02	2.74E–02	7.57E–03	5.25E–02	3.98E–01	2.07E–02	3.93E–01	2.55E–02	2.77E–02	1.15E–02	NA	NA
1,1-dichloroethane	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	8.60E–01	1.59E+00
1,2-dichloroethane	1.81E+00	4.92E–01	1.36E–01	2.69E+00	1.24E+00	3.72E–01	6.86E–01	4.57E–01	4.98E–01	2.07E–01	5.40E–01	1.10E+01
1,1-dichloroethene	2.20E+00	5.99E–01	1.65E–01	3.27E+00	1.50E+00	4.52E–01	8.35E–01	5.56E–01	6.05E–01	2.52E–01	NA	4.47E–01
Diethyl phthalate	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	1.00E+00
Di-n-butyl phthalate	4.56E+01	1.24E+01	3.43E+00	6.78E+01	1.41E–02	4.25E–03	7.85E–03	5.23E–03	1.3E+01	5.22E+00	1.48E+04	2.70E–01
Di-n-octylphthalate	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	3.10E–01
Fluoranthene	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	1.28E+02	3.20E–02

Table 7-8 (con't)

Constituent	W.F. Mouse	E.Cotton. Rabbit	Whitetail Deer	Indiana Bat	Robin	Canada Goose	Cooper's Hawk	Osprey	Mink	Coyote	Vegetation	Aquatic
Heptachlor	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	8.60E-04
Methylene chloride	1.43E+01	3.89E+00	1.07E+00	2.13E+01	9.78E+00	2.94E+00	5.42E+00	3.61E+00	3.9E+00	1.64E+00	5.60E+00	4.10E-01
Phenanthrene	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	1.28E+02	1.10E-01
Phenol	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	2.30E-04
Tetrachloroethene	1.51E+00	4.11E-01	1.13E-01	2.24E+00	1.03E+00	3.10E-01	5.72E-01	3.81E-01	4.15E-01	1.73E-01	1.57E+01	5.10E-01
Toluene	5.45E+01	1.48E+01	4.10E+00	8.10E+01	3.73E+01	1.12E+01	2.07E+01	1.38E+01	1.5E+01	6.24E+00	9.70E+00	2.60E-02
1,1,1-trichloroethane	8.55E+01	2.33E+01	6.43E+00	1.27E+02	5.85E+01	1.76E+01	3.25E+01	2.16E+01	2.4E+01	9.79E+00	6.10E+00	2.51E-01
Trichloroethene	1.62E+02	4.99E+01	1.38E+01	2.40E+02	1.11E+02	3.77E+01	6.95E+01	4.63E+01	5.0E+01	2.10E+01	6.70E-01	5.76E+00
Xylene	1.22E+03	3.33E+02	9.18E+01	1.82E+03	8.36E+02	2.51E+02	4.64E+02	3.09E+02	3.4E+02	1.40E+02	2.40E+01	2.68E+00
Aluminum	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	8.00E+00	8.70E-02
Antimony	1.21E+04	3.31E+03	9.13E+02	1.81E+04	8.31E+03	2.50E+03	4.61E+03	3.07E+03	3.3E+03	1.4E+03	3.00E+00	1.90E+00
Arsenic	1.02E-01	1.62E+00	7.60E-01	1.52E-01	7.00E-02	2.08E+00	2.26E+00	2.56E+00	1.6E+00	1.16E+00	1.50E+01	9.32E-01
Barium	1.25E+00	3.39E-01	9.37E-02	1.85E+00	8.52E-01	2.56E-01	4.73E-01	3.15E-01	3.43E-01	1.43E-01	5.00E+02	2.03E+01
Beryllium	1.32E+00	3.59E-01	9.92E-02	1.96E+00	9.02E-01	2.71E-01	5.01E-01	3.34E-01	3.63E-01	1.51E-01	1.00E+01	3.80E-03
Boron	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	7.00E-03
Cadmium	2.35E-02	1.26E-02	1.77E-03	3.50E-02	1.61E-02	1.78E-03	7.99E-02	2.19E-03	6.48E-03	9.92E-04	3.00E+00	1.10E-03
Chromium	5.86E+00	1.60E+00	4.41E-01	8.72E+00	4.01E+00	1.21E+00	2.23E+00	1.48E+00	1.6E+00	6.71E-01	7.50E+01	1.10E-02
Cobalt	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	2.50E+01	4.40E-03
Copper	1.83E-01	2.21E+01	2.57E-01	2.72E-01	1.25E-01	1.67E+01	3.82E+01	2.05E+01	9.42E-01	9.28E+00	6.00E+01	1.20E-02
Cyanide ion	2.64E+01	7.18E+00	2.63E-02	3.92E+01	1.80E+01	7.19E-02	1.00E+01	8.83E-02	7.3E+00	4.00E-02	NA	5.20E-03
Iron	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	1.00E+04	1.00E+00
Lead	7.09E-03	1.93E-03	5.33E-04	1.05E-02	1.59E-02	8.84E+00	1.63E+01	1.09E+01	1.95E-03	8.11E-04	1.00E+02	3.20E-03
Lithium	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	2.00E+00	NA
Magnesium	2.33E+02	6.34E+01	1.75E+01	3.46E+02	1.59E+02	4.79E+01	8.84E+01	5.89E+01	6.4E+01	2.67E+01	NA	1.60E-04
Manganese	2.00E+00	5.44E-01	1.50E-01	2.97E+00	1.37E+00	4.11E-01	7.59E-01	5.06E-01	5.51E-01	2.29E-01	1.50E+03	1.10E+00
Mercury	1.43E+01	6.92E-03	2.15E-02	2.13E+01	3.19E+00	4.57E-01	1.77E+00	5.62E-01	7.00E-03	2.91E-03	3.00E-01	1.30E-03
Molybdenum	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	2.00E+00	3.60E-01
Nickel	5.90E+01	1.61E+01	4.44E+00	8.77E+01	4.17E+00	1.25E+00	2.32E+00	1.54E+00	1.6E+01	6.75E+00	1.00E+02	1.60E-04
Potassium	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	[illegible]
Selenium	6.14E-02	1.67E-02	4.62E-03	9.13E-02	2.51E-01	7.53E-02	1.39E-01	9.26E-02	1.69E-02	7.03E-03	5.00E+00	3.50E-02
Silver	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	2.00E+00	2.00E-04
Sodium ion	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	[illegible]
Thallium	2.44E-02	6.65E-03	1.84E-03	3.63E-02	1.67E-02	5.02E-03	9.27E-03	6.18E-03	6.73E-03	2.80E-03	1.00E+00	[illegible]
Tin	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	5.00E+01	NA
Uranium oxyfluoride	1.51E-01	4.12E-02	1.14E-02	2.25E-01	2.20E+01	6.60E+00	1.22E+01	8.12E+00	4.17E-02	1.73E-02	NA	[illegible]
Vanadium	2.30E-01	6.26E-02	1.73E-02	3.42E-01	1.57E-01	4.73E-02	8.73E-02	5.82E-02	6.33E-02	2.63E-02	5.00E+01	[illegible]
Zinc	2.37E+01	6.45E+00	1.78E+00	3.52E+01	1.62E+01	4.87E+00	8.99E+00	5.99E+00	6.5E+00	2.71E+00	7.00E+01	8.10E-01

Table 7-8 (con't)

Constituent	W.F. Mouse	E.Cotton. Rabbit	Whitetail Deer	Indiana Bat	Robin	Canada Goose	Cooper's Hawk	Osprey	Mink	Coyote	Vegetation	Aquatic
Zirconium	7.54E-02	2.05E-02	5.67E-03	1.12E-01	5.16E-02	1.55E-02	2.86E-02	1.91E-02	2.08E-02	8.63E-01	NA	2.51E-01

[1]The source for all terrestrial benchmarks except those for vegetation was (Op93). For vegetation, the source was (Su93) and the *Massachusetts Military Reservation Risk Assessment Handbook, 1992.*
[2]The source for aquatic benchmarks was (Su92).
NA = Benchmark not available

4. As at INEL, it was assumed that terrestrial species with home ranges greater than the waste complex of each facility could receive at most a fraction of exposure comparable to the fraction of its home range contained within waste sites included in the source term data base (appendix B). The total area in waste sites was 137 ha (338 acres), 21 ha (53 acres), and 64 ha (158 acres) at Y-12, K-25, and X-10, respectively.

5. Unlike terrestrial species, which were assumed to have circular or rectangular habitats, species primarily associated with streams were assumed to have more linear habitats. The Indiana bat, if present on the ORR, would be expected to occur only along East Fork Poplar Creek, and Poplar Creek which contain effluents from the Y-12 Plant. The length of these streams with suitable habitat is about 20 km (12 miles). The estimated foraging habitat of the Indiana bat is less than the total area of contaminated stream (Appendix B). Therefore, it was assumed that the Indiana bat, if present, would be at risk at the level indicated by average hazard indexes determined for the Y-12 Plant.

   The mink, which can subsist entirely on aquatic foods (e.g., fish, frogs, etc.), forages along streams, ponds, wetlands, lakes, or rivers. Data for a mink on the ORR indicate a foraging distance of 3 to 5 km (2 to 3 mile). As is true for the Indiana bat, the mink could forage entirely within habitats containing effluents at the Y-12 Plant and X-10. Unlike the Indiana bat, however, suitable habitat is found throughout the ORR. Therefore, it was assumed that mink occuring along East Fork Poplar Creek, Poplar Creek, and Bear Creek for Y-12 and along White Oak Creek for X-10 would be at risk at the level indicated by average hazard indices, and that mink living along water bodies that do not contain effluents are not at risk. The only water included in the source term data base for the K-25 Site is a small stream, about 1.2 km (0.75 miles) of which contains contaminated sediment. Therefore, for the K-25 Site it was assumed that the mink could receive at most about 40% [e.g., 1.2 km (0.75 miles) divided by 3 km (2 miles)] of the exposure the average screening indicates.

   Because osprey generally hunt only in large bodies of water, such as the impounded river, the only source of contaminants from the ORR to osprey is probably from the impounded river. The source term data base does not contain data from the impounded river; therefore, osprey were assumed to feed from smaller streams as well.

   The home range for the osprey was assumed to be about 500 acres (see appendix B). Contaminated streams and ponds would be about 30%, 10%, and 1% of the osprey's feeding area for Y-12, K-25 and X-10 respectively.

   Other birds that feed on aquatic life in streams (e.g., the great blue heron and the belted kingfisher) were assumed to be exposed to contaminants similar to those calculated for the osprey.

6. As reported in the source term data base, only about 220 ha (550 acres) or about 1.5% of the surface area (e.g., nonaquatic) of the ORR is waste sites or known

areas of contamination, which are the only parts of the reservation considered for remediation. Terrestrial biota living in the remaining 98.5% of the reservation are only exposed to contaminants that have moved from waste sites in dust, sediment, contaminated water, and by contaminated wildlife and plants. As at INEL, although this contamination may be measurable and is known to be of concern in some areas, source terms were not available except for the Bear Creek floodplain and were assumed to be negligible compared known sources of contamination that are subject to remediation. Because most of the ORR was assumed to be simi!-r heterogeneous forest habitat, only about 1.5% of the area supporting terrestrial ecological endpoints was assumed to be affected by contaminants from the waste sites or contaminated areas reported in the source term data base

7. No estimates of surface area of water or wetlands on the ORR have been documentaed. As determined by ORR staff from the ORR GIS data base, the total surface area of streams, ponds, and embayments is bout 150 to 300 ha (375 to 750 acres). An additional 200 ha (5000 acres) of the impounded river border the ORR.

The surface or streams and ponds reported in the source term data base were 8890 ha (22,225 acres), 2.6 ha (6.5 acres), and 1550 ha (3875 acres for Y-12, K-25, and X-10, respectively. These surface areas for Y-12 and X-10 were apparently for the entire watershed, including terrestrial habitat, of East Fork Poplar Creek and White Oak Creek and are much larger than actual aquatic or wetland habitat.

More accurate estimates of surface areas of stream habitat affected by effluents from Y-12 and X-10 were derived from map distances and published data for East Fork Poplar Creek (SAIC 1994), resulting in estimates of 40 to 80 ha (100 to 200 acres) and 5 to 20 ha (12 to 50 acres) are for Y-12 and X-10, respectively.
Therefore, assuming that the total area of streams is 150 to 300 ha (375 to 750 acres) and 45 to 100 ha (112 to 250 acres) are affected by effluents, about one-third to one-half of the stream area on the ORR may be affected by effluents included in the source term data base. Popluations of species living in or dependent on streams for food that are on the remaining one-half to two-thirds of the streams of the ORR were assumed not to be at risk.

8. Wetland area associated with streams, ponds, and embayments was assumed to be proportional to the surface area of water. Therefore. the proportion of wetlanc affected would be compar. .e to the proportion of streams, ponds, and embayments affected.

9. Stream or wetland dependent species habitat is often defined by linear distance. However, habitat (e.g., food supply) was assumed to be related to surface area of water. Therefore, aquatic surface areas were used to estimate the proportion of contaminated and uncontaminated habitat.

10. As at INEL, except for threatened and endangered species (e.g., candidate species), for which the loss of an

TABLE 7-9A—*Home ranges[1] of and Hazard Index (HI) Correction Factors[2] (CF) for receptor species at the Y-12 Plant on the ORR*

Endpoint	Receptor	<4 ha (10 acres)	4 to 700 ha (10 to 700 acres)	> 700 ha (1700 acres)	Correction Factor
Threatened and Endangered	Indiana bat	X			1.0
	candidate songbirds	X			1.0
Wetlands	generic	X			1.0
Recreational wildlife	white-tailed deer		X		0.2
	cottontail rabbit	X			1.0
	Canada goose		X		0.2
	coyote			X	0.14
Agricultural	vegetation	X			1.0
Biodiversity	white-footed mouse	X			1.0
	Coopers hawk		X		0.2
	mink		X		1.0[3]
	robin		X		0.2
	osprey		X		0.3[3]

[1] See Appendix b.
[2] A CF of 1.0 was applied to HIs for each contaminant for each species having a home range ≤ 4 ha (10 acres); other CFs are equal to the ratio of contaminated land to the area of the waste coomplex; CFs for wide ranging species equal the ratio of contaminated area to the area of the home range (see text and Appendix B for discussion of CFs).
[3] These species feed near or in streams, ponds, and aquatic areas. Correction factors for these species are discussed in the text (Section 7.4).

TABLE 7-9B—*Home ranges of and Hazard Index (HI) Correction Factors (CF)*[2] *for receptor species at the K-25 Site on the ORR*

Endpoint	Receptor	<20 ha (50 acres)	> 20 ha (50 acres)	Correction Factor
Threatened and Endangered Indiana	Indiana bat	X		1.0
	candidate songbirds	X		1.0
Wetlands	generic	X		1.0
Recreational Wildlife	white-tailed deer		X	0.1
	cottontail rabbit	X		1.0
	Canada goose		X	0.04
	coyote		X	0.02
Agricultural	vegetation	X		1.0
Biodiversity	white-footed mouse	X		1.0
	Coopers hawk		X	0.1
	mink		X[1]	[3]0.5
	robin	X		1.0
	osprey		X[1]	0.01

[1] See appendix B.
[2] A CF of 1.0 was applied to HIs for each contaminant for each species having a home range ≤ 20 ha (50 acres); other CFs are equal to the ratio of contaminated area to the area of the home range (see text and Appendix B for discussion of CFs).
[3] These species feed near or in streams, ponds, and aquatic areas. Correction factors for these species are discussed in the text (Section 7.4).

TABLE 7-9C—*Home Ranges of and Hazard Index (HI) Correction Factors (CF)*[2] *for receptor species at X-10 on the ORR*

Endpoint	Receptor	<2 ha (5 acres)	2 to 450 ha (5 to 1100 acres)	450 ha (1100 acres)	Correction Factor
Threatened and Endangered	Indiana bat	X			1.0
	Candidate songbirds	X			1.0
Wetlands	generic	X			1.0
Recreational wildlife	white-tailed deer		X		0.15
	cottontail rabbit	X			1.0
	Canada goose			X	0.13
	coyote			X	0.06
Agricultural	vegetation	X			1.0
Biodiversity	white-footed mouse	X			1.0
	Coopers hawk		X		0.15
	mink		X[1]		1.0[3]
	robin	X			1.0
	osprey		X[1]		0.1[3]

[1] See Appendix B.
[2] A CF of 1.0 was applied to HIs for each contaminant for each species having a home range ≤ 2 ha (5 acres); other CFs are equal to the ratio of contaminated land to the area of the waste complex. CFs for wide ranging species equal the ratio of contaminated area to the area of the home range (see text and Appendix B for discussion of CFs).
[3] These species feed near or in streams, ponds, and aquatic areas. Correction factors for these species are discussed in the text (Section 7.4).

FIGURE 7-3

FIGURE 7-4

for which the loss of an individual is considered a significant risk to the population. other endpoints were assumed to be at risk only at the scale represented by the fraction of the terrestrial, aquatic, or wetland environments the ORR that are contaminated or in waste sites. As reported in the source term data base, the fraction of contaminated terrestrial environment on the ORR is about 1.5%.

7.5 CONTAMINANT HAZARD ASSESSMENTS

7.5.1 Baseline

The next step in the ecological risk assessment generated HIs that were representative of potential risk and that estimated the level of effects from exposure to contaminants.

7.5.1.1 Y-12 Plant

Baseline uncorrected HIs for terrestrial receptors exposed to the maximum source concentrations at the Y-12 site were greater than the criteria limit of 1 for 10 of 22 organic contaminants with benchmarks, and 23 of 28 inorganic chemicals with benchmarks. Exposure to the maximum concentrations of radionuclides resulted in HIs for all receptors of about 3E+9: radiological exposure was dominated by exposure to ^{90}Y and ^{141}Ce in soils.

The dominant organic contaminants responsible for producing a risk to receptors exposed to the maximum concentrations in soil or water were PCBs and pesticides.

Of the 20 radionuclides to which terrestrial receptors could potentially be exposed, only ^{141}Ce, ^{244}Cm, ^{90}Sr, and ^{90}Y resulted in HIs greater than 1 for all species.

Exposures of terrestrial species to average soil and water concentrations of contaminants at the site were calculated for those contaminants whose maximum concentrations resulted in HIs greater than 1 (table 7-10a). About 40% of the HI values were above 1 but below 10, 52% were above 10 but below 1000, and 8% still above 1000 (versus 11% for the maximum). The radiological dose to receptors remained the same, despite the much lower average dose from ^{90}Sr and ^{244}Cm: the total dose was predominantly from ^{90}Y, whose maximum and average soil concentrations were the same (table 7-10a).

Exposure of aquatic organisms to the maximum concentrations of chemical contaminants in surface water at the Y-12 site resulted in HIs over 1 for PCBs, phenol, toluene, vinyl chloride, benzene hexachloride, and Mg, K, and Na. Exposure of benthic macroinvertebrates to the maximum sediment pore-water concentrations (calculated from sediment concentrations) resulted in HIs over 1 for benzo(a)anthracene, BEHP, methylene chloride, vinyl chloride, and 24 inorganic contaminants.

Hazard indices resulting from exposure of aquatic organisms to the average surface water concentrations were still more than 1 for all of the organics except toluene and all of the inorganic contaminants (table 7-11a). Only exposure to the average concentration of vinyl chloride resulted in an HI over 1 for benthic macroinvertebrates in the sediment pore water (table 7-11a). Hazard indices for benthic macroinvertebrates exposed to the average sediment concentrations were still more than 1 for 20 inorganic chemicals (versus 24 for maximum sediment concentrations).

Exposure of aquatic organisms to the maximum radionuclide concentrations in the water and sediments resulted in HIs exceeding 1 only for macroinvertebrates exposed to ^{90}Sr. There were no HIs greater than 1 for aquatic organisms exposed to the average sediment concentrations (table 7-12a).

7.5.1.2 K-25 Site

Baseline hazard indices for terrestrial receptors exposed to the maximum source concentrations at the K-25 Site were greater than the criteria limit of 1 for 22 of 23 inorganic contaminants with benchmarks.

Of the 14 radionuclides to which terrestrial receptors could potentially be exposed, only ^{137}Cs, ^{241}Am, ^{238}Pu, ^{234m}Pa, ^{99}Tc, ^{228,234}Th and ^{90}Sr resulted in HIs greater than 1 for all species.

Exposures of terrestrial species to average soil concentrations at the site were calculated for those contaminants whose maximum concentrations resulted in HIs greater than 1 (table 7-10b). The HI from aluminum exposure of vegetation was still greater than 1000 because the average soil concentration remained on the order of 2+e4 (table 7-10b). The remaining HIs for inorganic contaminants were all less than 30. About 82% of these HI values were above 1 but below 10, 15% were above 10 but below 1000, leaving 3% still above 1000. The radiological dose to receptors from exposure to average concentrations decreased slightly to about 8+e12 and was primarily due to exposure to ^{234m}Pa (table 7-10b).

Exposure of aquatic organisms to the concentrations of nonradiological and radiological contaminants in surface water at the K-25 Site could not be calculated because contaminant concentrations in water were not provided in the source terms. Exposure of benthic macroinvertebrates to the maximum sediment pore-water concentrations (calculated from sediment concentrations) resulted in HIs over 1 for one organic chemical, BEHP, and 20 inorganic chemicals.

Hazard indices resulting from exposure of benthic macroinvertebrates to the average sediment pore-water concentrations were still over 1 for BEHP and 18 inorganic contaminants (table 7-11b). The HIs for B, Fe, Mg, and K, were more than 1000, and Al, Cr, Co, and Ag had HIs greater than 100 but less than 1000.

Exposure of benthic macroinvertebrates to the maximum and average concentrations of radionuclides in the sediment pore water resulted in HIs exceeding 1 for ^{90}Sr only (table 7-12b). Concentrations of ^{90}Sr in the sediments were on the order of 10^{13} pCi/kg (table 7-5b).

7.5.1.3 X-10

Baseline HIs for terrestrial receptors exposed to the maximum source concentrations at the X-10 site were greater than the criteria limit of 1 for 14 of 18 inorganic contaminants with benchmarks. There were no HIs greater than 1 for terrestrial receptors exposed to the maximum concentrations of organic contaminants. Exposure to the maximum concentrations of radionuclides resulted in HIs for all receptors of about 1.5E+05. The maximum radiological exposure was dominated by exposure to ^{137}Cs in soils.

Exposure of terrestrial species to average soil and water concentrations at the site were calculated for those contaminants whose maximum concentrations resulted in HIs greater than 1 (table 7-10c). About 73% of the HI values were above 1 but below 10 (versus 70% for the maximum), 25% were above 10 but below 1000 (versus 27% for the maximum), and about 2% were still above 1000 (versus 3% for the maximum). Theaverage radiological dose to receptors decreased to about 100 and was primarily due to exposure to ^{106}Ru (table 7-10c).

Exposure of aquatic organisms to the maximum concentrations of non-radiological contaminants in surface water at the X-10 site resulted in HIs over 1 for one organic contaminant, benzene hexachloride, and 13 inorganic contaminants.

Hazard indices resulting from exposure to the average surface water concentrations were still greater than 1 for 8 inorganic contaminants (table 7-11c).

Exposure to the average concentrations of radionuclides in the surface water or in the sediment pore water (macroinvertebrates only) did not result in any HIs exceeding 1 (table 7-12c).

7.5.1.4 Summary

For the three facilities combined, the initial screening using average contaminant values indicated 36 contaminants resulting in HI values greater than 10 (i.e., severe risk from contaminants) or HI values greater than 1 (i.e., intermediate risk from contaminants) for various endpoints (tables 7-10 a, b, c; 7-11 a, b, c; and 7-12 a, b, c). Following the assumptions outlined in section 7.4, the approximate home range or territory size of receptors was estimated to determine the proportion that could potentially be contained within waste sites.

Of the receptors included in the analyses, only the Indiana bat, small songbirds (including

TABLE 7-10A—*Baseline Average Hazard Indices for Y12 Terrestrial Organisms*

	Hazard Indices Calculated Using Average Contaminant Concentrations										
	Mouse	Rabbit	Deer	Ind. Bat	Robin	Geese	C. Hawk	Osprey	Mink	Coyote	Vegetation
Aroclor 1016	1.48E-04	1.92E-02	3.38E-02	1.18E-04	1.55E-04	2.69E-02	1.89E-02	2.59E+02	1.06E+03	2.91E-02	NA
Aroclor 1242	5.74E-03	7.54E-03	1.33E-02	4.56E-03	2.99E-03	5.29E-03	3.70E-03	2.35E+00	1.93E+01	1.15E-02	0.00
Aroclor 1248	2.29E-02	1.18E-01	8.45E-02	8.10E-03	6.49E-02	2.93E-01	1.39E-03	4.39E+01	1.80E+02	6.05E-03	NA
Aroclor 1254	4.72E-03	5.50E-03	6.71E-03	3.75E-03	1.50E-04	2.17E-04	1.85E-04	2.82E+00	2.59E+02	6.04E-03	0.00
Aroclor 1260	4.58E-04	8.17E-02	1.44E-01	3.64E-04	4.79E-04	1.15E-01	8.04E-02	1.04E+04	4.28E+04	1.24E-01	NA
4,4'-DDE	1.61E-07	4.12E-03	7.27E-03	1.28E-07	5.98E-05	5.79E-03	1.70E-04	2.77E+01	1.14E+02	6.25E-03	NA
4,4'-DDT	1.89E-03	8.70E-04	1.54E-03	1.50E-03	1.20E-04	1.22E-03	8.33E-05	2.06E+01	8.48E+01	1.33E-03	NA
Methylene chloride	3.37E-02	4.50E-02	7.24E-02	3.02E-02	2.83E-02	7.98E-02	9.90E-05	5.93E-04	2.00E-03	1.53E-04	2.64E-01
Tetrachloroethene	8.51E-04	1.12E-03	1.97E-03	6.76E-04	8.89E-04	1.57E-03	1.10E-03	5.10E-02	[illegible]E-01	1.70E-03	0.00
Toluene	1.38E-03	1.88E-03	2.91E-03	1.20E-03	1.29E-03	3.42E-03	6.97E-06	4.03E-04	[illegible]-03	1.08E-05	1.48E-01
Vinyl chloride	2.65E-03	3.49E-03	6.16E-03	2.11E-03	2.77E-03	4.91E-03	3.43E-03	2.29E-02	7.90E-02	5.30E-03	NA
Aluminum	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	1.89E+03
Antimony	6.75E-06	1.28E-05	1.57E-05	8.50E-06	1.16E-05	3.32E-05	1.21E-10	0.00	1.86E-10	6.85E-10	2.42E+00
Arsenic	2.30E-01	7.97E-03	3.56E-03	1.41E-01	6.74E-01	1.27E-02	1.22E-04	1.55E-04	5.41E-04	1.11E-04	5.45E-01
Barium	5.09E-01	9.94E-01	1.13E+00	6.09E-01	9.98E-01	2.64E+00	3.62E-04	1.65E-03	5.19E-03	5.64E-04	2.38E-01
Beryllium	1.43E-03	3.03E-03	1.44E-03	2.93E-04	5.34E-03	8.40E-03	5.57E-08	0.00	3.93E-08	1.62E-07	9.09E-02
Cadmium	6.38E+01	5.62E+01	1.60E+02	8.68E+01	7.52E+01	7.25E+02	4.82E-05	0.00	9.65E-04	8.86E-03	2.91E+01
Chromium	7.83E-03	1.62E-02	7.57E-03	1.19E-03	2.90E-02	4.44E-02	1.66E-06	0.00	1.19E-06	4.78E-06	2.92E-01
Cobalt	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	6.05E-01
Copper	1.77E-01	6.10E-04	2.09E-02	1.78E-01	2.08E-01	1.28E-03	3.06E-05	1.58E-03	1.50E-01	5.88E-05	3.00E-02
Cyanide	6.23E-03	1.22E-02	1.49E+00	1.26E-02	5.23E-03	2.48E+00	7.70E-13	0.00	2.42E-12	6.96E-10	NA
Iron	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	1.49E+00
Lead	1.15E+01	2.29E+01	1.80E+01	7.35E+00	9.93E+00	1.01E-02	6.44E-06	5.27E-04	1.30E+01	6.05E-02	2.71E-01
Lithium	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	2.32E+01
Magnesium	2.17E-01	3.30E-01	5.10E-01	2.44E-01	2.16E-01	6.90E-01	2.18E-02	9.09E-01	3.64E+00	3.37E-02	NA
Manganese	3.55E+00	6.43E+00	8.40E+00	4.46E+00	5.44E+00	1.61E+01	1.88E-01	6.10E+01	2.50E+02	2.30E-01	5.45E-01
Mercury	5.55E-01	5.48E+02	7.36E+01	8.26E-01	1.82E+00	1.54E+01	4.74E-03	0.00	2.15E+00	7.38E+00	1.03E+03
Molybdenum	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	5.04E-01
Nickel	1.54E-03	2.55E-03	2.47E-03	8.46E-04	3.16E-02	5.68E-02	1.98E-06	0.00	2.54E-07	8.26E-07	1.95E-01
Selenium	7.40E-01	1.36E+00	9.64E-01	2.62E-01	3.51E-01	5.72E-01	5.50E-05	0.00	3.05E-04	1.10E-03	3.02E+00
Silver	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	1.37E+01
Thallium	5.34E+00	1.15E+01	4.60E+00	4.74E-01	2.12E+01	3.21E+01	8.85E-03	0.00	5.87E-03	2.45E-02	6.80E+01

Table 7-10a (con't)

Hazard Indices Calculated Using Average Contaminant Concentrations											
	Mouse	Rabbit	Deer	Ind. Bat	Robin	Goose	C. Hawk	Osprey	Mink	Coyote	Vegetation
Vanadium	1.87E-01	3.96E-01	1.71E-01	2.19E-02	7.19E-01	1.09E+00	1.88E-05	0.00	1.29E-05	5.29E-05	4.30E-01
Zinc	5.57E-02	1.06E-01	1.63E-01	9.98E-02	5.59E-02	2.77E-01	2.81E-04	3.60E-01	1.48E+00	9.11E-04	5.28E-01
Zirconium	9.53E-02	2.05E-01	7.73E-02	4.32E-03	3.85E-01	5.73E-01	2.21E-05	0.00	1.44E-05	6.03E-05	NA

Radiological Doses (rad/d) Calculated Using Average Contaminant Concentrations											
	Mouse	Rabbit	Deer	Ind. Bat	Robin	Goose	C-Hawk	Osprey	Mink	Coyote	Vegetation
Cerium 141	2.23E+07	2.23E+07	2.23E+07	2.23E+07	2.23E+07	2.23E+07	2.23E+07	2.23E+07	2.23E+07	2.23E+07	2.24E+07
Curium-244	7.25E+02	7.25E+02	7.25E+02	7.25E+02	7.25E+02	7.25E+02	7.25E+02	7.25E+02	7.25E+02	7.25E+02	8.51E+02
Strontium-90	4.77E-08	4.77E-08	4.77E-08	4.77E-08	4.77E-08	4.77E-08	4.77E-08	4.77E-08	4.77E-08	4.77E-08	9.01E-08
Yttrium-90	2.81E+08	2.81E+08	2.81E+08	2.81E+08	2.81E+08	2.81E+08	2.81E+08	2.81E+08	2.81E+08	2.81E+08	2.83E+08
Total dose	3.03E+08	3.03E+08	3.03E+08	3.03E+08	3.03E+08	3.03E+08	3.03E+08	3.03E+08	3.03E+08	3.03E+08	3.05E+08
Radiological HI	3.03E+09	3.03E+09	3.03E+09	3.03E+09	3.03E+09	3.03E+09	3.03E+09	3.03E+09	3.03E+09	3.03E+09	3.05E+09

TABLE 7-10B—*Baseline Average Hazard Indices for K25 Terrestrial Organisms*

Hazard Indices Calculated Using Average Contaminant Concentrations											
	Mouse	Rabbit	Deer	Ind. Bat	Robin	Goose	C.Hawk	Osprey	Mink	Coyote	Vegetation
Benzo(a)pyrene	1.04E-01	2.02E-01	1.15E-01	2.38E-02	3.41E-01	5.31E-01	8.95E-05	0.00	7.16E-06	2.73E-04	8.09E-03
BEHP	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	7.97E-02
Di-n-butyl phthalate	9.46E-05	1.66E-04	1.37E-04	4.24E-05	5.19E-01	8.80E-01	2.15E-05	0.00	1.04E-09	3.55E-08	8.02E-05
Aluminum	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	2.14E+03
Antimony	2.33E-05	4.41E-05	5.41E-05	2.93E-05	4.01E-05	1.14E-04	4.19E-10	0.00	6.41E-11	2.36E-09	8.36E+00
Arsenic	2.67E-01	9.31E-03	4.07E-03	1.62E-01	7.94E-01	1.49E-02	2.84E-07	0.00	2.52E-08	5.88E-07	6.47E-01
Barium	7.39E-01	1.44E+00	1.64E+00	8.85E-01	1.45E+00	3.84E+00	2.27E-06	0.00	3.05E-07	1.16E-05	3.45E-01
Beryllium	9.06E-04	1.92E-03	9.13E-04	1.86E-04	3.39E-03	5.33E-03	3.53E-08	0.00	2.49E-09	1.03E-07	5.77E-02
Cadmium	1.15E+00	1.01E+00	2.89E+00	1.57E+00	1.36E+00	1.31E+01	8.70E-07	0.00	1.74E-06	5.89E-05	5.24E-01
Chromium	2.56E-02	5.31E-02	2.47E-02	3.89E-03	9.47E-02	1.45E-01	5.43E-06	0.00	3.87E-07	1.56E-05	9.52E-01
Cobalt	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	3.50E-01
Copper	8.84E+00	3.07E-02	1.04E+00	8.99E+00	1.05E+01	6.60E-02	1.99E-06	0.00	5.49E-07	1.66E-05	1.61E+00
Iron	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	4.42E+00
Lead	1.46E+01	2.92E+01	2.28E+01	9.35E+00	1.27E+01	1.29E-02	3.97E-05	0.00	1.21E-05	4.70E-04	3.46E-01
Lithium	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	9.20E+00
Magnesium	3.01E-01	4.61E-01	7.07E-01	3.45E-01	2.97E-01	9.89E-01	1.55E-05	0.00	4.14E-06	1.25E-04	NA
Manganese	2.11E+00	3.87E+00	5.00E+00	2.70E+00	3.28E+00	9.83E+00	1.37E-05	0.00	2.32E-06	8.32E-05	3.38E-01
Mercury	1.95E-03	1.92E+00	2.58E-01	2.90E-03	6.37E-03	5.40E-02	1.66E-05	0.00	7.56E-04	2.59E-02	3.61E+00
Molybdenum	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	9.99E-01
Nickel	2.22E-03	3.68E-03	3.57E-03	1.22E-03	4.56E-02	8.19E-02	2.85E-06	0.00	3.67E-08	1.19E-06	2.82E-01
Selenium	3.06E-01	5.62E-01	3.99E-01	1.08E-01	1.45E-01	2.37E-01	2.28E-05	0.00	1.26E-05	4.53E-04	1.25E+00
Silver	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	7.32E-01
Vanadium	5.05E-01	1.07E+00	4.60E-01	5.90E-02	1.94E+00	2.94E+00	5.05E-05	0.00	3.47E-06	1.42E-04	1.16E+00
Zinc	1.43E-01	2.71E-01	4.19E-01	2.56E-01	1.43E-01	7.11E-01	1.49E-04	0.00	3.93E-05	1.45E-03	1.36E+00
Zirconium	2.15E-01	4.63E-01	1.74E-01	9.75E-03	8.69E-01	1.29E+00	4.99E-05	0.00	3.26E-06	1.36E-04	NA

Table 7-10b (cont'd)

Radiological Doses (rad/d) Calculated Using Average Contaminant Concentrations											
	Mouse	Rabbit	Deer	Ind. Bat	Robin	Goose	C-Hawk	Osprey	Mink	Coyote	Vegetation
Americium-241	7.61E+00	7.61E+00	7.61E+00	7.61E+00	7.61E+00	7.61E+00	7.61E+00	7.61E+00	7.61E+00	7.61E+00	5.10E+02
Cesium-137	5.77E+02	5.77E+02	5.77E+02	5.77E+02	5.77E+02	5.77E+02	5.77E+02	5.77E+02	5.77E+02	5.77E+02	5.93E+02
Plutonium-238	3.04E+00	3.04E+00	3.04E+00	3.04E+00	3.04E+00	3.04E+00	3.04E+00	3.04E+00	3.04E+00	3.04E+00	1.37E+03
Protactinium-234M	7.76E+11	7.76E+11	7.76E+11	7.76E+11	7.76E+11	7.76E+11	7.76E+11	7.76E+11	7.76E+11	7.76E+11	7.77E+11
Strontium-90	5.72E+04	6.76E+04	5.72E+04	5.72E+04	5.73E+04	1.04E+05	5.72E+04	5.72E+04	5.72E+04	5.72E+04	1.08E+05
Technecium-99	5.58E−04	1.52E+00	5.58E−04	5.58E−04	1.25E−02	6.83E+00	5.58E−04	5.58E−04	5.58E−04	5.62E−04	2.44E−03
Thorium-228	2.00E+05	2.00E+05	2.00E+05	2.00E+05	2.00E+05	2.00E+05	2.00E+05	2.00E+05	2.00E+05	2.00E+05	2.88E+06
Thorium-230	1.09E−02	1.09E−02	1.09E−02	1.09E−02	1.09E−02	1.09E−02	1.09E−02	1.09E−02	1.09E−02	1.09E−02	2.00E+06
Thorium-234	1.96E+07	1.96E+07	1.96E+07	1.96E+07	1.96E+07	1.96E+07	1.96E+07	1.96E+07	1.96E+07	1.96E+07	7.71E+00
Total dose	7.76E+11	7.76E+11	7.76E+11	7.76E+11	7.76E+11	7.76E+11	7.76E+11	7.76E+11	7.76E+11	7.76E+11	7.77E+11
Radiological HI	7.76E+12	7.76E+12	7.76E+12	7.76E+12	7.76E+12	7.76E+12	7.76E+12	7.76E+12	7.76E+12	7.76E+12	7.77E+12

N/A = Benchmark not available, therefore hazard index could not be calculated

TABLE 7-10C—*Baseline Average Hazard Indices for X-10 Terrestrial Organisms*

Hazard Indices Calculated Using Average Contaminant Concentrations											
	Mouse	Rabbit	Deer	Ind. Bat	Robin	Goose	C. Hawk	Osprey	Mink	Coyote	Vegetation
Aluminum	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	6.62E+03
Barium	1.04E+00	2.01E+00	2.31E+00	1.23E+00	2.01E+00	5.29E+00	3.60E-02	1.65E-01	5.19E-01	5.56E-02	4.72E-01
Beryllium	2.22E-04	2.92E-04	5.16E-04	1.77E-04	2.32E-04	4.11E-04	2.88E-04	4.81E-03	1.85E-02	4.44E-04	NA
Cadmium	7.51E+00	6.60E+00	1.88E+01	1.02E+01	8.84E+00	8.49E+01	1.07E-02	4.22E+01	6.35E+01	4.01E-01	3.39E+00
Chromium	1.94E-02	4.00E-02	1.93E-02	3.22E-03	7.08E-02	1.09E-01	5.40E-04	9.38E-03	7.62E-02	8.39E-04	7.08E-01
Copper	1.46E-02	4.32E-05	1.81E-03	1.16E-02	1.52E-02	6.08E-05	3.43E-05	1.78E-03	1.69E-01	6.57E-05	NA
Lead	1.77E+00	2.33E+00	4.11E+00	1.41E+00	5.63E-01	5.39E-04	3.77E-04	3.10E-02	7.63E+02	3.53E+00	NA
Lithium	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	2.65E+01
Magnesium	7.59E-01	1.16E+00	1.78E+00	8.67E-01	7.50E-01	2.48E+00	1.63E-02	6.80E-01	2.72E+00	2.55E-02	NA
Manganese	1.29E+00	2.36E+00	3.06E+00	1.65E+00	2.00E+00	5.98E+00	2.07E-02	6.72E+00	2.75E+01	3.20E-02	2.05E-01
Mercury	5.18E-01	5.11E+02	6.87E+01	7.70E-01	1.69E+00	1.44E+01	4.42E-03	0.00	2.01E+00	6.88E+00	9.60E+02
Nickel	2.01E-02	3.34E-02	3.24E-02	1.11E-02	4.12E-01	7.41E-01	5.92E-04	4.65E-02	1.95E-02	1.01E-04	2.55E+00
Selenium	2.09E-01	2.74E-01	4.84E-01	1.66E-01	3.65E-02	6.46E-02	4.52E-02	6.27E+00	1.53E+02	4.17E-01	NA
Vanadium	4.80E-01	1.01E+00	4.42E-01	5.85E-02	1.83E+00	2.78E+00	4.70E-03	4.39E-02	1.60E-01	7.31E-03	1.09E+00
Zinc	8.12E-02	1.54E-01	2.38E-01	1.46E-01	8.14E-02	4.04E-01	2.74E-04	3.06E-01	1.26E+00	1.12E-03	7.71E-01
Zirconium	2.12E+00	4.51E+00	1.83E+00	1.49E-01	8.36E+00	1.25E+01	9.20E-02	3.68E-01	1.11E+00	1.43E-01	NA

Radiological Doses (rad/d) Calculated Using Average Contaminant Concentrations											
	Mouse	Rabbit	Deer	Ind. Bat	Robin	Goose	C-Hawk	Osprey	Mink	Coyote	Vegetation
Cesium-137	8.31E+00	8.31E+00	8.31E+00	8.31E+00	8.31E+00	8.31E+00	8.31E+00	8.31E+00	8.31E+00	8.31E+00	8.54E+00
Cobalt 60	2.75E-01	2.75E-01	2.75E-01	2.75E-01	2.75E-01	2.75E-01	2.75E-01	2.75E-01	2.75E-01	2.75E-01	2.77E-01
Ruthenium-106	1.00E+02	1.00E+02	1.00E+02	1.00E+02	1.00E+02	1.00E+02	1.00E+02	1.00E+02	1.00E+02	1.00E+02	1.03E+02
Strontium-90	4.00E+00	4.00E+00	4.00E+00	4.00E+00	4.00E+00	4.00E+00	4.00E+00	4.00E+00	4.00E+00	4.00E+00	7.56E+00
Total dose	1.13E+02	1.13E+02	1.13E+02	1.13E+02	1.13E+02	1.13E+02	1.13E+02	1.13E+02	1.13E+02	1.13E+02	1.20E+02
Radiological HI	1.13E+03	1.13E+03	1.13E+03	1.13E+03	1.13E+03	1.13E+03	1.13E+03	1.13E+03	1.13E+03	1.13E+03	1.20E+03

N/A = Benchmark not available, therefore hazard index could not be calculated

TABLE 7-11A—*Baseline Average Hazard Indices for Y12 Aquatic Organisms*

Constituent	Average Surface Water HI ([illegible])	Benthic Macroinvertebrate HI
Aroclor 1242	8.62E–01	NA
Aroclor 1248	6.25E+00	NA
Aroclor 1254	4.81E+00	4.12E–02
Aroclor 1260	1.19E+00	2.63E–03
Benzo(a)anthracene	NA	1.27E–01
Benzene hexachlonde (gamma)	3.13E+00	4.64E–02
BEHP	NA	4.53E–01
Methylene chloride	1.00E–02	2.03E–01
Phenol	1.30E+02	NA
Tetrachloroethene	9.43E–03	6.88E–04
Toluene	4.23E–02	7.98E–03
Vinyl chlonde	3.33E+00	1.94E+00
Aluminum	3.09E–01	6.21E+01
Antimony	NA	8.64E–01
Arsenic	2.25E–03	8.91E–02
Barium	6.39E–05	9.83E–02
Beryllium	NA	7.21E+00
Boron	NA	1.50E+05
Cadmium	NA	7.44E+02
Chromium	NA	5.29E+00
Cobalt	NA	8.89E+01
Copper	7.42E–01	5.83E+01
Iron	1.36E–03	1.52E+03
Lead	2.50E–01	2.28E+01
Magnesium	9.19E+04	7.08E+06
Manganese	9.91E–01	1.73E+01
Mercury	NA	1.01E+03
Molybdenum	NA	2.35E+00
Nickel	NA	1.36E+00
Potassium	3.80E+01	9.51E+05
Selenium	NA	1.20E+01
Silver	NA	1.83E+03
Sodium ion	6.58E+00	1.02E+03
Thallium	NA	1.66E+01
Vanadium	NA	8.05E–01
Zinc	1.39E–01	2.19E+01
Zirconium	NA	8.50E–03

N/A = Benchmark not available, therefor hazard index could not be calculated

TABLE 7-11B—*Baseline Average Hazard Indices for K25 Aquatic Organisms*

Constituent	Average Surface Water HI (fish)	Average Benthic Macroinvertebrate HI
BEHP	NA	8.47E+00
Aluminum	NA	2.78E+02
Arsenic	NA	7.45E-02
Barium	NA	2.65E-02
Beryllium	NA	4.86E-01
Boron	NA	3.81E+03
Cadmium	NA	6.27E+01
Chromium	NA	1.40E+02
Cobalt	NA	1.26E+02
Copper	NA	3.03E+02
Iron	NA	1.98E+03
Lead	NA	8.25E+00
Magnesium	NA	7.04E+06
Manganese	NA	1.14E+01
Mercury	NA	5.95E+01
Molybdenum	NA	1.39E+00
Nickel	NA	1.87E+01
Potassium	NA	6.64E+06
Selenium	NA	5.72E+00
Silver	NA	1.39E+02
Vanadium	NA	1.07E+00
Zinc	NA	9.81E+01

N/A = Benchmark not available, therefore hazard index could not be calculated

TABLE 7-11C—*Baseline Average Hazard Indices for X10 Aquatic Organisms*

Constituent	Average Surface Water HI (fish)	Benthic Macroinvertebrate HI
Benzene hexachloride (gamma)	2.50E+01	NA
Aluminum	8.05E+00	NA
Barium	6.39E-03	5.68E-01
Beryllium	2.89E-01	NA
Boron	1.14E+01	NA
Cadmium	5.91E+00	NA
Chromium	8.28E-01	NA
Cobalt	9.55E-01	NA
Copper	8.33E-01	NA
Iron	7.70E-01	
Lead	1.47E+01	9.10E+01
Magnesium	6.88E+04	NA
Manganese	1.09E-01	NA
Mercury	0.00	1.68E+03
Nickel	6.25E-02	2.71E+00
Selenium	1.37E+00	NA
Silver	3.15E+01	NA
Sodium ion	1.00E+01	NA
Vanadium	7.56E-02	NA
Zinc	1.18E-01	NA
Zirconium	7.97E-02	NA

N/A = Benchmark not available, therefore hazard index could not be calculated.

TABLE 7-12A—*Baseline Average Internal and External Radiological Doses for Y12 Aquatic Organisms (rad/d)*

	External	Internal Plants	Internal Invertebrates	Internal Fish	Internal Muskrats
Curium-244	0.00	0.00	4.57E−05	0.00	0.00
Strontium-90	0.00	0.00	7.84E−07	0.00	0.00
Total dose	0.00	0.00	4.64E−05	0.00	0.00

TABLE 7-12B—*Baseline Average Internal and External Radiological Doses for K25 Aquatic Organisms (rad/d)*

	External	Internal Plants	Internal Invertebrates	Internal Fish	Internal Muskrats
Cesium-137	0.00	0.00	2.00e-05	0.00	0.00
Plutonium-238	0.00	0.00	1.45E−04	0.00	0.00
Strontium-90	0.00	0.00	1.23E+06	0.00	0.00
Technecium-99	0.00	0.00	3.83E−02	0.00	0.00
Total doses (rad/d)	0.00	0.00	1.23E+06	0.00	0.00

TABLE 7-12C—*Baseline Average Internal and External Radiological Doses for X10 Aquatic Organisms (rad/d)*

	External	Internal Plants	Internal Invertebrates	Internal Fish	Internal Muskrats
Cesium-137	9.86E−05	7.23E−03	0.00	3.62E−02	5.10E−02
Cobalt-60	6.71E−04	7.82E−02	0.00	7.82E−03	1.54E−02
Strontium-90	7.12E−10	7.12E−07	0.00	7.12E−09	3.13E−06
Total doses (rad/d)	7.69E−04	8.55E−02	0.00	4.40E−02	6.63E−02

candidate species), the cotton tail rabbit, the deer mouse, aquatic species, and mink have home ranges small enough to potentially live entirely within waste sites or contaminated areas (see section 7.4 and appendix B). Except for the coyote for the Y-12 Plant, the K-25 Site, and X-10, and for the Canada goose at X-10, other terrestrially based receptors have home ranges greater than an individual typical waste site but less than the total area inclusive of most waste sites or the waste complex. The coyote home range is greater than the waste complex of each facility, and the estimated home range of the Canada goose is greater than the waste complex at X-10. Based on the assumptions discussed in section 7.5, appropriate correction factors were applied to HIs in tables 7-10 a, b, c; 7-11 a, b, c and 7-12 a, b, c to estimate severity of risks to endpoints which occupy waste sites or contaminated areas for the three sets of source terms (tables 7-9a,b,c). Risks were considered moderate for HIs from 1 to 10 and severe for HIs greater than 10. No correction factor was used for receptors with home ranges or territories less than a representative waste site, or for aquatic organisms or vegetation. As discussed in section 7.5, no correction factor was used for mink at the Y-12 Plant or X-10 or for the Indiana bat, which could occur only at the Y-12 Plant. For all other receptors at the Y-12 Plant except the coyote, a correction factor of 0.2 was used. For all other receptors at X-10 except the coyote and Canada goose, a correction factor of 0.15 was used. For the remaining receptors, a correction factor was determined by dividing the total area in all waste sites or contaminated streams and ponds by home range to approximate the percentage of contaminated home range. See appendix B for further discussion of correction factors.

Some contaminants may be highly localized, but data are lacking for their areal distribution. For example, of the contaminants which the analyses indicate result in moderate to severe risks, source terms for cyanide and copper represent less than 0.006 ha (0.02 acres) of contaminated land (appendix B). Source terms for other soil contaminants range from 0.07 ha (0.2 acres) to 68 ha (170 acres). Although data for most contaminants were reported for only some of the total area in waste sites, the data were assumed to be representative. The averaged source terms used in the risk analysis were, therefore, assumed to be present in all waste sites or contaminated areas (appendix B).

7.5.1.4.1 Y-12 Plant.

Threatened and Endangered Species. Risks to some threatened and endangered species would be moderate or severe if individuals occupy waste sites or contaminated areas (table 7-13a). Potentially severe risks would be present from cadmium and the sum of radioactive contaminants for the endangered Indiana bat and candidate songbirds. Risks would also be severe to the candidate songbirds from thallium and to the candidate Bewick's wren from lead. Potentially moderate risks would be present from these and other contaminants to all listed and candidate wildlife species (table 7-13a). There is no suitable habitat for candidate plant species in or near the contaminated or waste sites at the Y-12 Plant included in the analyses. Although the analyses indicated potential risks to species, a site-specific survey of individual waste sites for occurrences of threatened and endangered species would be necessary to determine if there are actual risks.

7.5.1.4.2 Wetlands. Risks to wetlands receptors (e.g., nonbenthic aquatic life and benthic macroinvertebrates) would be severe from 18 contaminants in waste ponds and streams and moderate from an additional 9 contaminants (table 7-13b). The total area of wetlands affected by contaminants at the Y-12 Plant is unavailable but is assumed to be proportional to the total area of contaminated water at the Y-12 Plant, which is about 40 to 80 ha (100 to 200 acres) or about one-third to one-half of the surface area of water in streams, embayments, and ponds on the ORR.

7.5.1.4.3 Recreational Species. For some recreational species occupying waste sites or contaminated areas, risks from Cd, Pb, Hg, Ti, and total radioactive contaminants would be severe (table 7-13c). Additional moderate risks would also be possible from manganese and selenium. Risks to individuals that do not occupy waste sites or contaminated areas would be negligible.

7.5.1.4.4 Agriculture. Aluminum, Cd, Li, Hg, Ag, Ti, and total radiological contaminants would pose severe risks to vegetation (e.g., hay or timber) growing in waste sites or

TABLE 7-13A—*Baseline potential risks[1] to threatened, endangered and candidate species[2] that occupy waste sites and contaminated areas of the Y-12 Site.*

Contaminant	Indiana bat	Candidate Songbirds[3] resident	Candidate Songbirds[3] migrant
Cadmium	S[4]	S	S
Lead	M	S	M
Manganese	M	M	M
Mercury		M	M
Thallium		S	S
Radiological	S	S	S

[1] Risks based on assumptions discussed in Section 7.4.
[2] The candidate hellbender and paddlefish only occur in the river reservoirs for which no source term data were available. No candidate plant species habitat is in waste sites or contaminated areas.
[3] Candidate songbirds are Bewick's wren and Bachman's sparrow. Risks were estimated from risks to the robin.
[4] M = moderate. S = severe.
Note: Risks to individuals that do not occupy waste sites are negligible. Waste sites and contaminated areas associated with Y-12 account for less than 1.5% of the land area and one third to one half of the streams and ponds on the ORR

TABLE 7-13B—*Baseline potential risks to wetlands that are waste sites or contaminated streams and sediments on the Y-12 Site.*

Contaminants	Non-benthic Aquatic[1]	Benthic Invertebrates[1]
Aroclor		
1248	M[2]	
1254	M	
1260	M	
Aluminum		S
Benzene hexa-chloride	M	
Beryllium		M
Boron		S
Cadmium		S
Chromium		M
Cobalt		S
Copper		S
Iron		S
Lead		S
Magnesium	S	S
Manganese		S
Mercury		S
Molybdenum		M
Nickel		M
Phenol	S	
Potassium	S	S
Selenium		S
Silver		S
Sodium	M	S
Thallium		S
Vinyl chloride	M	M
Zinc		S
Radiological		S

[1] Based on EPA Water Quality Criteria (Suter et al. 1992). We assume that benthic invertebrates are exposed to pore water concentrations while other wetland (aquatic) organisms are exposed to surface water.

[2] M = moderate. S = severe.

Note: Source terms were not available for other wetlands; therefore we assume risks to other wetlands are negligible.

TABLE 7-13C—*Baseline maximum potential risks to recreational wildlife that occupy waste sites or contaminated areas on the Y-12 Site.*

	Cottontail Rabbit	White-tailed Deer	Canada Goose	Coyote
Cadmium	S[1]	S	S	
Lead	S	M		
Manganese	M	M	M	
Mercury	S	S	M	M
Selenium	M			
Thallium	S	M	M	
Radiological	S	S	S	S

[1] M = moderate, S = severe.
Note: Risks to individuals that do not occupy waste sites or contaminated areas are negligible.

TABLE 7-13D—*Baseline potential risks to hay and timber that grow on waste sites or contaminated areas on the Y-12 Site.*

Contaminant	Vegetation
Aluminum	S[1]
Antimony	M
Cadmium	S
Iron	M
Lithium	S
Mercury	S
Selenium	M
Silver	S
Thallium	S
Radiological	S

[1] M = moderate, S = severe.
Note: No hay is harvested from contaminated areas, and timber is not grown on the ORR for commercial harvest. Therefore, baseline risks to agriculture and timber production are negligible.

ABLE - —*Baseline maximum potential risks to other important food web components that occupy waste sites or contaminated areas on the Y-12 Site.*

[illegible]	Mouse	Cooper's Hawk	Osprey	Mink	Robin
Aroclor					
1016			S[1]	S	
1242				S	
1248			S	S	
1254				S	
1260			S	S	
DDE			M	S	
DDT			M	S	
Cadmium	S				S
Lead	S			S	M
Magnesium				M	
Manganese	M		S	S	M
Mercury				M	
Thallium	M				M
Zinc				M	
Radiological	S	S	S	S	S

[1] M = moderate. S = severe.

Note: Risks to individuals that do not occupy waste sites and contaminated areas are negligible.

contaminated areas (table 7-13d). Similarly, Sb, Fe, L, and Se, would pose moderate risks to vegetation. Hay is not harvested in waste sites or other contaminated areas; therefore, potential risks to agriculture on the ORR are negligible. Similarly, trees are not grown for timber harvest on the ORR, and risks to forestry would be negligible.

7.5.1.4.5 Public Lands. Because risks to receptor species in the food web were assumed to be negligible unless receptors occupy waste sites or contaminated areas and because Clark Center Park is more than 1.6 km (1 mile) from the nearest waste sites, risks to public lands would be negligible for food web components with small home ranges. Wide-ranging species such as coyote, hawks, deer, and geese could be foraging in waste sites or contaminated areas and also foraging in public lands. Therefore, this endpoint could experience risks comparable to those for other endpoints because source terms for the impounded river were not included, risks to fish in public access areas downstream from Y-12 were not estimated.

7.5.1.4.6 Biodiversity. Risks to overall biodiversity of the forest ecosystem on the reservation would be negligible because waste sites and contaminated areas reported in the source term data base occupy only about 1.5% of the total land area. Risks to receptors in stream ecosystems and associated wetlands and floodplains could be substantial, potentially affecting as much as one-half of these areas (see section 7.4). As there are for other endpoints, there could be risks to some receptors important to biodiversity in waste sites. In addition to the receptor species discussed previously, Aroclor (all five forms), DDE, DDT, Cd, Pl, Mn, and total radiological contaminants pose potentially severe risks, and Mg, Hg, and Zn pose potentially moderate risks to other wildlife that could occupy waste sites (table 7-13e). The kingfisher and great blue heron, two birds that feed exclusively on aquatic life in streams and embayments, could feed exclusively in contaminated streams and experience risks similar to those estimated for the osprey (Landrum et al. 1993).

The Y-12 facility occupies less than 5% of the ORR, and public roads and utility and railroad rights-of-way occupy an additional small fraction. These disturbed sites provide opportunities for establishment of nonnative plant species and subsequent intrusion or [illegible] expansion of populations of these species into [illegible] surrounding native plant communities.

7.5.1.5 K-25 Site

7.5.1.5.1 Threatened and Endangered Species. Risks to some threatened and endangered species would be moderate or severe if individuals occupy waste sites (table 7-14a). Potentially severe risks to the candidate songbirds would be present from exposure to copper, lead, and the sum of radioactive contaminants and for the Indiana bat from radioactive contaminants. Potentially moderate risks would be present from these and other contaminants to candidate bird species (table 7-14a). No suitable habitat for candidate plant species exists in or near the contaminated or waste sites at the K-25 Site. Although the analyses indicated potential risks to species, a site-specific survey of individual waste sites for occurrences of threatened and endangered species would be necessary to determine if there are actual risks.

7.5.1.5.2 Wetlands. No source term data for water were included in the source terms for the K-25 Site. Risks to benthic macroinvertebrates in wetlands would be severe from 14 contaminants in waste ponds and streams and moderate from an additional 6 contaminants (table 7-14b). The total area of wetlands affected by the K-25 Site was not known, but it is assumed to be proportional to the total area of contaminated stream sediment at the K-25 Site reported in the source term data base, which is about 2.6 ha (6.5 acres) or less than 1% of the area of water in streams, embayments, and ponds on the ORR. Only 0.3 ha (0.8 acres) of the total is stream environment; the remainder is waste ponds.

7.5.1.5.3 Recreational Species. For some recreational species occupying waste sites or contaminated areas, risks from lead and total radioactive contaminants would be severe (table 7-14c). Additional moderate risks would also be possible from Be, Cd, Mn, Hg, and Se. Risks to individuals that do not occupy waste sites or contaminated areas would be negligible.

TABLE 7-14A—*Baseline potential risks[1] to threatened, endangered and candidate species[2] that occupy waste sites and contaminated areas on the K-25 Site. Risks to individuals that do not occupy waste sites are negligible. Waste sites and contaminated areas associated with K-25 account for less than 1.5% of the ORR*

Contaminant	Indiana Bat	Candidate Songbirds[3] Resident	Candidate Songbirds[3] Migrant
Barium		M[4]	
Cadmium		M	
Copper		S	M
Lead		S	M
Manganese		M	M
Vanadium		M	M
Radiological	S	S	S

[1] Risks based on assumptions discussed in Section 7.4.
[2] The candidate hellbender and paddlefish only occur in the river reservoirs for which no source term data were available. No candidate plant species habitat is in waste sites or contaminated areas.
[3] Bewick's wren and Bachman's sparrow represented by the robin in our analyses
[4] M = moderate. S = severe

TABLE 7-14B—*Baseline potential risks to wetlands that are waste sites or contaminated streams and sediments on the K-25 Site. Source terms were not available for units at K-25 or other wetlands on the ORR. We assume risks to other wetlands on the ORR are negligible*

Contaminants	Benthic Invertebrates[1]
Aluminum	S[2]
BEHP	M
Boron	S
Cadmium	S
Chromium	S
Cobalt	S
Copper	S
Iron	S
Lead	M
Magnesium	S
Manganese	S
Mercury	S
Molybdenum	M
Nickel	M
Potassium	S
Selenium	M
Silver	S
Vanadium	M
Vinc	S
Radiological	S

[1] Based on EPA Water Quality Criteria (Suter et al. 1992). We assume that benthic invertebrates are exposed to pore water concentrations while other wetland (aquatic) organisms are exposed to surface water.
[2] M = moderate. S = severe

TABLE 7-14C—*Baseline potential risks to recreational wildlife that occupy waste sites or contaminated areas on K-25 Site. Risks to individuals that do not occupy waste sites or contaminated areas are negligible*

	Cottontail Rabbit	White-tailed Deer	Canada Goose	Coyote
Barium	M			
Cadmium	M		M	
Lead	S	M		
Manganese	M		M	
Mercury	M			
Vanadium	M			
Radiological	S	S	S	S

[1] M = moderate. S = severe.

TABLE 7-14D—*Baseline potential risks to hay and timber that grow on waste sites or contaminated areas on K-25 Site. No hay is harvested from contaminated areas, and timber is not grown on the ORR for commercial harvest. Therefore, baseline risks to agriculture and timber production are negligible*

Contaminants	Vegetation
Aluminum	S[1]
Antimony	M
Copper	M
Iron	M
Lithium	M
Mercury	M
Selenium	M
Vanadium	M
Zinc	M
Radiological	S

[1] M = moderate. S = severe

TABLE 7-14E—Baseline potential risks to other important food web components that occupy waste sites or contaminated areas on K-25 Site. Risks to individuals that do not occupy waste sites and contaminated areas are negligible

	Mouse	Cooper's Hawk	Osprey	Mink
Cadmium	M[1]			
Copper	M			
Lead	S			
Manganese	M			
Radiological	S	S	S	S

[1] M = moderate. S = severe

7.5.1.5.4 Agriculture. Aluminum and total radiological contaminants would pose severe risks to vegetation (e.g., hay or timber) growing in waste sites or contaminated areas (table 7-14d). Similarly, Sb, Cu, Fe, Li, Se, V, and Zn would pose moderate risks to vegetation. Hay is not harvested from waste sites or other contaminated areas; therefore, potential risks to agriculture on the ORR are negligible. Similarly, trees are not grown for timber harvest on the ORR, and risks to forestry would be negligible.

7.5.1.5.5 Public Lands. Because risks to receptor species in the food web were assumed to be negligible unless receptors occupy waste sites or contaminated areas, risks to public lands would be negligible for terrestrial food web components with small home ranges. Wide-ranging species such as coyote, hawks, deer, and geese could be foraging in waste sites or contaminated areas and also foraging in public lands. Therefore, this endpoint could experience risks comparable to those for other endpoints. Because source terms for the impounded river were not included, risks to fish in public access areas near the K-25 Site were not estimated.

7.5.1.5.6 Biodiversity. Risks to overall biodiversity of the forest ecosystem on the reservation would also be negligible because waste sites and contaminated areas reported in the source term data base occupy only about 1.5% of the total land area. Risks to receptors in stream ecosystems and associated wetlands and floodplains would be negligible because of the small area of stream habitat affected [<0.3 ha (0.7 acres)]. As there are for other endpoints, there could be risks to some receptors important to biodiversity in waste sites. In addition to the receptor species discussed previously, Pb and total radiological contaminants pose potentially severe risks, and Cd, Cu, and Mn pose potentially moderate risks to other food web components that could occupy waste sites (table 7-14e).

7.5.1.6 X-10.

7.5.1.6.1 Threatened and Endangered Species. Risks to some threatened and endangered species would be moderate or severe if individuals occupy waste sites (table 7-15a). Potentially severe risks would be present from exposure to Al, Li, Hg, and the sum of radioactive contaminants for candidate plant species (e.g., tall larkspur). Risks would also be severe from the sum of radioactive contaminants to the candidate songbirds. Potentially moderate risks would be present from these and other contaminants to birds and plants (table 7-15a). There is no suitable habitat for the Indiana bat on or near the contaminated areas or waste sites at X-10. Although the analyses indicated potential risks to species, a site-specific survey of individual waste sites for occurrences of threatened and endangered species would be necessary to determine if there are actual risks.

TABLE 7-15A—*Baseline potential risks[1] to threatened, endangered and candidate species[2] that occupy waste sites and contaminated areas on the X-10 Site. Risks to individuals that do not occupy waste sites are negligible. Waste sites and contaminated areas associated with X-10 account for less than 1.5% of the ORR*

Contaminant	Candidate Songbirds[3] Resident	Candidate Songbirds[3] Migrant	Candidate Plant Species[4]
Aluminum			S[5]
Barium	M	M	
Cadmium	M	M	M
Llithium			S
Mmanganese	M	M	
Mercury	M		S
Nickel			M
Vanadium	M		M
Zirconium	M	M	
Radiological	S	S	S

[1] Risks based on assumptions discussed in Section 7.4.
[2] The candidate hellbender and paddlefish only occur in the river reservoirs for which no source term data were available. No suitable habitat for the Indiana bat is found in waste sites or contaminated areas at X-10.
[3] Candidate songbirds are Bewick's wren and Bachman's sparrow. Risks were estimated from risks to the robin.
[4] Tall larkspur represented by generic vegetation. These risks are the same as for the timber and agricultural endpoints.
[5] M = moderate, S = severe.

TABLE 7-15B—*Baseline potential risks to wetlands that are waste sites or contaminated streams and sediments at X-10. Source terms were not available for other wetlands; therefore we assume risks to other wetlands are negligible*

Contaminants	Non-Benthic Aquatic[1]	Benthic Invertebrates[1]
Aluminum	M[2]	
Benzene hexa-chloride	S	
Boron	S	
Cadmium	M	
Lead	S	S
Magnesium	S	
Mercury		S
Nickel		M
Selenium	M	
Silver	S	
Sodium	S	

[1] Based on EPA Water Quality Criteria (Suter et al. 1992). It was assumed that benthic invertebrates are exposed to pore water concentrations while other wetland (aquatic) organisms are exposed to surface water.
[2] M = moderate, S = severe.

TABLE 7-15C—***Baseline maximum potential risks to recreational wildlife that occupy waste sites or contaminated areas at X-10. Risks to individuals that do not occupy waste sites or contaminated areas are negligible***

	Cottontail Rabbit	White-Tailed Deer	Canada Goose	Coyote
Cadmium	M[1]	M	S	
Mercury	S	S	M	
Zirconium			M	
Radiological	S	S	S	S

[1] M = moderate, S = severe.

TABLE 7-15D—***Baseline potential risks to other important food web components that occupy waste sites or contaminated areas at X-10. Risk to individuals that do not occupy waste sites and contaminated areas are negligible***

	Mouse	Cooper's Hawk	Osprey	Mink	Robin
Barium	M				
Cadmium	M			S	M
Lead	M			S	
Magnesium				M	
Manganese	M			S	
Mercury				M	
Selenium				S	
Zinc				M	
Zirconium	M			M	M
Radiological	S	S	S	S	S

Baseline potential risks to hay and timber that grow on waste sites or contaminated areas are the same as for vegetation shown in Table 7-16a. No hay is harvested from contaminated areas, and timber is not grown on the ORR for commercial harvest. Therefore, baseline risks to agriculture and timber production are negligible

[2] M = moderate, S = severe.

7.5.1.6.2 Wetlands. Risks to wetlands receptors (e.g., nonbenthic aquatic life and benthic macroinvertebrates) would be severe from 7 contaminants in waste ponds and streams and moderate from an additional 4 contaminants (table 7-15b). The total area of wetlands affected by X-10, is not known but is assumed to be proportional to the total area of streams and ponds at X-10 as estimated in section 7.4. This area is about 5 to 20 ha (12 to 50 acres) or less than 2% of the area of water in streams, embayments, and ponds on the ORR.

7.5.1.6.3 Recreational Species. For some recreational species occupying waste sites or contaminated areas, risks from cadmium, mercury, and total radioactive contaminants would be severe (table 7-15c). Additional moderate risks would also be possible from zirconium. Risks to individuals that do not occupy waste sites or contaminated areas would be negligible.

7.5.1.6.4 Agriculture. Aluminum, Li, Hg, and total radiological contaminants would pose severe risks to vegetation (e.g., hay or timber) growing in waste sites or contaminated areas (table 7-15a). Similarly, Cd, Ni and V would pose moderate risks to vegetation. Hay is not harvested in waste sites or other contaminated areas; therefore, potential risks to agriculture on the ORR, are negligible. Similarly, trees are not grown for timber harvest on the ORR and risks to forestry would be negligible.

7.5.1.6.5 Public Lands. As for the Y-12 Plant and the K-25 Site, risks to public lands would be negligible for terrestrial food web components with small home ranges but could exist for wide-ranging species such as coyote, hawks, deer, and geese foraging in waste sites or contaminated areas and in public lands. Therefore, this endpoint could experience risks comparable to those for other endpoints. Because source terms for the impounded river were not included, risks to fish in public access areas near X-10 could not be estimated.

7.5.1.6.6 Biodiversity. As at the Y-12 Plant and the K-25 Site, risks to overall biodiversity of the forest ecosystem on the reservation would be negligible because waste sites and contaminated areas reported in the source term data base occupy only about 1.5% of the total land area. Risks to receptors in stream ecosystems and associated wetlands and floodplains would be negligible because of the small area of stream habitat affected [5 to 20 ha (12 to 50 acres)]. As there are for other endpoints, there could be risks to some receptors important to biodiversity in waste sites. In addition to the receptor species discussed previously, Cd, Pb, Mn, Se, and total radiological contaminants pose potentially severe risks, and Ba, Mg, Hg, Zn, and Zr pose potentially moderate risks to other food web components that could occupy waste sites (table 7-15d).

7.6 CUMULATIVE ASSESSMENT

7.6.1 On-Site Baseline

7.6.1.1 Risk from Contaminants

For 33 contaminants, HIs suggest potential risks to organisms inhabiting waste sites and contaminated streams (table 7-16). Of these contaminants, Sb, Li, and Ti pose risks only to vegetation. Other contaminants pose risks only to aquatic biota (benzene hexachloride, BEHP, B, Cr, Co, Mo, phenol, K, Na, and vinyl chloride). Aluminum, Cd, Cu, Pb, Mg, Hg, Se, Ti, V, Zr, and total radiological contaminants pose potential risks to many endpoints occupying waste sites and contaminated streams. Some of the waste sites are highly developed areas that do not provide suitable habitat for most organisms. Actual risks associated with these sites are probably lower than indicated by the HIs. Waste ponds, however, are probably used by wildlife and waterfowl; for these organisms current exposures may be substantial. Contaminated streams flow through relatively undisturbed regions of the ORR, and risks to aquatic biota and wildlife that feed on fish in these streams may also be substantial. For all of the sites, a future scenario involving closure of the ORR facilities without restoration would result in reoccupation of all waste sites by plants and animals; risks similar to those indicated in tables 7-13, 7-14, and 7-15 would then be expected.

TABLE 7-16—*Comparative summary of potential on-site cumulative risks[1] to ecological endpoints from baseline on the ORR. Risks are for endpoints which occupy waste sites and contaminated areas for which source terms were available[2]*

Source of Risk	Y-12	K-25	X-10	ORR
Construction[3]				
Aluminum	W,F	W,F	E,W,F,P	E,W,F,P
Antimony	F	F		F
Aroclor	W,B,P			W,B,P
Barium		E	E,R,B	E,R,B
Benzene hexacloride	W,P		W,P	W,P
BEHP		W		W
Beryllium	W			W
Boron	W	W	W,P	W,P
Cadmium	E,W,R,F,B	E,W,R,B	E,W,R,F,P,B	E,W,R,F,P,B
Chromium	W	W		W
Cobalt	W	W		W
Copper		E,W,F,B		E,W,F,B
DDE	B			B
DDT	B			B
Iron	W,F	W,F		W,F
Lead	E,W,R,B	E,W,R,B	W,P,B	E,W,R,P,B
Lithium	F	F	E,F	E,F
Magnesium	W,B,P	E,W	W,P,B	E,W,P,B
Manganese	E,W,R,B	W,R,B	E,B	E,W,R,B
Mercury	E,W,R,F,B	W,R,F	E,W,R,F,B	E,W,R,F,B
Molybdenum	W	W		W
Nickel	W	W	E,W,F	E,W,F
Phenol	W,P			W,P
Potassium	W,P	W		W,P
Selenium	W,R,F	W,F	W,P,B	W,R,F,P,B
Silver	W,F	W	W,P	W,F,P
Sodium	W,P		W,P	W,P
Thallium	E,W,R,F,B			E,W,R,F,B
Vanadium		E,W,R,F	E,F	E,W,R,F
Vinyl chloride	W,P			W,P
Zinc	W,B	W,F	B	W,F,B
Zirconium			E,R,B	E,R,B
Radiological	E,W,R,F	E,W,R,F,B	E,R,F,B	E,W,R,F,B

[1] Only those contaminants are listed which could pose severe or moderate risks to some endpoints. Risks could be severe from at least one contaminant for each endpoint (see Tables 7-16,7-17,7-18).
[2] Risks to endpoints which do not occupy waste sites or contaminated areas are assumed to be negligible (see Section 7.4).
[3] These are short-term risks. Long-term risks could be reduced with successful restoration of appropriate habitat.
[4] Ecological endpoints: E = threatened, endangered, and candidate species; W = wetlands; R = recreational fish and wildlife; F = agriculture and forestry; P = public land (fish); and B = biodiversity (only for receptors not included under other endpoints)

TABLE 7-17—*Comparison of Source Term Concentrations of Elements in Soil with Naturally Occuring Concentrations (ppm)*

Contaminant	Source Term Concentration (Y-12, K-25, X-10)	Ave. Background Concentration at ORR[1]	Ave. Concentration for Eastern U.S.[2]	Range of Naturally Occurring Concentration[2]
Aluminum	16800 19000 58800	9430-38500	33000	7000->100000
Antimony	14 47 --	0.08-0.3	0.52	<1-8.8
Barium	132 192 262	17-107	290	10-1500
Beryllium	1.0 0.6	0.43-1.6	0.55	<1-7
Boron	-- 2 -- (80)[3]	2-12	31	<20-150
Cadmium	97 2 11	NA[4]	NA[5]	NA
Chromium	24 79 59 (1310)	15-50	33	1-1000
Cobalt	17 10 --	3-19	6	<0.3-70
Copper	2 107 --	5-27	13	<1-700
Iron	16500 49100 --	13000-53000	14000	100-100000
Lead	30 38 --	12-33	14	<10-300
Lithium	52 20 59	3-36	17	<5-140
Magnesium	1400 2100 5210	413-3840	2100	50-50000
Manganese	908 563 341	126-1330	260	<2-7000

Contaminant	Source Term Concentration (Y-12, K-25, X-10)	Ave. Background Concentration at ORR[1]	Ave. Concentration for Eastern U.S.[2]	Range of Naturally Occurring Concentration[2]
Mercury	343 1 320	0.05-0.28	.081	0.01-3.4
Molybdenum	1 2 -- (17)	1.2-3[6]	.32	<3-15
Nickel	22 31 283	7-27	11	<5-700
Potassium	3160 1570 17200	301-3960	12000	50-37000
Selenium	17 7 -- (126)	0.4-0.8	0.3	<0.1-3.9
Silver	31 2 --	ND	NA	NA
Sodium	81 -- 2600	337-435	2500	500-50000
Thallium	76 -- -- (1590)	0.06-0.5[7]	NA	NA
Vanadium	24 64 61	28-67	43	<7-300
Zinc	41 106 60	37-149	40	<5-2900
Zirconium	4 10 92	NA	220	<20-2000

[1] Watkins et al., 1993

[2] Shacklette and Boerngen 1984

[3] Source term concentrations for sediment on the ORR was more than 10 times source term concentrations for soil only for these elements. All other source term concentrations for sediments were about the same or less than soil source term concentrations.

[4] ND = not detected.

[5] NA = not available.

[6] Not detectable in 97% of sites.

[7] Not detectable in 87% of samples.

Determining cumulative risks to endpoints that do not occupy waste sites is problematic. Data were not adequate to determine the contaminant levels across the reservation. Moreover, many of the inorganic contaminants (e.g., metals) included in the analyses are known to occur in soils throughout the United States at concentrations greater than or equal to concentrations in the ORR source term data base (table 7-17). Intensive sampling of soils throughout the ORR to determine reservation-wide background levels of contaminants also indicates that concentrations of many contaminants in the source term data base were similar to background levels (table 7-17). Therefore, some of the source term data may reflect naturally occurring concentrations rather than contamination. Even when background levels are known, interpretation of HIs for inorganic substances is often difficult because most analytical techniques do not distinguish between chemical forms that are available for uptake by organisms (e.g., dissolved in soil pore water or loosely bound to particles) and those that are biologically unavailable (e.g., insoluble salts.)

It was not possible to definitively determine either the fraction of inorganic substances in the source term data base actually attributable to contamination or the fraction of those substances biologically available to organisms living on the reservation. However, evaluation of existing data on ORR background levels permits some tentative conclusions. Ranges of concentrations for Al (except at X-10), B, Co, Fe, Be, Na (except at X-10), Mg, Mn, Mo, K, V, and Zn throughout the ORR are greater than or equal to the average source term data for the individual elements (table 7-17). Therefore, risks from these elements due to waste sources are probably negligible. At present, no data for zirconium are available for the ORR, but the mean concentration for the eastern United States is much greater than source terms for zirconium on the ORR (table 7-17). On the other hand, source terms for Sb, Ba, B (in sediment), Cd, Cr, Cn (at K-25), Li, Mg (at X-10), Hg, Mo (in sediment), Ni (at X-10), K, Se, Ag, and Tl were generally more than 10 times greater than background levels. Lead and cobalt source terms were somewhat higher than average ORR concentrations. Because of the high toxicity of lead and the uncertainty associated with background variability, risks from lead from waste sources may be present.

Despite difficulties in interpreting HIs, cumulative risks from available source term and benchmark data are adequate to compare alternatives. Because of the relatively small fraction of the terrestrial portion of the ORR that is in waste sites, potential risks to terrestrial endpoints except for endangered and threatened species would be negligible. Although available data are not adequate to accurately determine the fraction of water and sediment on the ORR (excluding the impounded rivers) that is contaminated, it is probably substantial (e.g., one-third to one-half of all stream area). Therefore, potential risks to (1) wetlands, (2) recreational fish, and (3) biodiversity could also be substantial. Risks to parks and public lands would be negligible, however, because most recreational fishing in these areas takes place only on the impounded rivers. Because no restoration activities are included in the baseline case, habitat disturbance/fragmentation risks would also be negligible.

7.6.1.2 Risks from fragmentation and other noncontaminant degradation of biodiversity

Large, undisturbed, and protected blocks of natural landscape are becoming more important for protection of biodiversity. The ORR is a large block of relatively undisturbed primarily native hardwood forest ecosystem, interspersed with ecologically sensitive cedar barrens and river bluff habitats. The surrounding landscape is a highly fragmented mosaic of pastures, cropland, forest, urban, and suburban areas (table 7-18).

Y-12, K-25, and X-10 facilities together occupy less than about 15% of the ORR, and public roads and utility and railroad rights-of-way occupy an additional small fraction. I

TABLE 7-18—*Land use in the four county area surrounding but not including the ORR, which is considered to be 80% in native forest vegetation with the remainder in facilities, roads, and rights-of-way*[1]

	Cropland	Pasture	Forest	Other	Total
1000s of ha (acres)	30 (75)	54 (133)	177 (437)	72 (177)	332 (822)
percent	9	16	53	22	

[1] Derived from Census of Agriculture, Volume 1 Geographic Area Series, Part 42: Tennessee State and County Data, U.S. Department of Commerce, Bureau of the Census, 1987; and Tennessee Statistical Abstracts 1992/1993, The University of Tennessee, Knoxville, Center for Business and Economic Research, 1993.

These disturbed sites provide opportunities for establishment of nonnative plant species and subsequent intrusion or expansion of populations of these species into surrounding native plant communities.

7.7.2 Off-Site

Contaminants from waste sites are transported off the reservation in streams leaving the ORR. After leaving the ORR, East Fork Poplar Creek, the largest of the contaminated streams, travels a short distance through the city of Oak Ridge before reentering the ORR. All contaminated streams enter the impounded river at the boundary of the ORR. Transport of contaminants from waste sites off the reservation through ingestion by wide-ranging wildlife such as Canada goose, coyote, and white-tailed deer is probably not a major mode of off-site transport. Of the three classes of contaminants (organics, inorganics, and radioactive elements) migrating from waste sites into nearby streams, the major source of radionuclides in the region would be the ORR. Therefore, regional (off-site) cumulative risks for radionuclides would be the same as on-site risks. At the time of the analyses, no regional data for organics or metals were available, although the Y-12 sites is known to be the principal source of mercury in East Fork Poplar Creek. Cumulative risks for the region of influence could not be estimated.

CHAPTER 8: ROCKY FLATS PLANT

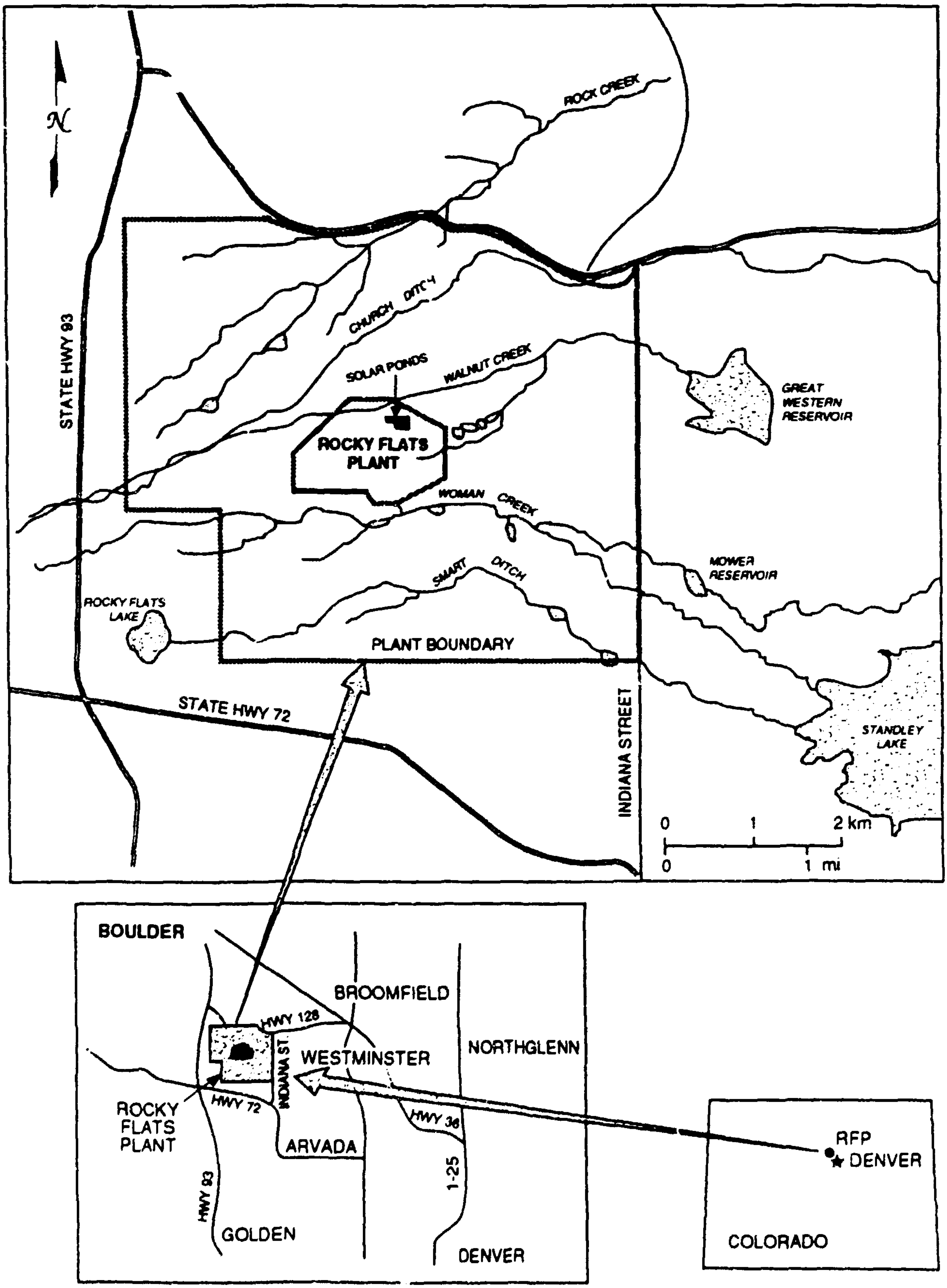
The Rocky Flats Plant (RFP) lies in northern Jefferson County, approximately 25 km (16 miles) northwest of Denver. RFP and its buffer zone occupy 2652 ha (6550 acres) of former rangeland on broad, relatively gently sloping alluvial fans immediately east of the Front Range of the Rocky Mountains. Elevations on the site range from 1722 m (5650 ft) in the east to 1890 m (6200 ft) at the western boundary. The continental climate is characterized by cold winters, moderately warm summers, and relatively low precipitation (an average of 38 cm or 15 in. per year). The growing season typically lasts from mid-May through late September. RFP soils tend to be fairly deep, well-drained clay, cobbly clay, and sandy loams of moderate to low permeability. Most of the RFP facilities lie within a centrally located, fenced industrial area of approximately 156 ha (384 acres). The buffer zone has several relatively minor developments such as holding ponds, gravel pits, a target range, a salvage yard, and a sanitary landfill, but for the most part the buffer zone is characterized by vegetation representative of tall grass prairie, short grass plains, lower montane, and foothill ravine regions. These communities in turn support wildlife typical of similar areas all along the foothills of the Front Range. Housing developments are encroaching into rangelands adjoining the northeast, east, and southeast perimeter of the buffer zone. Non-DOE industrial facilities are located near the southern boundary, whereas clay and gravel pit operations are found along the western boundary. Public lands near the site include Boulder County Open Space land adjoining the northern boundary and the Standley Lake Recreation Area to the east.

The surface waters at RFP provide natural and man-made habitat supporting aquatic communities characteristic of the semiarid foothills region where prairie and mountains meet. RFP surface waters are small in scale, and many contain water only intermittently, a natural condition in headwater streams due to a highly seasonal distribution of precipitation and snow melt. Aquatic ecosystems on the site consist primarily of holding ponds, farm ponds, ditches, springs, and three intermittent creek systems of the South Platte River drainage. Small wetland areas are associated with many of these surface waters. The three principal creek systems (Rock Creek, Walnut Creek, and Woman Creek) generally flow eastward across the site as shown in figure 8-1. Several impoundments of small to moderate size lie within these creek basins. Although intermittent surface runoff supplies some of the water to these aquatic ecosystems, perennial groundwater discharges through seeps and springs are more important in maintaining stable, long-lived aquatic habitats on the site. Small wetlands and areas of riparian habitat occur along streams and around springs and seeps.

More detailed descriptions of the environmental characteristics of the site and surrounding environs may be found in the Baseline Biological Characterization (DOE 1992) and the Final EIS for the RFP site (DOE 1980).

Most of the contaminated sites are associated with the central industrial area and the holding ponds downstream of the industrial area. Particularly important sites include the solar evaporation ponds and contaminated soils associated with these ponds and other waste facilities. In addition, almost one third of the surface soils of the RFP site and buffer zone, approximately 810 ha (2000 acres), is contaminated with low concentrations of plutonium and americium. Based on the source-term data (appendix B) used in this assessment, a total of 982 ha (2420 acres) of soil and 17.4 ha (42.9 acres) of surface water (and associated sediments) within the RFP site boundaries are contaminated by at least one contaminant. Moreover, another 552 ha (1360 acres) of off-site reservoirs and their sediments are contaminated by low levels of radionuclides:

ORNL-DWG 94M-5260



the 84-ha (210 acres) Great Western Reservoir, 465-ha (1150 acres) Standley Lake, and 3.6-ha (8.9 acres) Mower Reservoir.

8.1 Ecological Endpoints and Species Distribution

The ecological endpoints and representative receptors chosen for the Rocky Flats reservation are described in this chapter. In summary, at least five federally listed threatened, endangered, or candidate species of plants or animals are possible residents or visitors on the reservation; wetlands are found in swales, ditches, and ponds, along the streams, and in topographic depressions; recreational wildlife species are present but hunting is not allowed; and agricultural practices are prohibited. No public areas occur within the reservation, but public open land adjoins the northern boundary and a recreational area lies near the southeastern boundary. Vegetation and wildlife (i.e., biodiversity) are typical of that found in the surrounding area.

Vegetation representative of tall grass prairie, short grass plains, lower montane, and foothill ravine regions dominates most of the RFP reservation outside the highly disturbed central industrial area. These vegetation communities in turn support wildlife typical of the foothills of the Front Range. Most of the few non-riparian trees growing on the site were planted. Springs, streams, and holding ponds support small wetlands. Recreational fish are found in some of the holding ponds, and recreational wildlife are present, but neither hunting nor fishing is allowed on the reservation. Agriculture is not permitted on the reservation. No public lands occur on the reservation, but limited public land does occur adjacent to the reservation boundary. Four federally listed and candidate species are known to reside, visit, breed, or over-winter on or in the vicinity of the site. Several other listed or candidate species could possibly find suitable habitat on the reservation. Important species groups of concern for conservation of biodiversity include native vegetation, deer, rodents, jackrabbits, and wintering and migratory birds and wildlife.

Determining risks to endpoints requires (1) defining distribution and composition of endpoints and (2) selecting representative receptor species. The distribution of endpoints must be known in order to determine both exposure pathways for contaminants and risks to endpoints from construction.

For purposes of determining risk of exposure to contaminants, distribution of endpoints is considered to be either ubiquitous (i.e., more or less uniformly distributed throughout the reservation or region), discrete (i.e., located in one clearly identified location), or discontinuous (i.e., found in several locations within a limited area or areas). Risks to ubiquitous endpoints are assumed to be related to the total surface area affected by contaminant exposure or by disturbance from remediation. Risks to discontinuous and discrete endpoints are determined if their locations are known to be within contaminated areas or within areas affected by remedial activities or contaminant exposures.

Ubiquitous endpoints on the RFP reservation include endangered species, recreational wildlife, and certain components of biodiversity (table 8-1). On the other hand, wetlands, federally listed candidate and threatened species, and other elements of biodiversity and recreational wildlife exhibit discontinuous distributions. The distribution of endpoints for agricultural production and public lands (off-site only) can best be described as discontinuous and discrete, respectively. Locations of endpoints were determined from existing maps and publications.

Endpoints can be represented by many different receptors. The following sections describe endpoints on the RFP reservation and receptors selected for our analyses.

TABLE 8-1—*Distribution of Endpoints and Receptors on the Rocky Flats Plant Reservation*

Ubiquitous	Discontinuous	Discrete
Foraging **Federally listed species** (peregrine falcon, bald eagle, Preble's jumping mouse) **Recreational wildlife** (rabbit, deer, mallard) Important components of **biodiversity** not included in the above (coyote, meadowlark, vegetation)	Possible resident, **Federally listed and candidate species** (Ute lady's-tresses) **Wetlands** (benthos, fish, and riparian vegetation along streams)	Prairie dog colonies, one component of **biodiversity** **Public lands** near the reservation

8.1.1 Threatened and Endangered Species

8.1.1.1 Receptors

Four federally listed and candidate species have been known to occur at least occasionally at RFP: the endangered peregrine falcon (*Falco peregrinus*) and bald eagle (*Haliaeetus leucocephalus*) and the candidate ferruginous hawk (*Buteo regalis*) and Preble's meadow jumping mouse (*Zapus hudsonius preblei*). The endangered black-footed ferret (*Mustela nigripes*), a threatened flowering species, the Ute lady's-tresses (*Spiranthes diluvialis*), and five other candidate species have not been observed but could possibly occur on the reservation on the basis of what appears to be the presence of potentially suitable habitat. Prairie dog colonies on the reservation are considered too small to support even one black-footed ferret, however (EG&G 1991). The candidate species are the Colorado butterfly plant (*Gaura neomexicana* var. *coloradensis*), swift fox (*Vulpes velox*), white-faced ibis (*Plegadus chichi*), mountain plover (*Charadrius montanus*), and long-billed curlew (*Numenius americanus*). Table 8-2 lists those threatened, endangered, and candidate species that occur or may occur on the reservation. For purposes of this assessment, the bald eagle, peregrine falcon, Preble's meadow jumping mouse, and, because of the special interest expressed by the U.S. Fish and Wildlife Service, the Ute lady's-tresses, were selected as the receptors representing the threatened and endangered species endpoint.

8.1.1.2 Distribution

Candidate Preble's meadow jumping mice have been captured from three of the major drainages on the reservation: the Walnut Creek, Rock Creek, and Woman Creek drainages, usually in moist sites within 30–60 ft of a stream channel (Stoecker 1992). Shrubby riparian vegetation dominated the mouse habitat, in particular coyote willow, indigo bush, and western snowberry, with dense forbs, tall grasses, and sedges usually growing nearby. This type of habitat amounts to a very small fraction of the reservation. Food items include seeds of grasses and other plants, berries, insects, and fungus (EG&G 1991). The distribution of this species would be considered discontinuous.

Occasionally, the endangered bald eagle has been observed to soar over the reservation during winter or, as a migrant, during spring and fall. Although individuals also have occasionally been seen perching on utility poles in the northeast corner of the reservation, none have been observed roosting or actively hunting prey within the reservation (DOE 1992). These large birds of prey generally prefer large bodies of water with trees for perching nearby. Although these conditions are not met on the reservation, Great Western Reservoir, only about 0.5 km (0.3 mile) east of the reservation, and Standley Lake, about

TABLE 8-2—*Federally Listed Threatened, Endangered, And Candidate Species on the Rocky Flats Plant*[1]

Species	Common Name	Status[2]
BIRDS		
Haliaeetus leucocephalus	Bald eagle	E
Falco peregrinus	Peregrine falcon	E
Buteo regalis	Ferruginous hawk	C2
Lanius ludovicianus	Loggerhead shrike	C2
Plegadis chihi	White-faced ibis	C2[3]
Charadrius montanus	Mountain plover	C2[3]
Numenius americanus	Long-billed curlew	C2[3]
MAMMALS		
Mustela nigripes	Black-footed ferret	E[3]
Zapus hudsonius preblei	Preble's meadow jumping mouse	C2
Vulpes velox	Swift fox	C2[3]
PLANTS		
Spiranthes diluvialis	Ute lady's-tresses	T[3]
Gaura neomexicana var. *coloradensis*	Colorado butterfly plant	C2[3]

[1] Endangered and threatened wildlife and plants, 50 CFR 17.11 and 17.12, July 15, 1991; Endangered and threatened wildlife and plants: candidate review, 56 FR 58804 - 58836, November 21, 1991.

[2] E = endangered, T = threatened, C2 = candidate under review

[3] Not observed at RFP, but known from region and potential habitat identified on site.

1.9 km (1.2 miles) east, appear to satisfy these preferences, given reports of roosting bald eagles at these reservoirs (Uppendahl 1990). If available, fish usually make up most of their diet. However, if freezing of reservoir surfaces prevent preying on fish in the winter, the eagles may infrequently feed on carrion or small mammals on the RFP reservation. The nearest known nest is 40 km (25 miles) from RFP. This species is considered to have a ubiquitous distribution when it is present on the reservation.

The nearest suitable nesting habitat of the endangered peregrine falcon (cliffs and river gorges) is approximately 8 km (5 miles) southwest of the reservation (EG&G 1991). The reservation is, however, well within the hunting range of the peregrine falcon, and these birds have been observed on occasion to fly over, pursue prey, and perch on the reservation (DOE 1992). Their diet consists primarily of other birds and, secondarily, small rodents. Like the bald eagle, the peregrine falcon's distribution on the reservation is considered to be ubiquitous when it occurs at all.

A terrestrial orchid, the threatened Ute lady's-tresses, has not been found on the reservation. The presence, however, of apparently appropriate habitat in the form of moist, grass-dominated swales and wetland edges supporting cattails, rushes, and sedges, in concert with the location of known populations a few kilometers north and south of the reservation (EG&G 1991), argued for its inclusion in this assessment. If present, this orchid would have a discontinuous distribution.

8.1.2 Wetlands

8.1.2.1 Receptors

Wetlands on and in the vicinity of the reservation, including riparian woodland, marshes, and wet meadows, support a variety of wetland vegetation, aquatic life, and wildlife. Wetland plants on the site include watercress, sandbar willow, cottonwood, cattails, rushes, and sedges. Twenty-three species of waterfowl and shorebirds, of which the mallard is most abundant, make use of reservation wetland resources to satisfy their requirements for shelter, food, and breeding habitat (DOE 1992). Because species-specific toxicity benchmarks for most wetland-dependent organisms are limited, benthic macroinvertebrates and fish were selected as generic receptors representative of the wetland endpoint. The mallard also was selected as a representative wetland receptor.

8.1.2.2 Distribution

Several wetland types are distributed discontinuously throughout the reservation according to wetland maps prepared by the U.S. Fish and Wildlife Service (FWS 1975) and studies conducted by the U.S. Army Corps of Engineers and EG&G (1990). These wetlands are mostly associated with open holding reservoirs and ponds, numerous intermittent streams, and hillside seeps. Total measured wetlands on the reservation amount to 43 ha (107 acres) (EG&G 1990), or approximately 1.6% of the entire reservation area. In addition, approximately 26 km (85,000 linear ft) of wetland occur along intermittent stream courses. Altogether, about 3.6% of the reservation is in one kind of wetland (including open water) or another. East of the reservation, but potentially under its influence another 63 ha (156 acres) of aerial wetlands and 4.3 km (14,200 ft) of linear wetlands occur (EG&G 1990). Most of these wetlands (57 ha or 140 acres) are associated with the Great Western Reservoir.

8.1.3 Recreational Fish and Wildlife

8.1.3.1 Receptors

Although the entire reservation is closed to the public, the buffer zone supports or is periodically visited by several recreationally desirable species of fish and wildlife. Among these are mule deer, white-tailed deer, elk, desert cottontail, black-tailed jackrabbit, coyote, raccoon, Canada goose, mallard, bufflehead, largemouth bass, green sunfish, and white sucker (DOE 1992). For the assessment of the RFP reservation, the mule deer, jackrabbit, coyote, and mallard, along with fish in general, were chosen as receptors representative of the recreational fish and wildlife endpoint. To maintain conservatism in the analysis, all of these receptors are considered to be year-round residents; at RFP, this is certainly a reasonable assumption, since even the mallard is common on the reservation throughout the year.

8.1.3.2 Distribution

The mule deer, jackrabbit, coyote, and mallard are assumed to have ubiquitous distributions. Fish on the reservation exhibit a discontinuous distribution defined principally by perennial water bodies such as holding ponds.

8.1.4 Agricultural Production

8.1.4.1 Receptors

Although once a part of the vast area of open rangeland dominating this region in the past, the reservation is now off-limits to agriculture of any kind. This endpoint, therefore, will not be considered further.

8.1.5 Parks and Other Public Lands

8.1.5.1 Receptors

As pointed out in the introduction to this chapter, no public lands overlap the site, and the only designated public lands near the site are the Boulder County Open Space land adjoining the northern boundary of the reservation and the Standley Lake Recreation Area 1.9 km (1.2 miles) to the east. Maximum risks to these endpoints were assumed to be equivalent to those calculated for the same food web components (receptors) within the reservation boundary in the case of the adjacent Boulder County Open Space land. This holds true for Standley Lake as well since it was included in the total area of contamination used to calculate HIs for the various receptors.

8.1.5.2 Distribution

Each of these public lands is considered to have a discrete distribution.

8.1.6 Biodiversity

8.1.6.1 Receptors

Because (1) the RFP site occupies an ecological and topographical transition zone including elements of both the prairie and Front Range foothills, and (2) most of the reservation outside the fairly small industrial area is relatively undisturbed (especially when compared with the continuing development of surrounding lands), this reservation represents an important reservoir of biodiversity in the region. In particular, the reservation exhibits diverse plant communities including tall and short grass prairie, small stands of riparian woodlands, marshes and other small wetlands, prickly pear and yucca uplands, and ravine uplands supporting wild plum, chokecherry, and hawthorn. These plant communities in turn support, directly or indirectly, diverse arthropod, amphibian, reptile, bird, and mammal communities. Recent sampling at RFP identified 1232 taxa of plants and animals, including 768 species of terrestrial and aquatic plants, 300 taxa of terrestrial animals, and 164 taxa of aquatic animals (DOE 1992). All of the receptors already identified for the preceding threatened and endangered, wetland, and recreational fish and wildlife endpoints are also important elements of the reservation's food webs and, ultimately, biodiversity. Other receptors selected for this assessment of risks to biodiversity are the prairie dog, the meadowlark, coyote, and vegetation.

8.1.6.2 Distribution

The two prairie dog colonies on site exhibit discrete distributions, one paralleling about 700 m (2300 ft) of the northeast boundary (the greater part of this colony is actually outside the reservation boundary), the other just south and west of the east gate. The fish and benthic macroinvertebrates have discontinuous distributions defined by wetlands, streams, and man-made impoundments, whereas the meadowlark and vegetation are assumed to have ubiquitous distributions (table 8-1).

8.2 Constituents of Potential Concern

The constituents of potential concern at Rocky Flats include inorganic, organic, and radioactive contaminants (table 8-3). The most prevalent radionuclides, according to relative average concentrations, are ^{241}Am and ^{90}Sr, whereas Al, Ba, Be, cyanide ion, Pb, Mn, Hg, and Zn are the

TABLE 8-3—*Maximum and Average Soil Concentrations on the Rocky Flats Plant [mg/kg dry weight (for chemical constituents) or pCi/kg dry weight (for radionuclides)]*

Constituent	Maximum Concentration	Constituent	Average Concentration
Acetone	2.60E+01	Acetone	7.46E-01
Aroclor 1254	5.40E+01	Aroclor 1254	5.40E+01
Aroclor 1260	1.60E+03	Aroclor 1260	7.47E+00
BEHP	1.40E+03	BEHP	4.70E+00
2-butanone	3.90E-01	Di-n-butyl phthalate	2.70E+00
Carbon disulfide	1.90E+01	Toluene	2.76E+01
Carbon tetrachloride	1.00E-01	Aluminum	1.18E+04
1,2-dichloroethane	1.10E-01	Antimony	3.96E+01
di-n-butyl phthalate	2.70E+00	Arsenic	1.27E+01
Ethyl benzene	7.80E-01	Barium	3.24E[illegible]01
Methylene chloride	1.30E-01	Beryllium	1.97E+03
4-methyl-2-pentanone	6.80E-02	Chromium	9.0[illegible]-02
1,1,1-trichloroethane	2.50E-01	Copper	6.53E+01
Trichlorethylene	1.50E-01	Cyanide ion	8.70E+00
Xylene	3.30E+00	Iron	2.82E+04
Aluminum	1.76E+04	Lead	1.31E+01
Antimony	3.96E+01	Magnesium	2.32E+03
Arsenic	3.70E+01	Manganese	3.36E+02
Barium	5.30E+02	Mercury	9.66E+00
Beryllium	1.97E+03	Nickel	2.81E+01
Boron	2.77E+00	Vanadium	5.49E+01
Chromium	7.56E+01	Zinc	7.51E+01
Copper	7.36E+01	Americium-241	2.47E+08
Cyanide ion	8.70E+00	Strontium-90	9.76E+13
Iron	1.23E+05		
Lead	8.69E+01		
Magnesium	3.87E+03		
Manganese	5.51E+02		
Mercury	1.14E+02		
Nickel	2.81E+01		
Vanadium	6.00E+01		
Zinc	1.73E+02		
Americium-241	5.92E+11		
Plutonium-238	1.34E+03		
Plutonium-239	2.05E+07		
Radium-226	1.60E+03		
Strontium-90	9.76E+13		
Uranium-234	2.20E+03		
Uranium-235	3.30E+02		
Uranium-238	4.50E+05		

TABLE 8-4—*Maximum and Average Water Concentrations on the Rocky Flats Plant*
[mg/L (for chemical constituents) or pCi/L (for radionuclides)]

Constituent	Maximum Concentration	Constituent	Average Concentration
Acetone	2.90E–02	Acetone	5.75E–03
Aldrin	6.00E–02	BEHP	1.86E–02
Ammonia	5.00E–01	Di-n-butyl phthalate	1.85E–03
BEHP	6.50E–01	Phenol	6.44E–02
Benzene	2.46E–03	Toluene	2.82E–03
Bromoform	2.13E–03	Aluminum	4.21E–01
2-butanone	1.30E–02	Antimony	6.70E–02
Butylbenzylphthalate	3.00E–03	Arsenic	1.30E–02
Carbon disulfide	4.00E–03	Barium	1.02E–01
Carbon tetrachloride	7.00E–03	Beryllium	3.90E–03
Chlorobenzene	6.00E–03	Cadmium	3.94E–01
Chloroform	1.00E–02	Chromium	1.09E–03
Diazinon	2.80E–03	Cobalt	1.85E–03
1,1-dichloroethane	1.10E–02	Copper	1.47E–02
1,2-dichloroethane	3.00E–03	Cyanide ion	1.36E+03
1,1-dichloroethene	2.38E–03	Iron	6.84E–01
trans-1,2-dichloroethylene	3.00E–03	Lead	3.58E–03
di-n-butyl phthalate	2.00E–02	Magnesium	4.48E+01
di-n-octylphthalate	1.60E–02	Manganese	9.68E–02
Ethyl benzene	3.12E–03	Mercury	2.03E–01
2-hexanone	8.46E–03	Molybdenum	6.00E–03
Methylene chloride	7.90E–02	Nickel	6.92E–02
4-methyl-2-pentanone	3.10E–02	Potassium	3.67E+00
2-methylphenol	2.40E–02	Silver	6.71E–03
n-nitrosodiphenylamine	3.00E–01	Sodium	1.95E+02
n-nitrosodipropylamine	3.90E+00	Thallium	7.58E–03
Parathion-ethyl	2.00E–02	Vanadium	3.13E–02
Phenol	2.00E+00	Zinc	2.57E–01
Simazine	6.00E+00	Americium-241	2.42E–02
Simetryn	6.40E–01	Strontium-90	7.44E+10
Tetrachlorethene	1.40E–02		
Toluene	1.50E–02		
1,1-trichlorethane	2.96E–03		
1,1,1-trichloroethane	6.00E–03		
Trichlorethylene	2.60E–02		
Vinyl acetate	8.37E–03		
Xylene	3.00E–03		
Aluminum	7.39E+01		
Antimony	9.44E–02		
Arsenic	1.40E–02		
Barium	1.05E+00		
Beryllium	1.30E–01		
Cadmium	6.43E+00		
Chloride	7.63E+02		
Chromium	9.50E–02		
Cobalt	8.00E–02		
Copper	1.40E–01		
Cyanide ion	9.65E+03		

Table 8-4 (cont'd)

Constituent	Maximum Concentration	Constituent	Average Concentration
Acetone	2.90E-02	Acetone	5.75E-03
Flouride	7.30E+01		
Iron	7.72E+01		
Lead	1.30E-01		
Lithium	2.60E+01		
Magnesium	1.81E+02		
Manganese	4.25E+00		
Mercury	2.00E+00		
Molybdenum	5.00E-01		
Nickel	8.20E-01		
Nitrate	1.60E+03		
Nitrite	7.50E+01		
Potassium	3.76E+02		
Selenium	2.83E-02		
Silver	4.46E+00		
Sodium	2.44E+03		
Sulfate	7.36E+02		
Thallium	2.10E-02		
Tin	2.03E-01		
Vanadium	3.13E-01		
Zinc	4.21E+00		
Americium-241	8.60E+00		
Cesium-137	1.00E-01		
Plutonium-239	6.70E+02		
Radium-226	6.20E+00		
Radium-228	7.90E+00		
Strontium-90	1.20E+11		
Tritium	1.05E+03		
Uranium-234	2.60E+03		
Uranium-235	1.00E+02		
Uranium-238	3.90E+03		

TABLE 8-5—*Maximum and Average Sediment Concentrations on the Rocky Flats Plant [mg/kg (for chemicals) or pCi/kg (for radionuclides)]*

Constituent	Maximum Concentration	Constituent	Average Concentration
Acenapthene	4.50E+00	Acetone	4.70E–02
Acetone	4.70E–02	Phenol	7.40E+00
Ammonia	1.35E+02	Toluene	1.00E–03
Atrazine	1.00E+01	Aluminum	2.50E+03
2-butanone	2.00E–03	Barium	7.70E+01
4-chloro-3-methyl phenol	7.90E+00	Cadmium	8.06E+01
2-chlorophenol	7.70E+00	Chromium	7.36E+00
1,4-dichlorobenzene	4.00E+00	Copper	7.36E+01
2,4-dinitrotoluene	3.50E+00	Cyanide ion	3.20E+03
Methylene chloride	5.00E–03	Iron	1.28E+04
n-nitrosodiphenylamine	3.70E–01	Lead	1.26E+01
Phenol	7.40E+00	Magnesium	3.81E+03
Pyrene	4.60E+00	Manganese	1.34E+02
Tetrachloroethane	1.30E–01	Mercury	2.00E+00
Toluene	1.00E–03	Nickel	6.97E–02
1,2,4-trichlorobenzene	4.30E+00	Silver	8.93E–02
Aluminum	1.00E+04	Sodium	7.78E+02
Barium	1.54E+02	Thallium	7.00E+00
Cadmium	1.08E+02	Vanadium	1.98E+01
Chloride	1.12E+04	Zinc	8.47E+01
Chromium	1.47E+01	Americium-241	6.71E+08
Copper	9.60E+01	Strontium-90	1.00E+13
Cyanide ion	3.20E+03		
Iron	2.13E+04		
Lead	2.61E+01		
Lithium	4.30E+01		
Magnesium	1.37E+04		
Manganese	2.08E+02		
Mercury	2.00E+00		
Nickel	1.65E+01		
Nitrate	1.30E+04		
Nitrite	4.70E+02		
Silver	2.12E+01		
Sodium	3.13E+04		
Sulfate	6.95E+03		
Sulphide	5.60E+01		
Thallium	7.00E+00		
Vanadium	3.96E+01		
Zinc	1.01E+02		
Americium-241	3.00E+01		
Cesium-137	9.00E+02		
Plutonium-239	1.90E+04		
Strontium-90	1.20E+14		
Uranium-234	9.50E+02		
Uranium-238	1.00E+03		

most important inorganics based on their prevalence and/or toxicity. The principal organics are acetone, polychlorinated biphenyl (PCBs), bis(2-ethylhexyl)phthalate (BEHP), and toluene.

Maximum and average concentrations of chemical and radiological constituents in soil, surface water, and sediment were determined from the source terms provided by PNL (tables 8-3, 8-4, and 8-5). Determination of these average and maximum concentrations required that certain assumptions be made with regard to data interpretation and compensation for data gaps. Appendix B describes the methodology used to develop the source terms (contaminant concentrations) for input into the exposure and risk assessment.

8.3 Exposure Assessment

Estimating contaminant exposure for representative receptor species on the reservation involves knowledge of the number and kinds of individual organisms exposed to wastes, the amount of time spent in waste areas, and the amount of contaminant uptake. Because site-specific home ranges, behavior patterns, and habitat requirements at Rocky Flats are not well known, an initial assessment for contaminant exposure was conducted using maximum known contaminant concentrations of each contaminant in each medium (i.e., soil, water, and sediment). Even though only a few individuals of certain species with small home ranges (e.g., small birds and mammals) could reside within contaminated areas for most of their lives, and even fewer individuals could contact the most contaminated areas, in this initial screening, these maximum concentrations, where available, were applied to all receptor species to identify the worst-case potential contaminants. Contaminants that did not pose a risk to any of the receptor species from exposure to the maximum values were not considered further. If exposure to the maximum concentrations of contaminants posed a risk to organisms, however, then the average concentrations of those contaminants were estimated and used in the assessment to determine the most probable and reasonable exposure and risk.

This risk assessment estimates the risk to vegetation, terrestrial wildlife, and aquatic organisms from chronic exposure to radiological and nonradiological contaminants [refer to appendix A for a more detailed discussion of methods]. It is desirable in exposure analysis to consider all ecological endpoints and their corresponding species. However, due to (1) limited availability of exposure sensitivity data for many species (e.g., threatened and endangered species) and (2) presumed similarities in exposure risk (e.g., similarly sized raptors feeding on the same prey), representative organisms for each endpoint were chosen for evaluation. A food web was developed that includes receptor species representing the endpoints (figure 8-1). Where data were available, conservative estimates of exposure and risk were made by selecting receptors that are (1) most sensitive to contaminants or habitat alteration, (2) most likely to experience additional risk because of bioaccumulation or larger body size, or (3) at greatest risk because of rarity. Other abundant species on the reservation were included as important prey components of the foodweb, such as mice and insects (risk estimates were not determined for insects).

The primary exposure routes for terrestrial wildlife species are exposure to external radiation and ingestion of food (including soils for some species) and water. Table 8-6 lists the body weights and consumption rates for the representative species. With respect to herbivore species, the jackrabbit and prairie dog are assumed to feed exclusively on the vegetative parts of plants, whereas the mule deer is assumed to eat 80% vegetation and 20% fruits and seeds. The diet of the mallard duck is assumed to consist of 100% fruits. On the basis of a review of the literature, the percentages of prey items consumed by omnivores and predators were also estimated (table 8-6; figure 8-2). The mouse is assumed to eat 20% fruits and seeds and 80% insects; the meadowlark, 70% fruits and seeds and 30% insects; the peregrine falcon, 80% meadowlark and 20% mice; the bald eagle, 30% fish, 50% mallards, and 20% jackrabbits; and the coyote, 30% mice, 40% jackrabbits, and 30% prairie dogs. Insects are assumed to eat 100% plant tissue.

Except for the raptors and coyote, all species are assumed to purposely or incidentally ingest soil while eating, grooming, or preening (table 8-6). The soil ingestion rate (Q_s) for black-tailed jackrabbits is 6.3% of the dry-matter intake (Arthur and Gates 1988); the mule deer soil ingestion rate is 1.35% of the dry-matter intake (Arthur and Alldredge 1979). The soil ingestion rates for the mouse and mallard are 2% and 8.2% of the dry-matter intake, respectively (Beyer et al. 1991). Because published values of soil ingestion rates were not found for the meadowlark, it was conservatively estimated to be 10% of the dry-matter intake.

The estimated daily rates of food and water consumption [Q_v, (Q_f, Q_H), Q_W, respectively] for each representative species were calculated from allometric regression equations that are based on the weight of the organism (EPA 1988) (appendix A). These equations are based on the combined measurements for laboratory animals, livestock, and selected wildlife and bird species.

Because details of the behaviors and habitat requirements of most of the representative wildlife species are not well known, it is assumed that all species, except the bald eagle and the peregrine falcon, spend 100% of their time on the reservation. Thus, all representative species, except the two raptors, are considered to be year-round residents at Rocky Flats. Therefore, the fraction of contaminated vegetation, fruit, prey, soil, and water consumed (F_v, F_f, F_H, F_S, F_W, respectively) is set at 100% (table 8-6). The bald eagle and peregrine falcon are present on or near the reservation only about six months or less each year (DOE 1992), and thus their values are set at 50%.

Contaminant concentrations in vegetation, the first level in the foodchain, are estimated from source-term concentrations in the soils using published element- or chemical-specific soil-to-plant transfer factors (Baes et al. 1984; Travis and Arms 1988) (table 8-7). Transfer factors for inorganic chemicals are available for both the vegetative and fruiting parts of plants (Baes et al. 1984); however, the transfer factors for organic chemicals do not make this distinction (Travis and Arms 1988). Moreover, the methodology used to predict contaminant concentrations in vegetation does not make a distinction between different plant types or species. Therefore, all species ingest "generic" vegetation containing contaminant concentrations derived from soil concentrations by the use of transfer factors.

Transfer factors for contaminants of concern are used to predict concentrations in the tissues of terrestrial mammalian receptors from consumption of vegetation, soil, and water (collectively termed B_b) (Baes et al. 1984; Travis and Arms 1988) (table 8-7). Data on transfer factors from vegetation or soil to insects and earthworms are very limited in the literature. Therefore, the concentration in insects was derived from vegetation concentrations, and a default, conservative one-to-one transfer between vegetation and insects was assumed. Fish bioconcentration factors were applied to estimate the concentrations of contaminants in fish tissue for consumption by the bald eagle (Droppo, et al. 1989; and Strange and Peterson 1989) (table 8-7). The rationale and limitations for applying these transfer factors are discussed in appendix A.

The consumption rates and the benchmark limits or no-observable-adverse-effects level (NOAEL) values are typically reported in wet weights, whereas the vegetation and soil concentrations are usually reported in dry weights. Therefore, conversion factors were applied to account for this difference. The concentration conversion factor for wet to dry weight for the vegetative parts of plants on Rocky Flats is assumed to be 0.91 [the lower end of the range of water content for hay grasses (Suter 1993)]. The conversion factor for the fruiting parts of plants on Rocky Flats was assumed to be 0.17 (Morrison 1959). The conversion factor for soils was assumed to be 0.98, based on the conversion factor for soils in southwest Idaho (Rope et al. 1988).

For the baseline assessment of Rocky Flats, the concentrations of radionuclides in animal tissues and the resulting doses were not decay-corrected. Doses are estimated for existing conditions and not for some point in the future. The primary radionuclides of concern, ^{241}Am and ^{90}Sr, have relatively long half-lives (432 and 29 years, respectively), so this assumption is not unreasonable. The radionuclide-concentration

TABLE 8-6—*Body Weights and Consumption Rates*[a] *for Terrestrial Species*[b] *on the Rocky Flats Plant*

Parameter	Preble's Jumping Mouse	Black-tailed Jackrabbit	Prairie Dog	Mule Deer	Western Meadowlark	Mallard	Peregrine Falcon	Bald Eagle	Coyote
Body weight, BW (kg)	1.90E-02[c]	2.27E+00[d]	1.19E+00[e]	1.10E+02[f]	9.77E-02[g]	1.18E+00[h]	8.34E-01[i]	4.50E+00[j]	1.60E+01[k]
Water intake rate, Q_w (L/d)	6.40E-03	1.83E-01	1.26E-01	4.45E+00	2.24E-02	1.25E-01	1.13E-01	3.59E-01	7.73E-01
Water ingestion fraction, FI_w	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	5.00E-01	5.00E-01	1.00E+00
Soil intake rate, Q_s (kg/d)	5.19E-05[l]	9.32E-03[m]	1.63E-04[n]	3.04E-02[o]	4.89E-04[p]	5.64E-03[q]	0.00	0.00	0.00
Soil ingestion fraction, FI_s	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	0.00	0.00	0.00
Vegetation intake rate, Q_v (kg/d)	0.00	1.59E-01[r]	1.63E-04	2.13E+00[s]	0.00	0.00	0.00	0.00	0.00
Vegetation ingestion fraction, FI_v	0.00	1.00E+00	1.00E+00	1.00E+00	0.00	0.00	0.00	0.00	0.00
Fruit/seeds intake rate, Q_f (kg/d)	8.20E-0[illegible][t]	0.00	0.00	5.32E-01	7.35E-03[u]	7.41E-02	0.00	0.00	0.00
Fruit/seeds ingestion fraction, FI_f	1.00E+00	0.00	0.00	1.00E+00	1.00E+00	1.00E+00	0.00	0.00	0.00
Prey 1 intake rate, Q_{H1} (kg/d)	3.28E-03 (insects)	0.00	0.00	0.00	3.15E-03 (insects)	0.00	1.29E-02 (mice)[v]	6.43E-02 (fish)[w]	1.75E-01 (mice)[x]
Prey 1 ingestion fraction, FI_{H1}	1.00E+00	0.00	0.00	0.00	1.00E+00	0.00	5.00E-01	5.00E-01	1.00E+00
Prey 2 intake rate, Q_{H2} (kg/d)	0.00	0.00	0.00	0.00	0.00	0.00	5.14E-02 (meadowlarks)	4.28E-02 (rabbits)	2.34E-01 (rabbits)
Prey 2 ingestion fraction, FI_{H2}	0.00	0.00	0.00	0.00	0.00	0.00	5.00E-01	5.00E-01	1.00E+00
Prey 3 intake rate, Q_{H3} (kg/d)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.07E-01 (mallards)	1.75E-01 (prairie dog)
Prey 3 ingestion fraction, FI_{H3}	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5.00E-01	1.00E+00

[a] All values are on a wet weight basis. For soils, the wet:dry ratio is 0.98 (Rope et al. 1988), for vegetation the ratio is 0.91 (the lower bound on the range for hay/grasses reported in (Suter 1993) and for fruits/seeds, the ratio is 0.17 (Morrison 1959).

[b] Water and food consumption rates were computed by methods in EPA 1988 (Table 4-8) unless otherwise noted.

[c] Whitaker 1972.

[d] Burt et al. 1976.

[e] Whitaker 1988

[f] Anderson et al. 1984.

[g] Western Bird Banding Association 1984

[h] Terres 1980.

[i] Terres 1980.

[j] Brown et al. 1968.

[k] Burt et al. 1976.

[l] The mouse soil ingestion rate is 2% of dry vegetation intake (Beyer et al. 191).

[m] The soil ingestion rate of the jackrabbit is 6.3% (Arthur et al. 1988).

[n] The prairie dog is assumed to have the same soil ingestion rate as the jackrabbit (6.3%)(Arthur et al. 1988).

[o] The mule deer soil ingestion rate is 1.35% of dry matter intake (Arthur et al. 1979).

[p] The meadowlark soil ingestion rate is assumed to be 10% of dry matter intake.

[q] The mallard soil ingestion rate is 8.2% of dry matter intake (Beyer et al. 1991).

[r] The black-tailed jackrabbit ingestion rate is 159 g/day wet weight (Arnold and Reynolds 1943).

[s] The mule deer is assumed to eat 80% vegetation and 20% fruit and seeds (Anderson et al 1984).

[t] The mouse is assumed to eat 20% fruit and seeds and 80% insects (Whitaker 1972).

[u] The meadowlark is assumed to eat 70% fruits and seeds and 30% insects (Terres 1980).

[v] The peregrine falcon is assumed to eat 20% mice and 80% meadowlarks (Terres 1980).

[w] The bald eagle is assumed to eat 50% mallard ducks, 20% rabbits and 30% fish (Terres 1980).

[x] The coyote is assumed to eat 30% mice, 30% prairie dog, and 40% rabbits (Whitaker 1988).

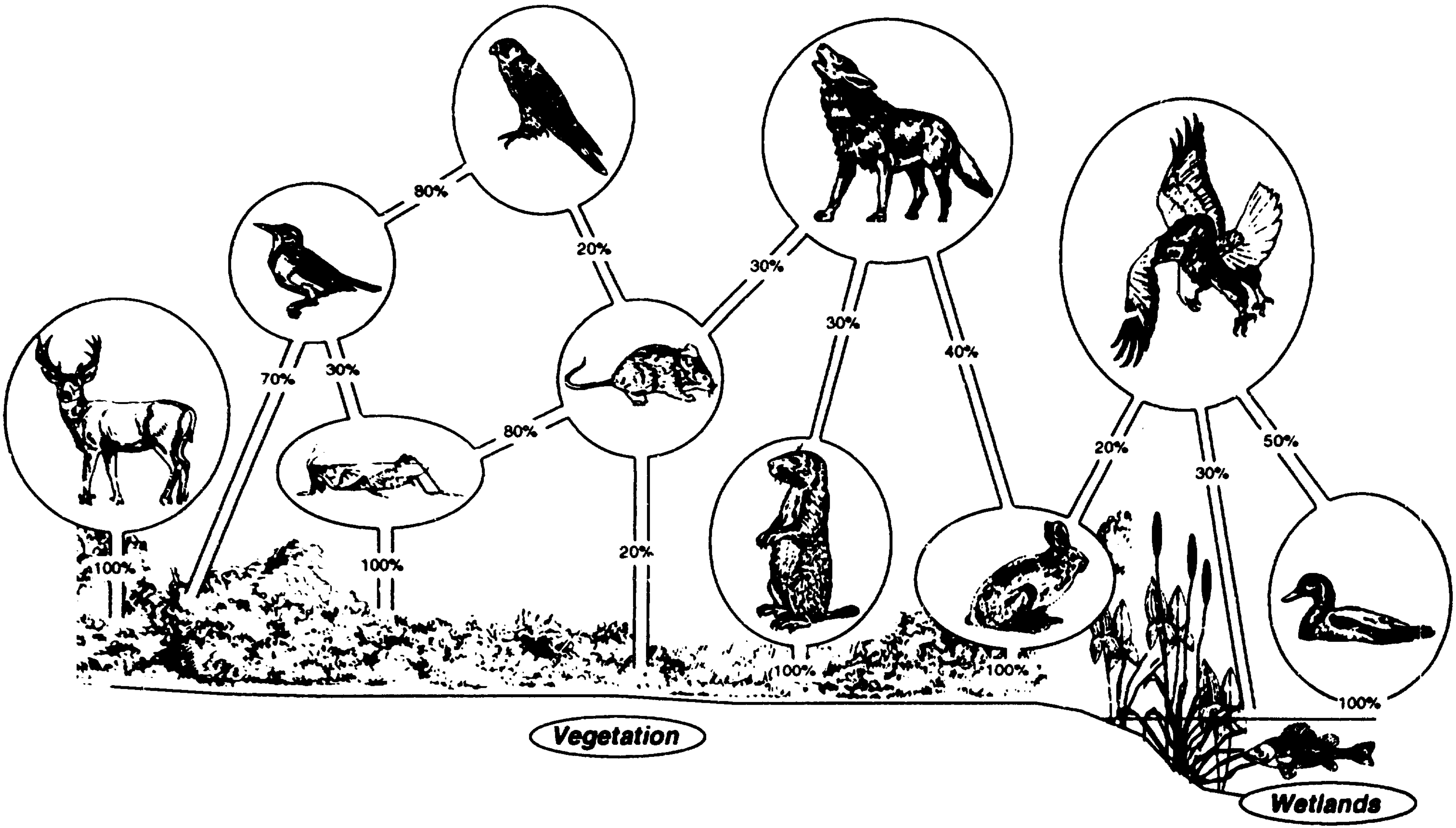


FIGURE 8-2. REPRESENTATION OF THE TERRESTRIAL FOOD WEB OF THE ROCKY FLATS RESERVATION

TABLE 8-7—*Soil to Vegetation, Soil to Fruit and Plant to Beef Transfer Factors, and Fish Bioconcentration Factors for Constituents of Concern at the Rocky Flats Plant*

Constituent	Fish Bioconcentration Factor	Soil to Vegetation Transfer Factor	Soil to Fruit Transfer Factor	Vegetation to Beef Transfer Factor
Acenapthene	6.46E+02	2.16E-01	2.16E-01	2.30E-04
Acetone	3.89E-01	5.33E+01	5.33E+01	1.44E-08
Aldrin	3.14E+03	7.14E-01	7.14E-01	2.51E-05
Aroclor 1254	2.30E+04	2.25E-02	2.25E-02	1.00E-02
Aroclor 1260	1.60E+05	2.25E-02	2.25E-02	1.00E-02
Atrazine	1.31E+01	4.03E+00	4.03E+00	1.26E-06
BEHP	1.19E+07	4.37E-02	4.37E-02	3.16E-03
Benzene	2.41E+01	2.37E+00	2.37E+00	3.16E-06
Bromoform	4.31E+01	1.63E+00	1.63E+00	6.03E-06
2-butanone	9.51E-01	2.63E+01	2.63E+01	4.90E-08
Butylbenzylphthalate	3.54E+03	5.70E-02	5.70E-02	2.00E-03
Carbon disulfide	1.95E+01	2.70E+00	2.70E+00	2.51E-06
Carbon tetrachloride	1.70E+01	9.32E-01	9.32E-01	1.59E-05
Chlorobenzene	6.45E+02	9.32E-01	9.32E-01	1.59E-05
Chloroform	1.85E+01	2.70E+00	2.70E+00	2.51E-06
2-chlorophenol	6.40E+00	2.07E+00	2.07E+00	3.98E-06
Diazinon	4.63E+02	2.46E-01	2.46E-01	1.58E-04
1,4-dichlorobenzene	6.00E+01	4.20E-01	4.20E-01	6.31E-05
1,1-dichloroethane	1.35E+01	3.53E+00	3.53E+00	1.58E-06
1,2-dichloroethane	2.00E+00	5.26E+00	5.26E+00	7.94E-07
1,1-dichloroethene	1.47E+01	2.37E+00	2.37E+00	3.16E-06
trans-1,2-dichloroethylene	1.36E+00	2.37E+00	2.37E+00	3.16E-06
di-n-butyl phthalate	1.07E+04	3.82E-02	3.82E-02	3.98E-03
di-n-octylphthalate	1.87E+07	1.86E-04	1.86E-04	3.98E+01
2,4-dinitrotoluene	1.95E+01	2.70E+00	2.70E+00	2.51E-06
Ethyl benzene	1.46E+02	4.92E-01	4.92E-01	4.79E-05
2-hexanone	6.59E+00	6.17E+00	6.17E+00	6.03E-07
Methylene chloride	5.74E+00	6.86E+00	6.86E+00	5.01E-07
4-methyl-2-pentanone	2.08E+00	7.84E+00	7.84E+00	3.98E-07
2-methylphenol	1.85E+01	2.85E+00	2.85E+00	2.29E-06
n-nitrosodiphenylamine	1.41E+02	6.25E-01	6.25E-01	3.16E-05
n-nitrosodipropylamine	7.99E+00	5.33E+00	5.33E+00	7.76E-07
Parathion-ethyl	4.63E+02	2.46E-01	2.46E-01	1.58E-04
Phenol	7.57E+00	5.26E+00	5.26E+00	7.94E-07
Pyrene	2.80E+03	3.35E-02	3.35E-02	5.01E-03
Simazine	6.69E-01	3.87E+01	3.87E+01	2.51E-08
Simetryn	6.69E-01	3.87E+01	3.87E+01	2.51E-08
Tetrachloroethane	3.90E+01	2.07E+00	2.07E+00	3.98E-06
Tetrachlorethene	5.57E+01	4.20E-01	4.20E-01	6.30E-05
Toluene	6.99E+01	1.07E+00	1.07E+00	1.26E-05
1,2,4-trichlorobenzene	1.09E+03	1.27E-01	1.27E-01	5.01E-04
1,1-trichlorethane	6.69E-01	3.87E+01	3.87E+01	2.51E-08
1,1,1-trichloroethane	9.00E+00	1.39E+00	1.39E+00	7.94E-06
Trichlorethylene	3.79E+01	1.59E+00	1.59E+00	6.31E-06
Vinyl acetate	1.34E+00	1.47E+01	1.47E+01	1.35E-07
Xylene	1.77E+02	5.48E-01	5.48E-01	3.98E-05
Aluminum	1.00E+00	4.00E-03	6.50E-04	1.50E-03
Antimony	1.00E+00	2.00E-01	3.00E-02	1.00E-03
Arsenic	1.00E+00	4.00E-02	6.00E-03	2.00E-03
Barium	4.00E+00	1.50E-01	6.50E-04	1.50E-04
Beryllium	1.90E+01	1.00E-02	1.50E-03	1.00E-03
Boron	2.20E-01	4.00E+00	2.00E+00	8.00E-04
Cadmium	2.00E+02	5.50E-01	1.50E-01	5.50E-04

Table 8-7 (cont'd)

Constituent	Fish Bioconcentration Factor	Soil to Vegetation Transfer Factor	Soil to Fruit Transfer Factor	Vegetation to Beef Transfer Factor
Chromium	2.00E+01	7.50E-03	4.50E-03	5.50E-03
Cobalt	5.00E+01	2.00E-02	7.00E-03	2.00E-02
Copper	5.00E+01	4.00E-01	2.50E-01	1.00E-02
Cyanide ion	3.79E-01	5.41E+01	5.41E+01	1.41E-06
Iron	1.00E+02	4.00E-03	1.00E-03	2.00E-02
Lead	1.00E+02	4.50E-02	9.00E-03	3.00E-04
Lithium	5.00E-01	2.50E-02	4.00E-03	1.00E-02
Magnesium	5.00E+01	1.00E+00	5.50E-01	5.00E-03
Manganese	4.00E+02	2.50E-01	5.00E-02	4.00E-04
Mercury	2.00E+05	9.00E-01	2.00E-01	2.50E-01
Molybdenum	1.00E+01	2.50E-01	6.00E-02	6.00E-03
Nickel	1.00E+02	6.00E-02	6.00E-02	6.00E-03
Potassium	1.00E+03	1.00E+00	5.50E-01	2.00E-02
Selenium	1.70E+02	2.50E-02	2.50E-02	1.50E-02
Silver	2.30E+00	4.00E-01	1.00E-01	3.00E-03
Sodium	1.00E+02	7.50E-02	5.50E-02	5.50E-02
Sulphide	NA	1.50E+00	1.50E+00	1.00E-01
Thallium	1.00E+04	4.00E-03	4.00E-04	4.00E-02
Tin	3.00E+03	3.00E-02	6.00E-03	8.00E-02
Vanadium	1.00E+01	5.50E-03	3.00E-03	2.50E-03
Zinc	2.00E+03	1.50E+00	9.00E-01	1.00E-01
Americium-241	2.50E+01	5.50E-03	3.00E-02	3.50E-06
Cesium-137	2.00E+03	8.00E-02	3.00E-02	2.00E-02
Plutonium-238	3.50E+00	4.50E-04	4.50E-05	5.00E-07
Plutonium-239	3.50E+00	4.50E-04	4.50E-05	5.00E-07
Radium-226	5.00E+01	1.50E-02	1.50E-03	2.50E-04
Radium-228	5.00E+01	1.50E-02	1.50E-03	2.50E-04
Strontium-90	3.00E+01	2.50E+00	2.50E-01	3.00E-04
Tritium	1.00E+00	1.00E+00	1.00E+00	1.00E+00
Uranium-234	2.00E+00	8.50E-03	4.00E-03	2.00E-04
Uranium-235	2.00E+00	8.50E-03	4.00E-03	2.00E-04
Uranium-238	2.00E+00	8.50E-03	4.00E-03	2.00E-04

NA = Transfer factor could not be calculated.

Source: For organics, the transfer factors were calculated from equations in Travis and Arms (1988) using K_{ow} values from the *Superfund Chemical Data Matrix* (1991). For inorganics and radionuclides, the transfer factors were taken from Baes et al. (1984). The K_{ow} for cyanide was taken from MEPAS and the transfer factors were calculated from equations in Travis and Arms (1988).

source terms were decay-corrected by PNL to the time of disposal or release. Estimated dose to terrestrial receptors was based not only on the radionuclides themselves, but on all short-lived daughter products as well.

Aquatic organisms considered in the assessment include benthic macroinvertebrates and a generic fish species. For radiological analyses, emergent vegetation (i.e., cattails) and muskrats are also included. All aquatic organisms, except for benthic macroinvertebrates, are exposed to contaminants in surface water. Benthic macroinvertebrates are assumed to be exposed only to the sediment pore-water for calculation of internal radiation dose and exposure to chemicals. The external radiation dose from exposure to surface water was calculated for all organisms.

8.4 CONTAMINANT EFFECTS ASSESSMENT

Two pathways are used to determine the effects of contaminant exposure (chapter 8.3) on ecological endpoint receptors. For terrestrial receptors, consumption rates of contaminated food and water are compared with toxicological benchmarks. For aquatic receptors, contaminant concentrations in water or sediment pore water are compared with chemical-specific aquatic benchmarks. To quantify risk to terrestrial receptors exposed to organic and inorganic contaminants, the daily consumption rates of contaminated food and water, normalized to body weight (in units of mg/kg/d), were compared to the NOAEL benchmark (mg/kg/d). For purposes of this assessment, the resulting ratio is termed the hazard index (HI). Ratios greater than 1 are considered to pose a potential risk to organisms but do not necessarily indicate the severity of the effect(s). However, it is reasonable to assume that the higher the ratio, the greater the risk of adverse effects. Dose to terrestrial receptors, including vegetation, from internal and external exposure to radionuclides was also determined from calculated tissue concentrations and soil concentrations, respectively. Doses that exceeded 0.1 rad/d were considered to pose a potentially unacceptable risk (HI $\geq$ 1) to terrestrial organisms (IAEA 1992). Methods used to calculate exposure and risk are described in appendix A.

Toxicological benchmarks for terrestrial organisms, excluding vegetation, were obtained from Opresko et al. (1993) (table 8-8). For representative receptor species that were not listed in the data base, extrapolation techniques were employed to obtain the chronic NOAEL by adjusting for differences in body weight between the receptor and a test organism. If a NOAEL was available for a laboratory test species, the NOAEL for a receptor species could be estimated by extrapolation. Many of the NOAEL benchmarks were derived by extrapolation from small mammal laboratory data (Opresko et al. 1993). There were a few contaminants, however, for which no wildlife toxicity data were found. For these cases, wildlife NOAELs were extrapolated from human non-carcinogenic toxicity data listed in the MEPAS constituent data base, and normalized to the "standard man" body weight of 70 kg. Thus, for our purposes, wildlife species that weigh less than 70 kg would have a higher benchmark than a human being would have; wildlife species weighing more than 70 kg would have lower benchmarks.

Literature sources for inorganic terrestrial phytotoxicity (vegetation) benchmarks were summarized and reported by Suter and Futrell (1993) (table 8-8). Where applicable, the lowest source concentration in a soil medium that produced phytotoxically excessive effects was chosen from the database. Several benchmarks were derived from experiments using nutrient solutions. However, uncertainty values were not applied to these data to account for differences in growth media. A methodology for deriving phytotoxicity benchmarks for organic constituents was developed by Eskew and Babb (1992) (table 8-8).

Risks to aquatic organisms from exposure to organic and inorganic contaminants in water and sediments (pore-water) were calculated by comparing the water or sediment pore-water concentrations with the chemical-specific aquatic benchmark (Suter et al. 1992) (table 8-8). To determine internal dose to aquatic plants, fish, and muskrats from exposure to radionuclides, the surface water concentrations were multiplied by radionuclide and organism-specific (internal) dose conversion factors to produce a daily dose in rads (Killough and McKay 1976). To determine the internal dose to benthic macroinvertebrates and other bottom-dwelling organisms (e.g., fish larvae) from exposure to radionuclides, the sediment pore-water concentrations were multiplied by radionuclide and organism-specific (internal) dose conversion factors to produce a daily dose. The external dose to all organisms was determined by multiplying the surface water concentration by the external radionuclide-specific dose conversion factor. Combined internal and external doses greater than 1 rad/d are considered to pose a potential risk to aquatic organisms (i.e., a HI equal to or greater than 1; NCRP 1991).

Although it is reasonable to assume that many species are exposed to contaminants only some of the time and that contaminant concentrations are not as high as maximum values, an initial screening assessment was conducted using the maximum concentrations of each contaminant on-site to identify worst-case potential contaminants. Following this initial screening, average concentrations were used to represent more realistic exposures for contaminants and receptors that did not pass the initial screening.

Estimating realistic exposures for all endpoints on the reservation is impossible because data are lacking or incomplete in regard to numbers of individuals actually exposed to wastes, amount of time spent in waste areas, and actual amounts of contaminants ingested. In some cases, for example, benchmarks were lacking; consequently, HIs could not be calculated and risks could not be assessed. Specific home ranges, behavior, and habitat requirements of many of the representative species at RFP are not well known or they vary widely, and only a few species with small home ranges (e.g., very small mammals and small birds) may reside within a contaminated area for most of their lives.

For contaminant and receptor combinations that did not pass the average concentration screening, an attempt was made to further define exposure risks by comparing the home range sizes of receptor species with the potential fraction of the home range that could be contaminated.

Receptor species at RFP have home ranges or territories that range from small [e.g., 1 ha (about 2.5 acres) or less for very small animals such as the prairie dog, mouse, and certain aquatic species] to thousands of hectares for the peregrine falcon and coyote (table 8-9). Small species generally have home ranges small enough to be contained within waste sites or other contaminated areas. Other species may have such large home ranges that the waste sites would represent only a relatively small part of the area the species would occupy, if the waste sites were used at all.

To further interpret results of this risk analysis, the following assumptions concerning the contribution of waste sources to receptors are made.

1. For most of the DOE sites assessed in this PEIS, correction factors based on the ratio of the total contaminated area to the home range of terrestrial receptors were developed. These factors were applied to the HIs calculated for the average concentrations screening to produce a more reasonable or effective HI. This was done for this assessment as well; home ranges and ratios (correction factors) are presented in table 8-9. However, because the estimate of total contaminated area used in determining exposures is so large, only one receptor species selected for this assessment (the coyote, estimated minimum home range of 2100 ha) has an estimated minimum home range larger than the reservation's estimated total contaminated area of 980 ha of soil. Published estimates of home ranges for one other species, the endangered peregrine falcon, vary from 65 to 31,000 ha (160 to 77,000 acres) (Brown and Amadon 1968, Schoener 1968). Although the nearest suitable nesting habitat of the peregrine falcon (cliffs and river gorges) is approximately 8 km (5 miles) southwest of the reservation (EG&G 1991), the reservation is well within hunting range of the falcon, and these birds occasionally fly over, pursue prey, and perch on the reservation (DOE 1992). Thus, for this avian receptor a home range centered on the nearest nesting

TABLE 8-8—*Criteria Benchmarks for Terrestrial[a] and Aquatic[b] Species at the Rocky Flats Plant (NOAELs listed in mg/kg/d for terrestrial benchmarks or mg/L for aquatic benchmarks)*

Constituent	Jumping Mouse	Blacktailed Jackrabbit	Prairie Dog	Mule Deer	Meadowlark	Mallard	Peregrine Falcon	Bald Eagle	Coyote	Vegetation	Aquatic
Acenapthene	NA	NA	NA	NA	NA	NA	NA	NA	NA	1.28E+02	1.97E-01
Acetone	2.64E+01	1.86E+01	6.65E+00	1.47E+00	1.53E+01	6.67E+00	7.49E+00	4.27E+00	2.80E+00	9.65E+01	2.37E+01
Aroclor 1254	1.53E-01	6.05E-02	6.92E-02	1.39E-02	2.92E+00	1.55E+00	1.74E+00	9.92E-01	2.52E-02	1.00E+01	5.20E-04
Aroclor 1260	1.57E+00	1.19E-02	2.92E-03	6.46E-04	9.12E-01	2.93E-03	3.29E-03	1.87E-03	1.23E-03	NA	2.10E-03
BEHP	NA	NA	NA	NA	NA	NA	NA	NA	NA	1.40E+01	3.00E-04
Benzene	6.60E+00	4.66E+00	1.66E+00	3.68E-01	3.83E+00	1.67E+00	1.87E+00	1.07E+00	6.99E-01	NA	2.10E-02
Bromoform	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
2-butanone	2.43E+01	1.72E+01	6.12E+00	1.35E+00	1.41E+01	6.14E+00	6.89E+00	3.93E+00	2.57E+00	NA	NA
Carbon disulfide	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	1.00E+03
Carbon tetrachloride	1.88E-01	1.32E-01	4.72E-02	1.04E-02	1.09E-01	4.74E-02	5.32E-02	3.03E-02	1.99E-02	5.60E+01	6.50E-02
Chlorobenzene	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	1.65E-01
Chloroform	2.38E+01	1.68E+01	5.99E+00	6.28E-01	1.38E+01	6.00E+00	3.20E+00	1.82E+00	1.19E+00	NA	8.40E+00
1,1-dichloroethane	NA	NA	NA	NA	NA	NA	NA	NA	NA	8.60E-01	1.59E+00
1,2-dichloroethane	1.95E+00	1.38E+00	4.92E-01	1.09E-01	1.13E+00	4.94E-01	5.54E-01	3.16E-01	2.07E-01	5.40E-01	1.10E+01
1,1-dichloroethene	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	4.47E-01
trans-1,2-dichloroethylene	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
di-n-butyl phthalate	4.93E+01	1.79E+02	1.24E+01	2.74E+00	1.29E-02	5.64E-03	6.33E-03	3.61E-03	5.22E+00	1.48E+04	2.70E-01
di-n octylphthalate	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	3.10E-01
Ethyl benzene	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	4.40E+02
2-hexanone	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	1.26E+03
Methylene chloride	1.54E+01	1.09E+01	3.89E+00	8.60E-01	8.95E+00	3.90E+00	4.38E+00	2.50E+00	1.64E+00	5.60E+00	4.10E-01
4-methyl-2-pentanone	1.32E+01	9.32E+00	3.33E+00	7.35E-01	7.65E+00	3.33E+00	3.74E+00	2.13E+00	1.40E+00	NA	1.59E+03
2-methylphenol	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	7.40E+01
n-nitrosodiphenylamine	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	4.00E+01
Phenol	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	2.30E-04
Pyrene	NA	NA	NA	NA	NA	NA	NA	NA	NA	1.28E+02	NA
Tetrachloroethane	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	1.30E+01
Tetrachlorethene	1.63E+00	5.92E+00	4.11E-01	9.08E-02	9.45E-01	4.12E-01	4.62E-01	2.63E-01	1.73E-01	1.57E+01	5.10E-01
Toluene	5.89E+01	4.16E+01	1.48E+01	3.28E+00	3.41E+01	1.49E+01	1.67E+01	9.52E+00	6.24E+00	9.70E+00	2.60E-02
1,1,1-trichloroethane	NA	NA	NA	NA	NA	NA	NA	NA	NA	6.10E+00	2.51E-01
Trichlorethylene	1.75E+02	1.40E+02	4.99E+01	1.10E+01	9.45E-01	5.00E+01	5.62E+01	3.20E+01	2.10E+01	6.70E-01	5.76E+00
Vinyl acetate	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	1.08E+02
Xylene	1.32E+03	9.32E+02	3.33E+02	7.35E+01	7.65E+02	3.33E+02	3.74E+02	2.13E+02	1.40E+02	2.40E+01	2.68E+00
Aluminum	NA	NA	NA	NA	NA	NA	NA	NA	NA	8.00E+00	8.70E-02
Antimony	1.31E+04	1.35E+04	3.31E+03	7.31E+02	7.61E+03	3.31E+03	3.72E+03	2.12E+03	1.39E+03	5.00E+00	1.90E+00
Arsenic	1.11E-01	4.55E+00	1.62E+00	6.09E-01	6.41E-02	1.63E+00	3.10E+00	1.77E+00	1.16E+00	1.50E+01	9.32E-01
Barium	1.35E+00	9.51E-01	3.39E-01	7.50E-02	7.80E-01	3.40E-01	3.82E-01	2.18E-01	1.43E-01	5.00E+02	2.03E+01
Beryllium	1.43E+00	1.01E+00	3.59E-01	7.94E-02	8.26E-01	3.60E-01	4.04E-01	2.31E-01	1.51E-01	1.00E+01	3.80E-03
Boron	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	7.00E-03
Cadmium	2.54E-02	1.21E-01	6.40E-03	1.42E-03	1.32E-01	5.75E-02	2.66E-03	1.51E-03	2.69E-03	3.00E+00	1.10E-03
Chromium	6.34E+00	4.48E+00	1.60E+00	3.53E-01	3.67E+00	1.60E+00	1.80E+00	1.02E+00	6.71E-01	7.50E+01	1.10E-02

[a] The source for all terrestrial benchmarks, except those for vegetation, is Opresko et al., 1993. For vegetation, the source is Suter and Futrell, 1993, and the *Massachusetts Military Reservation Assessment Handbook*, 1992.
[b] The source for aquatic benchmarks is Suter et al., 1992.

Table 8-8 (con't)

Constituent	Jumping Mouse	Blacktailed Jackrabbit	Prairie Dog	Mule Deer	Meadowlark	Mallard	Peregrine Falcon	Bald Eagle	Coyote	Vegetation	Aquatic
Cobalt	NA	NA	NA	NA	NA	NA	NA	NA	NA	2.50E+01	4.40E-03
Copper	1.98E-01	2.61E+00	9.31E-01	2.06E-01	6.30E+01	2.74E+01	2.49E+01	1.42E+01	3.92E-01	6.00E+01	1.20E-02
Cyanide ion	2.85E+01	2.09E-02	7.18E+00	2.10E-02	1.65E+01	7.20E+00	8.09E+00	6.11E-02	4.00E-02	NA	5.20E-03
Iron	NA	NA	NA	NA	NA	NA	NA	NA	NA	1.00E+04	1.00E+00
Lead	7.66E-03	5.41E-03	1.93E-03	4.27E-04	1.46E-02	1.17E+01	1.32E+01	7.51E+00	8.11E-04	1.00E+02	3.20E-03
Lithium	NA	NA	NA	NA	NA	NA	NA	NA	NA	2.00E+00	NA
Magnesium	2.52E+02	4.18E+02	6.34E+01	1.40E+01	1.46E+02	6.36E+01	7.14E+01	4.07E+01	2.67E+01	NA	1.60E-04
Manganese	2.16E+00	4.46E-02	5.44E-01	1.20E-01	1.25E+00	5.46E-01	6.13E-01	3.49E-01	2.29E-01	1.50E+03	1.10E+00
Mercury	1.55E+01	8.78E-03	6.92E-03	1.72E-02	2.92E+00	2.83E-02	6.81E-01	3.88E-01	3.27E-02	3.00E-01	1.30E-03
Molybdenum	NA	NA	NA	NA	NA	NA	NA	NA	NA	2.00E+00	3.60E-01
Nickel	6.38E+01	4.50E+01	1.61E+01	3.55E+00	3.82E+00	1.67E+00	1.87E+00	1.07E+00	6.75E+00	1.00E+02	1.60E-01
Potassium	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	1.30E-04
Selenium	6.64E-02	2.41E-01	1.67E-02	3.70E-03	2.29E-01	1.00E-01	1.12E-01	6.40E-02	7.03E-03	5.00E+00	3.50E-02
Silver	NA	NA	NA	NA	NA	NA	NA	NA	NA	2.00E+00	2.00E-04
Sodium	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	4.80E-01
Thallium	2.64E-02	1.86E-02	6.65E-03	1.47E-03	1.53E-02	6.67E-03	7.49E-03	4.27E-03	2.80E-03	1.00E+00	6.40E-02
Tin	NA	NA	NA	NA	NA	NA	NA	NA	NA	5.00E+01	NA
Vanadium	2.49E-01	7.81E-02	6.26E-02	1.39E-02	1.44E-01	6.28E-02	7.05E-02	4.02E-02	2.63E-02	5.00E+01	4.10E-02
Zinc	2.56E+01	1.81E+01	6.45E+00	1.43E+00	1.48E+01	6.47E+00	7.26E+00	4.14E+00	2.71E+00	7.00E+01	1.10E-01

NA = Benchmark not available.

habitat and large enough to encompass the entire RFP reservation, that is, approximately 20,000 ha, (49,000 acres) was assumed. On the basis of this estimate, a correction factor of 0.049 was calculated (table 8-9).

2. The endangered bald eagle presents a rather different situation. This large bird of prey soars over the reservation during winter or, as a migrant, during spring and fall. Thus far, none have been observed roosting or actively hunting prey within the reservation (DOE 1992). These birds generally prefer large bodies of water because their preferred prey is fish. Although these conditions are not wholly met on the reservation, Great Western Reservoir, only about 0.5 km (0.3 mile) east of the reservation, and Standley Lake, about 1.9 km (1.2 miles) east, appear to satisfy these preferences, especially given reports of roosting bald eagles at these reservoirs (Uppendahl 1990). Nevertheless, this analysis treats these birds as potential residents of the contaminated areas for the following reasons. First, if frozen reservoirs prevent preying on fish in the winter, the RFP reservation may prove to be an attractive source of carrion, small mammals, or other birds for the eagles to feed on. Second, Standley Lake and Great Western Reservoir are contaminated by some of the pollutants originating at RFP; thus these birds presumably would incur some exposure whether or not they feed on the reservation. Third, the reported home range of the bald eagle is between 500 and 800 ha (1200 - 2000 acres) (Terres 1980), so any eagle in the general area would probably find the reservation, and more particularly, the contaminated area, sufficiently large to attract and support it. Fourth, the RFP reservation may represent a refugium for many potential prey species that are probably already undergoing considerable disturbances in surrounding habitat from agricultural and industrial practices as well as residential development. For these reasons, the appropriate correction factor is considered to be 1.0 (table 8-9).

3. For all other terrestrial endpoint receptors at RFP, minimum home ranges are smaller than the estimated total contaminated area. Thus, no correction factor (i.e., a correction factor of 1.0) was applied to the calculated HIs in tables 8-10 through 8-13 to determine the effective HIs used to characterize risk (see tables 8-14a through 8-14d). In other words, receptor species with minimum home ranges of about 980 ha or less (table 8-9) could receive as much exposure as the average screening of this analysis indicates.

4. The contaminated area actually varies with different contaminant species, but lacking sufficient contaminant-specific distribution data, the estimated total area of 980 ha of contaminated soil and 17 ha of contaminated surface waters and wetlands is assumed to apply to each contaminant. Exposure of biota living completely outside the 38% of the reservation that is contaminated is limited to contaminants that have moved from waste sites in dust, water, and by movement of contaminated wildlife. Although some contaminants possibly occur in measurable concentrations outside waste sites, for the most part there are no source terms or measurement data for them and it is assumed they are minor compared with the amounts and concentrations in the waste sites.

5. Although the threatened Ute lady's-tresses have not been observed on the reservation itself, this terrestrial orchid is included in this assessment because of its known proximity (a few kilometers north and south of the reservation) and the identification of potentially suitable

habitat along swales and the edges of wetlands within the reservation.

6. Wetland and aquatic receptors (fish, benthic invertebrates, and plants) are assumed to be fully exposed to contaminants measured in aquatic habitat (i.e., creeks, ponds, and associated wetlands) outside the solar evaporation ponds in the central industrial area, but not in the solar ponds themselves, because reported contaminant concentrations and other water quality and habitat conditions in these small waste ponds would be unlikely to support most aquatic life. Consequently, the actual exposures and risks incurred by aquatic receptor species are likely to be considerably lower than indicated by the HIs shown in table 8-14a through 8-14d and discussed in chapter 8.5.

7. Grazing livestock are not allowed onto the RFP reservation. Risks to this resource would occur only if livestock were allowed to graze in contaminated areas.

8.5 Contaminant Hazard Assessment

8.5.1 Baseline

The next step in the ecological risk assessment generates HIs that are representative of potential relative risks from exposure to contaminants. Baseline hazard indices (HIs) for terrestrial receptors exposed to the maximum source concentrations exceeded 1 for 15 out of 19 inorganic contaminants (for which benchmarks were available), and 6 out of 17 organic contaminants. Exposure to the maximum concentrations of radionuclides resulted in HIs for all receptors of about 5E+07. Radiological dose was dominated overwhelmingly by exposure to ^{90}Sr in soils.

Exposure of terrestrial species to average soil and water concentrations at the site were calculated for those contaminants whose maximum concentrations resulted in HIs greater than 1 (table 8-10). Because ^{90}Sr concentrations were so much higher than concentrations of other radionuclides, and average ^{90}Sr concentrations could not be estimated, the HIs for all species exposed to the average concentrations of radionuclides were effectively the same as the HIs for species exposed to the maximum concentrations. ^{90}Sr concentrations in the soil thus remained the dominant radionuclide contributing to the total dose for all species.

About 60% of HI values for all species-contaminant combinations were between 1 and 10 (versus 49% for the maximum); 35% were about 10 but below 1000 (versus 43% for the maximum), and about 5% were still above 1000 (versus 8% for the maximum).

Exposure of aquatic organisms to the maximum concentrations of non-radiological contaminants in surface water resulted in HIs over 1000 for the organics BEHP and phenol. No other organic contaminants resulted in HIs greater than 1. Hazard indices also exceed 1000 for aquatic organisms exposed to the maximum concentrations of cyanide ion, Cd, Mg, Hg, K, Ag, and Na in the surface water. Exposure of aquatic biota to Be, Cr, Co, Cu, Fe, Pb, Mn, Mo, Ni, and V resulted in HIs less than 100. Many of the contaminants that appear hazardous to surface water organisms also posed risks to bottom-dwelling organisms. Exposure of benthic macroinvertebrates to the maximum sediment pore-water concentrations (calculated from sediment concentrations) resulted in HIs over 1000 for the same contaminants that resulted in HIs over 1000 for surface water dwellers, except for phenol, K and Hg.

Compared with maximum exposure HIs, there was a 37% decrease in the number of contaminants with HIs greater than 1 for aquatic organisms exposed to average concentrations (table 8-12). Hazard indices were still over 1000, however, for cyanide ion, Mg and K. The HIs for benthic macroinvertebrates exposed to the average pore-water concentrations were generally within the same order of magnitude as the HIs for maximum exposures, except for Na and Ag, whose HIs for average exposures decreased by 2 to 3 orders of magnitude, respectively (table 8-12).

Exposure to the maximum concentrations of radionuclides in the surface water or in the sediment pore-water (macroinvertebrates only) resulted in extremely high HIs (or doses) for all

TABLE 8-9—*Home Ranges[1] of and Hazard Index (HI) Correction Factors (CF)[2] for Terrestrial Receptor Species on the Rocky Flats Plant*

Receptor Species	Home Range[3] (ha) ≤980 ha	Home Range[3] (ha) >980 ha	Correction Factor
Meadow jumping mouse	X (0.08 - 1.1)		1.0
Black-tailed jackrabbit	X (7.3 - 160)		1.0
Prairie dog	X (2.4 - 2.8)		1.0
Coyote.		X (2100 - 8000)	0.47
Mule deer	X (39 - 3400)		1.0
Western meadowlark	X (1.2 - 6.1)		1.0
Mallard duck	X (4.0)		1.0
Bald eagle	X (520-940)		1.0
Peregrine falcon		X (65 - 31,000)[3]	0.049
Vegetation	X (<0.1)		1.0

[1]Anderson and Wallmo 1984; Brown and Amadon 1968; Burt and Grossenheider 1976 Bekoff 1977; Chapman and Feldhamer 1982; Chapman et al. 1980; Clark et al. 1971; Lim 1987; Schoener 1966; Terres 1980.

[2]Unless otherwise noted, the minimum home range was used to calculate HI correction factors. A CF of 1.0 was applied to HIs for each contaminant for each species having home range ≤ 980 ha.

[3]A home range of 20,000 ha was used to calculate the correction factor.

TABLE 8-10—*Baseline Hazard Indicies for Terrestrial Organisms on the Rocky Flats Plant*

BASELINE AVERAGE HAZARD INDICES FOR ROCKY FLATS TERRESTRIAL ORGANISMS										
Hazard Indices Calculated Using Average Contaminant Concentrations										
	Preble's Jumping Mouse	Rabbit	Prairie Dog	Mule Deer	Western Meadowlark	Mallard	Peregrine Falcon	Bald Eagle	Coyote	Vegetation
Acetone	9.44E-02	1.36E-01	3.41E-01	4.99E-01	6.04E-02	6.43E-02	5.22E-05	5.75E-05	9.93E-05	7.58E-03
Aroclor 1254	1.44E+00	4.87E+00	1.10E+00	2.66E+00	1.00E-01	1.72E-01	5.26E-06	6.97E-05	4.28E-03	5.29E+00
Aroclor 1260	1.94E-02	3.42E+00	3.62E+00	7.92E+00	4.44E-02	1.26E+01	3.85E-04	5.10E-03	1.22E-02	NA
BEHP	NA	NA	NA	NA	NA	NA	NA	NA	NA	3.29E-01
Di-n-butyl phthalate	2.91E-04	9.84E-05	5.20E-04	9.88E-04	1.24E+00	2.47E+00	1.99E-02	3.91E+01	1.76E-05	1.79E-04
Toluene	3.25E-02	4.77E-02	1.13E-01	1.67E-01	2.39E-02	2.98E-02	1.15E-05	1.60E-04	2.20E-05	2.79E+00
Aluminum	NA	NA	NA	NA	NA	NA	NA	NA	^E^H"	1.45E+03 Antimony
4.38E-05	4.96E-05	1.40E-04	2.10E-04	4.03E-05	6.19E-05	1.22E-06	1.49E-06	2.35E-06	2.76E+00	
Arsenic	6.06E-01	1.86E-02	1.98E-02	2.13E-02	1.12E+00	3.79E-02	2.85E-04	3.48E-04	5.48E-04	8.30E-01
Barium	2.89E-01	4.71E-01	8.62E-01	1.31E+00	2.98E-01	4.79E-01	1.81E-02	3.21E-02	3.46E-02	6.35E-02
Beryllium	4.48E+00	9.12E+00	3.87E+00	1.11E+01	1.20E+01	2.57E+01	7.31E-04	3.97E-03	3.39E-03	1.93E+02
Cadmium	5.22E+00	2.53E-01	6.52E+00	1.13E+01	6.85E-01	7.26E-01	1.01E+01	3.82E+02	7.07E+00	0.00
Chromium	1.02E-04	1.10E-04	1.04E-04	2.29E-04	1.92E-04	3.39E-04	4.12E-05	1.94E-04	7.86E-05	1.18E-03
Cobalt	NA	NA	NA	NA	NA	NA	NA	NA	NA	0.00
Copper	8.90E+00	7.39E-01	1.61E+00	2.39E+00	1.27E-02	1.76E-02	4.13E-05	4.31E-04	3.96E-03	1.07E+00
Cyanide ion	1.71E+01	6.70E+03	2.38E+01	3.03E+03	1.95E+01	2.07E+01	1.14E+01	9.50E+02	1.64E+03	NA
Iron	NA	NA	NA	NA	NA	NA	NA	NA	NA	2.76E+00
Lead	9.10E+00	1.67E+01	1.85E+01	3.32E+01	4.99E+00	5.37E-03	1.85E-05	3.59E-04	2.15E-01	1.28E-01
Magnesium	6.31E-01	3.84E-01	2.17E+00	3.16E+00	4.24E-01	4.60E-01	4.26E-02	4.37E-01	8.25E-02	NA
Manganese	2.63E+00	1.50E+02	8.90E+00	1.32E+01	2.20E+00	3.23E+00	1.07E-02	8.02E-01	2.09E-02	2.20E-01
Mercury	3.80E-02	6.94E+01	7.50E+01	9.62E+00	7.14E-02	3.09E+00	2.05E-02	7.47E+02	5.07E-01	3.16E+01
Molybdenum	NA	NA	NA	NA	NA	NA	NA	NA	NA	0.00
Nickel	3.20E-03	5.02E-03	6.68E-03	1.17E-02	5.04-02	9.43E-02	2.52E-03	4.90E-02	5.03E-04	2.75E-01
Silver	NA	NA	NA	NA	NA	NA	NA	NA	NA	0.00
Thallium	9.67E-02	3.28E-02	1.21E-01	2.08E-01	1.14E-01	1.20E-01	6.88E-02	1.27E+02	1.31E-01	0.00
Vanadium	7.05E-01	3.11E+00	4.46E-01	1.56E+00	1.95E+00	4.18E+00	3.02E-02	8.71E-02	5.82E-02	1.08E+00
Zinc	2.74E-[illegible]	4.15E-01	1.00E+00	1.45E+00	1.65E-01	1.70E-01	2.52E-03	8.91E-01	1.69E-02	1.05E+00

N/A = Benchmark not available, therefore hazard index could not be calculated.

TABLE 8-11—***Baseline Average Radiological Doses for Terrestrial Organisms on the Rocky Flats Plant***

	Radiological Doses (rad/d) Calculated Using Average Contaminant Concentrations									
	Preble's Jumping Mouse	Jackrabbit	Prairie Dog	Mule Deer	Meadowlark	Mallard	Peregrine Falcon	Bald Eagle	Coyote	Vegetation
Americium-241	1.04E+00	1.04E+00	1.04E+00	1.04E+00	1.04E+00	1.04E+00	1.04E+00	1.04E+00	1.04E+00	1.40E+00
Strontium-90	5.53E+06	5.53E+06	5.53E+06	5.54E+06	5.53E+06	5.53E+06	5.53E+06	5.53E+06	5.53E+06	1.84E+07
Total dose	5.53E+06	5.53E+06	5.53E+06	5.54E+06	5.53E+06	5.53E+06	5.53E+06	5.53E+06	5.53E+06	1.84E+07
Radiological HI	5.53E+07	5.53E+07	5.53E+07	5.54E+07	5.53E+07	5.53E+07	5.53E+07	5.53E+07	5.53E+07	1.84E+08

TABLE 8-12—*Baseline Average Hazard Indices for Aquatic Organisms on the Rocky Flats Plant*

Constituent	Average Surface Water HI (Fish)	Average Benthic Macroinvertebrate HI
Acetone	2.42E–04	3.45E–01
BEHP	6.20E+01	NA
Di-n-butyl phthalate	6.85E–03	NA
Phenol	2.80E+02	1.02E+05
Toluene	1.08E–01	7.67E–03
Aluminum	4.84E+00	1.92E+01
Antimony	3.53E–02	NA
Arsenic	1.39E–02	NA
Barium	5.02E–03	9.47E–02
Beryllium	1.03E+00	NA
Cadmium	3.58E+02	1.13E+04
Chromium	9.91E–02	7.87E–01
Cobalt	4.21E–01	NA
Copper	1.23E+00	1.75E+02
Cyanide ion	2.62E+05	1.10E+06
Iron	6.84E–01	5.12E+02
Lead	1.12E+00	4.38E+00
Magnesium	2.80E+05	5.29E+06
Manganese	8.80E–02	1.87E+00
Mercury	1.56E+02	1.54E+02
Molybdenum	1.67E–02	NA
Nickel	4.32E–01	2.90E–03
Potassium	2.83E+04	NA
Silver	3.36E+01	9.93E+00
Sodium	4.06E+02	2.49E+02
Thallium	1.18E–01	7.29E–02
Vanadium	7.63E–01	4.83E–01
Zinc	2.34E+00	1.93E+01

NA = Benchmark not available, therefore hazard index could not be calculated.

TABLE 8-13—*Baseline Maximum Radiological Doses for Terrestrial Organisms on the Rocky Flats Plant*

Radiological Doses (rad/d) Calculated Using Maximum Contaminant Concentrations										
	Preble's Jumping Mouse	Jackrabbit	Prairie Dog	Mule Deer	Meadowlark	Mallard	Peregrine Falcon	Bald Eagle	Coyote	Vegetation
Americium-241	2.50E+03	2.50E+03	2.50E+03	2.50E+03	2.50E+03	2.50E+03	2.50E+03	2.50E+03	2.50E+03	3.36E+03
Cesium-137	5.32E-13	1.52E-11	1.05E-11	3.70E-10	1.86E-12	1.04E-11	4.71E-12	5.35E-09	6.42E-11	0.00
Plutonium-238	8.33E-07	8.33E-07	8.33E-07	8.33E-07	8.33E-07	8.33E-07	8.33E-07	8.33E-07	8.33E-07	9.90E-07
Plutonium-239	7.65E-03	7.65E-03	7.65E-03	7.65E-03	7.65E-03	7.65E-03	7.65E-03	7.65E-03	7.65E-03	9.90E-03
Radium-226	2.13E-04	2.13E-04	2.13E-04	2.13E-04	2.13E-04	2.13E-04	2.13E-04	2.13E-04	2.13E-04	2.44E-04
Radium-228	9.44E-13	2.70E-11	1.86E-11	6.56E-10	3.30E-12	1.84E-11	8.36E-12	2.63E-10	1.14E-10	0.00
Strontium-90	5.53E+06	5.53E+06	5.53E+06	5.54E+06	5.53E+06	5.53E+06	5.53E+06	5.53E+06	5.53+06	1.84+07
Tritium	1.72E-09	4.92E-08	3.39E-08	1.20E-06	6.02E-09	3.36E-08	1.52E-08	5.69E-08	2.08E-07	0.00
Uranium-234	1.65E-06	1.67E-06	1.66E-06	2.23E-06	1.65E-06	1.66E-06	1.65E-06	1.68E-06	1.75E-06	5.88E-06
Uranium-235	6.47E-06	6.47E-06	6.47E-06	6.49E-06	6.47E-06	6.47E-06	6.47E-06	6.47E-06	6.47E-06	7.10E-06
Uranium-238	2.05E-02	2.06E-02	2.05E-02	2.06E-02	2.05E-02	2.06E-02	2.05E-02	2.05E-02	2.06E-02	2.18E-02
Total dose	5.53E+06	5.53E+06	5.53E+06	5.54E+06	5.53E+06	5.53E+06	5.53E+06	5.53E+06	5.53E+06	1.84E+07
Radiological HI	5.53E+07	5.53E+07	5.53E+07	5.54E+07	5.53E+07	5.53E+07	5.53E+07	5.53E+07	5.53E+07	1.84E+08

TABLE 8-14a—*Baseline Potential Risks*[1,2] *to Federally Listed Threatened, Endangered, and Candidate Species That May Reside, Feed, or Drink in the Immediate Vicinity of Contaminated Soils, Sediments, or Waters on Rocky Flats Plant*[3].

Contaminant	Jumping Mouse	Bald Eagle	Peregrine Falcon	Ute's Lady's Tresses
Aroclor 1254	M			M
Di-n-butyl phthalate		S		
Toluene				M
Aluminum				S
Antimony				M
Beryllium	M			S
Cadmium	M	S		
Copper	M			M
Cyanide ion	S	S		
Iron				M
Lead	M			
Manganese	M			
Mercury		S		S
Thallium		S		
Vanadium				M
Zinc				M
Radiologic dose	S	S	S	S

[1] Potential risks based on assumptions discussed in Section 8.4.3.

[2] M = moderate risk, where HI is equal to or greater than 1.0, but less than 10; S = severe risk, where HI is equal to or greater than 10.

[3] Risks to individuals that are not in the immediate vicinity of the contaminated resources are negligible. Contaminated sites and contaminated waters account for 38% and 100% of the surface area and water resources, respectively, on the Rocky Flats Plant

TABLE 8-14b—*Baseline Potential Risks*[1] *to Wetlands on the Rocky Flats Plant*

Contaminant	Benthos[2]	Fish
BEHP		S
Phenol	S	S
Aluminum	S	M
Beryllium		M
Cadmium	S	S
Copper	S	M
Cyanide ion	S	S
Iron	S	
Lead	M	M
Magnesium	S	S
Manganese	M	
Mercury	S	S
Potassium		S
Silver	M	S
Sodium	S	S
Zinc	S	M
Radiological dose	S	S

[1]M = moderate risk, where HI is equal to or greater than 1.0, but less than 10; S = severe risk, where HI is equal to or greater than 10.

[2]Based on EPA Water Quality Criteria (Suter et al. 1992). We assume that benthic invertebrates are exposed to pore water concentrations while other wetland (aquatic) organisms are exposed to surface water.

TABLE 8-14c—*Baseline Maximum Potential Risks[1] to Recreational Wildlife that Occupy or Include Waste Sites or Contaminated Waters in Their Home Ranges on the Rocky Flats Plant*

Contaminant	Jackrabbit	Mule Deer	Mallard
Aroclor 1254	M	M	
Aroclor 1260	M	M	S
Di-n-butyl phthalate			M
Barium		M	
Beryllium	M	S	S
Cadmium		S	
Copper		M	
Cyanide ion	S	S	S
Lead	S	S	
Magnesium		M	
Manganese	S	S	M
Mercury	S	M	M
Vanadium	M	M	M
Zinc		M	
Radiologic dose	S	S	S

[1]M = moderate risk, where HI is equal to or greater than 1.0, but less than 10; S = severe risk, where HI is equal to or greater than 10.

TABLE 8-14a—Baseline Potential Risks[1] to Other Important Food Web Components that Occupy Contaminated Sites on the Rocky Flats Plant

Contaminant	Prairie Dog	Coyote	Meadowlark	Vegetation
Aroclor 1254	M			M
Aroclor 1260	M			
Di-n-butyl phthalate			M	
Toluene				M
Aluminum				S
Antimony				M
Arsenic			M	
Beryllium	M		S	S
Cadmium	M	M		
Copper	M			M
Cyanide ion	S	S	S	
Iron				M
Lead	S		M	
Magnesium	M			
Manganese	M		M	
Mercury	S			S
Vanadium			M	M
Zinc	M			M
Radiologic dose	S	S	S	S

[1]M = moderate risk, where HI is equal to or greater than 1.0, but less than 10; S = severe risk, where HI is equal to or greater than 10.

aquatic organisms exposed to ^{90}Sr. Exposure to average concentrations resulted in substantially the same HIs for the same reasons stated above for terrestrial receptors (table 8-13).

From the initial suite of 92 constituents of concern, the two-stage screening process using maximum and then average contaminant values yielded 27 contaminants producing HI values equal to or greater than 1 (i.e., representing at least an intermediate risk from contaminants) for at least one endpoint receptor, as shown in tables 8-10 through 8-13). Of these, 20 contaminants produce HI values of 10 or greater (i.e., severe risk) for one or more endpoint receptors. A few contaminant - species combinations resulted in HIs in the thousands, and, indeed, HIs as high as 1.8 e+8 for terrestrial organisms and 9.0 e+6 for aquatic organisms were calculated for radionuclides. Because these radionuclide values are not credible this matter will be addressed in more detail below. Otherwise, inorganics (primarily trace elements) most commonly exceeded HI values of one, followed by organic compounds.

The incomprehensibly high HI values ($\sim 10^6 - 10^8$) calculated for radiation exposures to all receptors are almost entirely due to one radioactive contaminant, ^{90}Sr. And yet even ponds designed and used on the reservation specifically for containment of contaminated water and sediments appear to support relatively healthy aquatic communities, including, for example, largemouth bass. This fact alone demonstrates that the calculated HI values for radionuclides are not credible. Moreover, examination of the source term data base (Worksheet "B") reveals no ^{90}Sr concentrations higher than 1.8 pCi/L in surface waters and 0.1 pCi/g in sediments. To put this in perspective, continual exposure of fish to a concentration of 1.8 pCi/L would produce a HI (rads per day) of only 5.5 e-7, or about 14 orders of magnitude below the HI calculated in this assessment.

On the other hand, it was found that concentrations of strontium *metal* in the water of solar evaporation ponds within the central industrial complex were up to six times the concentrations found off-site and elsewhere on the reservation. Similarly, solar pond sediments exhibited elevated strontium metal concentrations [about three times the mean concentration reported for the western U.S., but well within the range of concentrations reported for this region (Shacklette and Boerngen 1984)]. However, only if *all* strontium metal in these solar ponds were assumed to be ^{90}Sr would the magnitude of HIs reported in this document be feasible. Back-calculations indicate that is exactly what happened sometime early in the data gathering process for calculation of source terms. Based on examination of the evidence available, it is therefore concluded that ^{90}Sr does not pose undue risks to receptor species outside of the solar ponds, but, because it cannot be ascertained for certain that considerable quantities of ^{90}Sr do not exist in the solar ponds themselves, we have recorded the HIs for total radionuclides in this EIS to indicate possible relative risk to any organism residing in, or otherwise using these ponds, however unlikely that may be. Even without ^{90}Sr, the HI of 2900 (i.e., highly "severe" risk) for ^{241}Am-effects on aquatic invertebrates would still be cause for concern, but a similar examination of the available data on ^{241}Am indicates that this particular HI is also probably incorrect. Based on soil data, however, the ^{241}Am HIs of 1.0 (representing the threshold for moderate risk) for all terrestrial wildlife do appear potentially valid.

Following the assumptions outlined in Section 8.4, the approximate home range or territory size of receptors was determined to calculate the proportion of their range that could potentially encompass contaminated lands or surface waters (table 8-9). Because of the large extent of the area assumed for this analysis to be contaminated [i.e., 980 ha (2400 ac) of contaminated soil and virtually all reservation surface waters and wetlands, plus off-site, but downstream, reservoirs (570 ha or 1400 ac)], only two receptor species exhibit minimum home ranges larger than the postulated contaminated area. These are the coyote (2100 ha home range) and the peregrine falcon (20,000 ha home range).

8.5.1.1 Threatened and Endangered Species

As shown in table 8-14a, all four Federally listed threatened, endangered, or candidate species used as receptors in this assessment are subject to HIs greater than 1, although radionuclides (^{90}Sr and

^{241}Am) were the only contaminants generating such a hazard index for the peregrine falcon. Six contaminants (radionuclides, three metals, and one organic) all pose severe risks to the bald eagle if it should forage and drink regularly on the reservation. The Preble's meadow jumping mouse (a candidate species) incurs severe risks from cyanide and radiation exposure, and moderate risks from six other contaminants (five metals and one organic). Finally, a total of 11 contaminants exhibit HIs greater than one with respect to a federally listed threatened plant, the Ute lady's-tresses. Four of these contaminants (Al, Be, Hg, and radionuclides) pose severe risks. Although by these analyses, individuals of these species utilizing contaminated areas would presumably die, a site specific analysis using individual waste sources and actual occurrences of threatened and endangered species would be necessary to determine actual risks.

8.5.1.2 Wetlands

Risks to wetland receptors (e.g., benthic macroinvertebrates and fish) that might receive contamination from the waste sites are shown in table 8-14b. Potential risks to benthic invertebrates are considered severe for 11 contaminants and moderate for three, while potential risks to fish residing in wetlands are severe for 10 contaminants and moderate for five.

It should be noted, however that the aqueous concentrations of some contaminants (Mg and K in particular) that result in severe risk ratings for fish and/or benthic macroinvertebrates only moderately exceed average background concentrations and are well within the range of concentrations reported for natural waters (Bowen 1979). The benchmarks used in this analysis may well be based on test species that are unusually sensitive to these contaminants, thereby resulting in the severe risk ratings. Magnesium and K, therefore, almost certainly do not represent severe risks to aquatic life at the concentrations used in this analysis.

8.5.1.3 Recreational Wildlife

Table 8-14c summarizes risks to recreationally desirable species at RFP. Baseline average HIs for recreational terrestrial species as represented by the jackrabbit, mule deer, and mallard duck exceeded unity for 15 different contaminants, including trace metals, cyanide ion, PCBs (Aroclor 1254 and 1260), and radionuclides. Moreover, based on this assessment, five of the contaminants pose severe risks to jackrabbits, four would produce severe risks to mallards, and six contaminants would put deer at severe risk.

8.5.1.4 Agriculture and Timber Production

Although once a part of the vast area of open rangeland dominating this region in the past, the reservation is now off limits to agriculture of any kind. This endpoint, therefore, was not a factor in this assessment.

8.5.1.5 Parks and Other Public Lands

No public lands overlap the site, and the only designated public lands near the site are the Boulder County Open Space land adjoining the northern boundary of the reservation and the Standley Lake Recreation Area to the east. Maximum potential risks to receptors in this endpoint, therefore, are assumed to be equivalent to those calculated for similar food web components (receptors) within the reservation boundary in the case of the adjacent Boulder County Open Space land, but also for the Standley Lake area as well since it was included in the total area of contamination used to calculate Hazard Indices for the various receptors. Thus tables 8-11 and 8-12 and the remarks in this section concerning these tables represent the maximum potential risks to receptors in these public lands. Most probably, however, contaminant levels in these public lands are far below those reported for contaminated areas in the reservation; consequently actual risks to receptor species on public lands are almost certainly much lower than the values reported for on-site receptors.

8.5.1.6 Biodiversity

Table 8-14d summarizes the baseline potential risks to four food web components selected as representative receptor species for the biodiversity endpoint. It should be understood, however, that all of the other receptor species evaluated in this assessment (and many that were not considered in this assessment at all) are also important elements of biodiversity at RFP.

Each of a total of 19 contaminants pose moderate or severe risks to one or more of the biodiversity endpoint receptor species selected for this analysis: the prairie dog, coyote, meadowlark, and vegetation. With respect to the prairie dog, four contaminants (cyanide, lead, mercury, and radionuclides) resulted in severe risks, and eight contaminants produced moderate risks. Cyanide and radiologic exposure result in severe risks to the coyote and meadowlark as well. The coyote incurs a moderate risk from cadmium, while the meadowlark is subject to a severe risk from beryllium exposure and moderate risks from four metals and one organic compound (di-n-butyl phthalate). Finally, four contaminants (aluminum, beryllium, mercury, and radiologic exposure) are seen to be severe risks for vegetation, while six other contaminants pose moderate risks.

8.5.1.7 Conclusions

Based on the assumptions and calculations used in this assessment, certain contaminants at certain locations pose moderate to severe risks from a large suite of contaminants to selected receptor species (depending on the particular contaminant) in the endangered species, wetlands, recreational wildlife, and biodiversity endpoint categories. Under some circumstances, receptor species on two nearby public lands may incur risks. Table 8-15 shows which individual contaminants pose risks to one or more receptor species in the six endpoints.

The HI values generated by this analysis should not be viewed as absolute measures of risk; they represent estimated *relative potential risks* to be used for comparative purposes only, and should be understood only in that sense. For numerous reasons discussed earlier, many of these HIs are likely to prove to be highly conservative. The actual areas of ecologically hazardous levels of contamination, for example, are probably far smaller for most contaminants than assumed in this analysis; consequently exposures and risks incurred by most aquatic and terrestrial organisms not in the immediate areas of contamination would likely be far less than indicated by these indices of relative risk (hazard indices). The value of these hazard indices, rather, lies in their usefulness as tools that can provide decisionmakers and other interested persons information needed to compare or rank relative risks among the many contaminants occurring within a given DOE facility, and among the various DOE facilities.

8.6 Habitat Disturbance/Fragmentation Assessment

8.6.1 Baseline

Although nearly 88% (approximately 2300 ha or 5800 acre) of the reservation is relatively undisturbed by construction and operation of the Rocky Flats Plant facilities (about 320 ha or 790 acre), all or nearly all of the reservation prior to construction of the plant was used as grazing range for livestock. Even though the reservation is hardly a perfect example of the montane-prairie transition ecosystem that once dominated the region, the non-developed and largely recovered buffer zone nevertheless presents a reasonably good semblance of the former undisturbed ecosystem, and supports many of the structural and functional elements necessary to the persistence of such an ecosystem. Moreover, the value of this buffer zone to regional biodiversity and aesthetics continually increases as similar land succumbs on an almost daily basis to agricultural, industrial, and residential development. As long as this buffer zone is secured from such development, the baseline condition (or no-action alternative) will have little direct effect on habitat in terms of disturbance or fragmentation beyond the limited damage already done by past construction and operations.

8.7 Cumulative Assessment

8.7.1 On-Site

8.7.1.1 Baseline

As many as 26 contaminants present at RFP have been identified on the basis of this analysis as potential hazards (HIs ≥ 1) to the well-being of certain endpoint receptor species of local ecosystems, including four federally listed

TABLE 8-15—*Comparative Summary of Potential Risks[1] to Ecological Endpoints From Baseline and ARAR Alternatives on the Rocky Flats Plant. Risks are for endpoints which occupy or use contaminated land and/or waters[2]*

Source of Risk	Endpoints[4] - No-Action (Baseline)	Endpoints - ARAR (to be provided)
Construction[3]		
Aroclor 1254	E, R, B	
Aroclor 1260	R, B	
BEHP	W	
Cyanide ion	E, W, R, B	
Di-n-butyl phthalate	E, R, B	
Phenol	W	
Toluene	E	
Aluminum	E, W, B	
Antimony	E, B	
Arsenic	B	
Barium	R	
Beryllium	E, W, R, B	
Cadmium	E, W, R, B	
Copper	E, W, R, B	
Iron	E, W, B	
Lead	E, W, R, B	
Magnesium	W, R, B	
Manganese	E, W, R, B	
Mercury	E, W, R, B	
Potassium	W	
Silver	W	
Sodium	W	
Thallium	E	
Vanadium	E, R, B	
Zinc	E, W, R, B	
Radiologic dose	E, W, R, B	

[1]Only those contaminants are listed which our analyses showed could pose severe or moderate risks to some endpoints.
[2]Risks to endpoints which do not include known contaminated areas within their ranges are assumed to be negligible (see Section 4.4.3).
[3]These are short-term risks. Long-term risks could be reduced with successful restoration of appropriate habitat.
[4] Ecological endpoints: E = threatened, endangered, and candidate species; W = wetlands; R = recreational fish and wildlife; F = agriculture and timber production; P = parks and other public lands; B = biodiversity (only for receptors not included under other endpoints)

threatened, endangered, and candidate species, recreationally desirable fish and wildlife, and other elements of biodiversity. More specifically, 17 contaminants representing all three contaminant classes (organics, inorganics, and radionuclides) pose moderate to severe risks to one or more federally listed species and wetland receptor species. Similarly, 15 contaminants represent potentially moderate to severe risks to recreational wildlife, and a total of 19 contaminants could pose moderate or higher risks to other important elements of biodiversity. With the exception of radionuclides, the cyanide ion represents severe risks to the most receptor species (ten of 13 species), followed in importance by the metals Be, Cd, Pb, and Al. On the basis of closer examination of other evidence available (see discussion in chapter 8.5.1), these estimates of risks from radionuclides appear to be far too excessive, and, in fact, radionuclides as a class are probably of little consequence to any organisms not residing in the immediate vicinity of a few small waste sites. Moreover, certain other contaminants that appear to represent moderate or severe risks to some receptors occur at concentrations comparable to, or even well below, background concentrations reported for the western United States (chapter 8.5.1). Table 8-15 summarizes which contaminants pose moderate or severe risks to one or more receptor species in four of the six endpoints that occur on-site.

Neither agricultural and timber production, nor public lands, occur on the reservation, but public lands do occur off-site where they may possibly be affected by small amounts of RFP-generated contaminants (see chapter 8.7.2 below).

8.7.2 Off-Site

8.7.2.1 Baseline

Some of the contaminants found on the RFP reservation (mostly radionuclides) are known to occur in relatively low concentrations in three downstream reservoirs where they possibly, but not likely, affect offsite terrestrial and aquatic receptors using these reservoirs. Even though these reservoirs were included in the cumulative area of "contaminated waters" used in this assessment, the available data on contaminant levels in these reservoirs (indicating very low concentrations of contaminants) strongly suggest that terrestrial and aquatic life would not, in fact, be adversely affected. In the unlikely event these contaminants eventually should be found to exert some degree of stress on resident organisms, then cumulative effects of these contaminants and other external stresses, including physical disturbances such dredging, and other sources of pollutants such as runoff from agricultural, residential, and industrial development in the watersheds, would be expected to be greater than if RFP-generated contaminants acted alone.

Other possible mechanisms for contaminant transport off-site are contaminant ingestion by widely ranging wildlfife (e.g., migratory birds and coyotes), and wind-borne dust. Neither mechanism would likely be as important at Rocky Flats as hydrologic transport of contaminants.

CHAPTER 9: PORTSMOUTH GASEOUS DIFFUSION PLANT

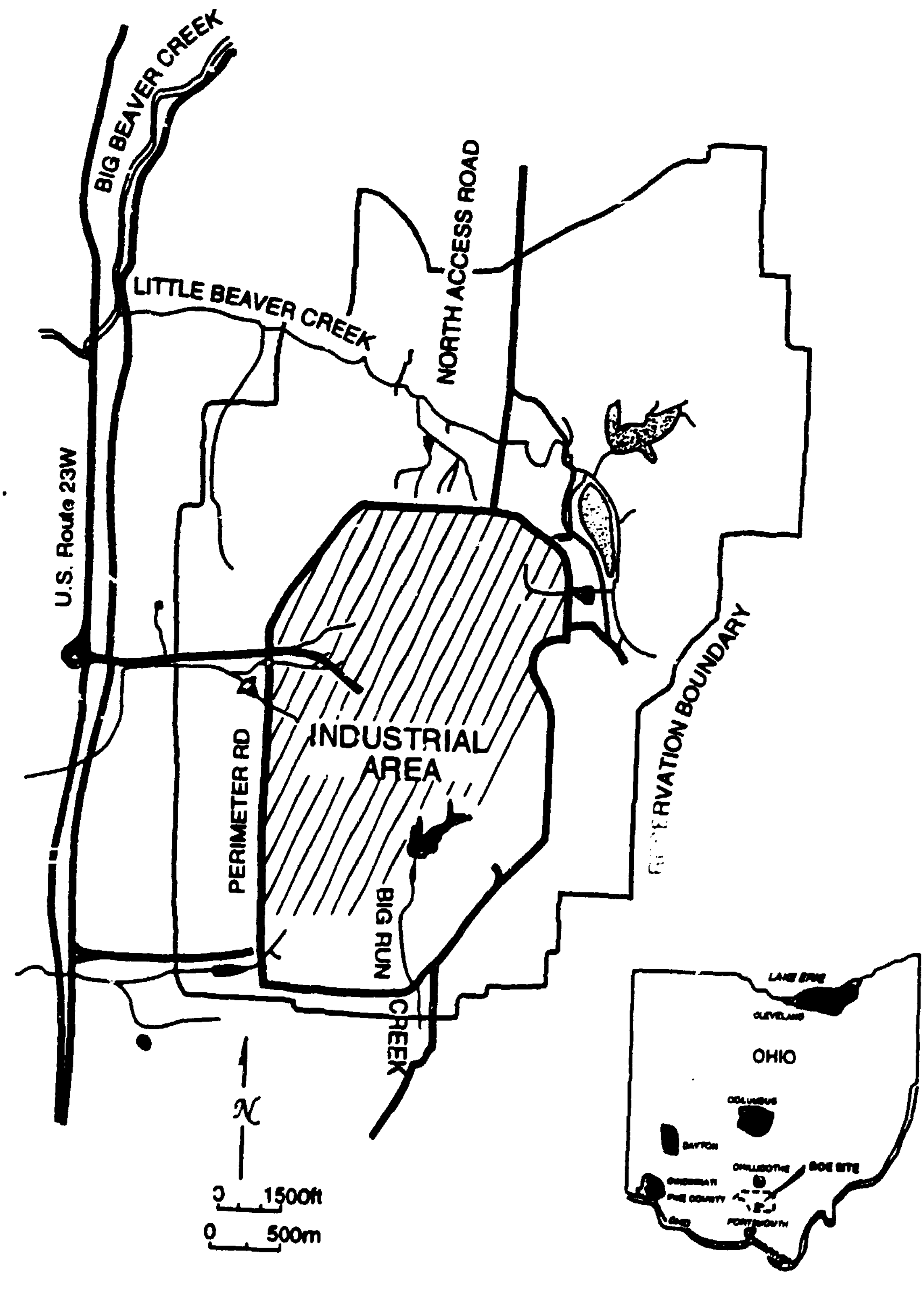
The Portsmouth Gaseous Diffusion Plant (PORTS) occupies about 400 ha (1000 acres) of a 1620-ha [4000-acre; 6.2-km^2 (6.3-mi^2)] reservation in sparsely populated Pike County, Ohio. The primary process at Portsmouth, since beginning operation in 1954, has been separating uranium isotopes by way of a gaseous diffusion cascade. The reservation is about 1.6 km (1 mile) east of the Scioto River Valley at an elevation approximately 36.6 m (120 ft) above the Scioto River floodplain [162 m (530 ft) above mean sea level] (figure 9-1). The areas of the plant not occupied by buildings and roads are mowed grassy fields with a few wooded areas. The surrounding DOE land is pasture; old fields; upland and bottomland hardwood forest and pine forest; second-growth hardwood forest dominated by white oak and red oak, with some hickory; and scrub thicket. Much of the site was logged in 1977. Cattle graze selected portions of open pasture and forest. Land surrounding the Portsmouth Reservation, except for the Scioto River floodplain, is marginal farmland and densely forested hills. The floodplain is farmed extensively, particularly with row crops such as corn and soybeans. Hillsides and terraces are commonly used for cattle grazing. Currently, there are no systematic programs to monitor or characterize ecological resources at Portsmouth. However, a work plan (DOE 1993) is being prepared to characterize the environmental setting and to determine ecological effects from the release of contaminants. Information in this report was drawn from Rogers et al. (1988); ERDA (1977a and b); and Saylor et al. (1990).

The Portsmouth Reservation lies within the Scioto River drainage basin at the headwaters of two small tributaries to the Scioto River—Little Beaver Creek and Big Run Creek. The Scioto River is a major tributary of the Ohio River. Both groundwater and surface water are drained from the reservation by this network of tributaries (DOE 1993). Little Beaver Creek drains the northern portion of Portsmouth; shortly after leaving the reservation it flows into Big Beaver Creek which also receives runoff directly from the northeastern portion of the plant. Big Beaver Creek flows to the Scioto River. Storm water is drained from the southern portion of Portsmouth via the South Holding Pond, which overflows to Big Run Creek, and from the southwest, central, and western portions of the plant via holding ponds, drainage ditches, and intermittent unnamed tributaries to the Scioto River.

The reservation itself is characterized by (1) the fenced centrally located production and waste storage area [about 400 ha (1000 acres)] surrounded by grasses and herbaceous dicots that are mowed throughout the growing season, (2) several small pine plantations and extensive old field and second-growth hardwoods (oak-hickory) north and east of the plant, (3) pastureland used partly for grazing of cattle south and north of the plant, (4) bottomland mixed hardwoods along the creeks, and (5) upland mixed hardwoods along the western border of the reservation. No federally listed threatened, endangered, or candidate species of plants, or animals are known to inhabit the Portsmouth Reservation. Wetland swales and ditches and emergent wetlands occur primarily along streams, in topographic depressions, and along roads. In addition, small wetland areas formed around holding ponds are utilized by migratory waterfowl. Recreational fish [e.g., longear sunfish (*Lepomis megalotis*) and smallmouth bass (*Micropterus dolomieu*)] occur in downstream segments of Little Beaver Creek. Although hunting is not allowed, several recreational wildlife species are present. Important species groups of concern for conservation of biodiversity at Portsmouth include songbirds, raptors, deer, fox, bats, amphibians, fish, and vegetation.

9.1 ECOLOGICAL ENDPOINTS AND SPECIES DISTRIBUTION

Endpoints can be represented by many different receptors. The ecological endpoints and receptors chosen for the Portsmouth Reservation


BIG BEAVER CREEK
LITTLE BEAVER CREEK
NORTH ACCESS ROAD
U.S. Route 23W
PERIMETER RD
INDUSTRIAL AREA
BIG RUN
CREEK
RVATION BOUNDARY
N
0 1500ft
0 500m
LAKE ERIE
CLEVELAND
OHIO
COLUMBUS
DAYTON
CHILLICOTHE
DOE SITE
CINCINNATI
PIKE COUNTY
PORTSMOUTH

ecological risk assessment are described in this section of the report. In summary, currently, no federally listed threatened, endangered, or candidate species of plants or animals are known to occur on the reservation; wetlands are found in swales, ditches, and ponds, along the streams, and in topographic depressions; recreational wildlife species are present but hunting is not allowed; grazing is limited to specific areas; no public areas occur on the reservation; and the vegetation and wildlife (i.e., biodiversity) are typical of that found in the surrounding area.

Determining risks to endpoints requires (1) defining distribution and composition of endpoints and (2) selecting receptor species. The distribution of endpoints must be known in order to determine both exposure pathways for contaminants and risks to endpoints from construction.

For purposes of determining risk of exposure to contaminants, distribution of endpoints is considered to be either ubiquitous (i.e., more or less uniformly distributed throughout the reservation or region); discrete (i.e., located in one clearly identified location); or discontinuous (i.e., found in several locations within a limited area or areas). Risks to ubiquitous endpoints are assumed to be related to the total surface area affected by contaminant exposure or by disturbance from construction. Risks to discontinuous and discrete endpoints are determined if their locations are known to be within contaminated areas or within areas affected by remediation-related construction or contaminant exposures.

Ubiquitous endpoints include recreational wildlife and certain components of biodiversity (table 9-1). Wetlands, agriculture and forestry, and the only federally listed species (if present) exhibit discontinuous distributions. Locations of endpoints were determined from existing maps and publications.

Endpoints can be represented by many different receptors. The following sections describe endpoints on the Portsmouth Reservation and receptors selected for these analyses.

9.1.1 Threatened and Endangered Species

9.1.1.1 Receptors

The geographic range of the federally listed endangered Indiana bat (*Myotis sodalis*) encompasses the Portsmouth Reservation. Although the Indiana bat is not known to inhabit the reservation, it was selected as representative of a federally listed threatened, endangered, or candidate species under the Endangered Species Act that may at least forage on the reservation. Currently, no federally listed or candidate species are known to occur at Portsmouth.

9.1.1.2 Distribution

The Indiana bat has been reported in the Portsmouth area (Houlberg et al. 1992). As do most bats, the Indiana bat lives in caves and feeds on flying insects. At the time of this report, no caves were known to exist on Portsmouth. However, the site may provide suitable foraging habitat. Foraging habitat for one colony of Indiana bats ranged from 1.5 ha (3.6 acres) in early summer to 4.5 ha (11.2 acres) after young bats are flying (Humphrey et al. 1977). In the summer, these bats forage for insects in the upper woodland canopy (Thomson 1982). They prefer mature riparian woodland, with dead trees for shelter, along small to medium-sized streams.

9.1.2 Wetlands

9.1.2.1 Receptors

Representative wetland organisms include minnows and other small fish species, benthic invertebrates, and wetland vegetation such as cattails and rushes. For this assessment, benthic invertebrates and fish were selected as the receptors representative of reservation wetlands.

9.1.2.2 Distribution

The extent of wetlands on the reservation is unknown. A wetland survey was completed in 1993 for Quadrant III of the Portsmouth

TABLE 9-1—*Distribution of Ecological Endpoints and Receptors at the Portsmouth Reservation*

Ubiquitous	Discontinuous	Discrete
Recreational wildlife (fish, rabbit, and deer)	**Wetlands** (fish, benthic invertebrates, and vegetation)	
Components of **biodiversity** not included above (bats, mice, songbirds, raptors, foxes, and insects)	**Agricultural and timber production** (vegetation)	
	Threatened and endangered species (Indiana bat, if present)	

Reservation Manual for Identifying and Delineating Jurisdictional Wetlands. This survey delineated wetland swales and ditches, emergent wetlands on alluvial soils, and nine wetland areas. Wetland swales exist adjacent to many roads in Quadrant III and are identified by cattails and other vegetation. Emergent wetlands and wetland areas are identified by hydric soils. They occur primarily along streams and topographic depressions in Quadrant III (DOE 1993). Holding ponds located around the reservation also provide wetland habitat for muskrats and migrating waterfowl. These wetlands and the receptors chosen to represent them exhibit discontinuous distributions. For purposes of this assessment, the wetlands are considered to be under the influence of the waste sites.

9.1.3 Recreational Fish and Wildlife

9.1.3.1 Receptors

Several recreationally desirable animals occur on the Portsmouth Reservation, although the reservation is closed to public access. Fish (particularly those of the catfish and sunfish families), the cottontail rabbit, and the white-tailed deer were selected for this assessment as representative of the recreational fish and wildlife at the reservation. The data available for fish are not specific to species of interest; therefore, the assessment is limited to risks to fish as a class.

9.1.3.3 Distribution

Little Beaver Creek is the largest stream on the Portsmouth Reservation. It drains the northern and northeastern part of the site before discharging into Big Beaver Creek upstream of the reservation. Little Beaver Creek has intermittent flow throughout the year. Nevertheless, populations of spotted bass, northern hog sucker, longear sunfish, and several darter species are commonly found at sites a short distance downstream from all Portsmouth inputs. Recreationally desirable fish (e.g., sunfish, bass, and crappie) are also found in Big Beaver Creek and, of course, in the Scioto River. Game mammals and birds that occur on the reservation include the eastern cottontail rabbit (*Sylvilagus floridanus*), white-tailed deer (*Odocoileus virginianus*), and the bobwhite quail (*Colinus virginianus*). The fish have a discontinuous distribution, whereas both mammalian species are considered to be ubiquitous in distribution.

9.1.4 Agricultural or Timber Production

9.1.4.1 Receptors

Although cattle are allowed to graze on the Portsmouth Reservation, under normal circumstances they do not have access to contaminated sites. Therefore, vegetation (representing grass and planted pines), but not cattle, was selected for this assessment as the endpoint receptor representative of agricultural production.

9.1.4.2 Distribution

Much of the land on which Portsmouth was constructed was originally cropland. The area within the perimeter road not occupied by buildings and roads is mowed grassy fields. A few wooded areas also exist. The DOE property surrounding the perimeter road supports pasture, old fields, upland and bottomland mixed hardwoods and pine forest, second-growth hardwoods, and scrub thicket. Much of the site was logged in 1977. This assessment considers only vegetation on or adjacent to the contaminated sites.

9.1.5 Parks and Other Public Lands

9.1.5.1 Receptors

Except for Wayne National Forest, no likely receptors in terms of parks and public lands were identified for this assessment.

9.1.5.2 Distribution

There are no parks or public lands on the reservation. The land surrounding the reservation is mostly privately owned croplands. Wayne National Forest is adjacent to the Portsmouth property on the east and southeast. The Brush Creek State Forest is about 1.6 km (1 mile) southwest of the property and west of the Scioto River.

9.1.6 Biodiversity

9.1.6.1 Receptors

Ecosystems of the reservation and environs underwent substantial alteration with the arrival of the first European settlers. Virgin forest and the complex plant and animal communities it supported no longer exist in the area. What woodland exists is fragmented, and current practices in land management on the reservation (e.g., mowing and gazing) prevent the establishment of truly climax communities. Even so, the fragmented and disturbed terrestrial systems support a variety of plant and animal communities.

Except for cattle, all of the animals and plants used as representative of the other endpoints discussed above are considered as representative elements of area biodiversity and, therefore, are used in this assessment of impacts on biodiversity (i.e., the mouse, rabbit, deer, robin, bat, hawk, fox, vegetation, aquatic invertebrates, and fish). Note that for this assessment aquatic organisms are assumed to be absent from the actual waste sites.

9.1.6.2 Distribution

All but two of the selected receptors representative of the area's biodiversity are considered to have ubiquitous distributions. Fish and benthic invertebrates have discontinuous distributions.

9.2 CONTAMINANTS OF POTENTIAL CONCERN

The contaminants of potential concern at Portsmouth include radionuclides and inorganic and organic contaminants. The primary radionuclides are ^{238}U and ^{99}Tc; the primary inorganics are Al, As, Ba, Cd, Cu, Hg and Pb; the primary organic contaminants are polychlorinated biphenyls (PCBs), vinyl chloride and benzo(a)pyrene.

Maximum and average concentrations of chemical and radiological contaminants in soil, surface water, and sediment were determined from the source terms provided by PNL (tables 9-2, 9-3 and 9-4 respectively) and compared to toxicological benchmarks. Determination of these average and maximum concentrations required that certain assumptions be made with regard to data interpretation and compensation for data gaps. Appendix A describes the methodology used to develop the source terms for input into the exposure and risk assessment.

9.3 Exposure Assessment

Where available for Portsmouth, the maximum concentrations of each contaminant in each medium (i.e., soil, water, and sediment) were used to identify the worst-case potential contaminants. Contaminants that did not pose a risk to any of the receptor species from exposure to the maximum values (when compared to toxicological benchmarks, see chapter 9.4) were not considered further. If exposure to the maximum concentrations of contaminants posed a risk to organisms, then the average concentrations of those contaminants were estimated and used in the assessment to determine the most probable and reasonable exposure and risk.

Estimating contaminant exposure for receptor species on the reservation also depends on knowing the amount of time species spend in waste areas and the amount of contaminants ingested. Because specific home ranges and habits of many of the receptor species on Portsmouth are not well known, an initial screening assessment for contaminant exposure was conducted using conservative assumptions. Even though only a few species with small home ranges (e.g., small mammals, and birds) could reside within contaminated areas for most of their lives and even fewer individuals could contact areas of maximum concentrations (see chapter 9.4 for discussion of home ranges), the conservative assumptions were applied routinely.

The risk assessment (appendix A) estimates the risk to vegetation, terrestrial wildlife, and aquatic organisms from chronic exposure to radiological and nonradiological contaminants. In these exposure analyses, the ecological endpoints and their receptor species were considered. However, due to limited availability of sensitivity data for many species (e.g., threatened and endangered species) and to similarities in exposure risk (e.g., similarly sized receptors feeding on the same prey), representative organisms for each endpoint were chosen for evaluation. A food web was developed that includes receptor species representing the endpoints (figure 9-2). In all cases in which data were available, conservative estimates of exposure and risk were made by selecting receptors that are either (1) most sensitive to contaminants or habitat alteration, (2) most likely to experience additional risk because of bioaccumulation or larger body size, or (3) at greatest risk because of rarity. Other abundant species on the reservation were included as important prey components of the foodweb, such as mice and insects (risk estimates were not determined for insects).

The primary exposure routes for terrestrial wildlife species are exposure to external radiation and ingestion of food (including soils for some species) and water. Table 9-5 lists the body weights and consumption rates for the representative species. The cow is assumed to feed exclusively on the vegetative parts of plants. The cottontail rabbit and white-tailed deer are assumed to eat 50% vegetation and 50% fruits and seeds. On the basis of a review of the literature, the percentage of prey items consumed by omnivores and predators was estimated (table 9-5; figure 9-2). The mouse and robin are assumed to eat 70% fruit/seeds and 30% insects; the red-tailed hawk eats 80% mice and 20% rabbits; and the red fox eats 70% mice and 30% rabbits. The bat is assumed to eat 100% insects, and the insects are assumed to eat 100% vegetative plant parts.

All species are assumed to purposely or incidentally ingest soil while eating, grooming, or preening except for the bat, hawk, and red fox (table 9-5). The soil ingestion rate (Q_s) for cottontail rabbits was assumed to be the same as that reported for the jackrabbit, 6.3% of the dry-matter intake (Arthur and Gates 1988). The white-tailed deer soil ingestion rate is assumed to be the same as that reported for the mule deer, 1.35% of the dry-matter intake (Arthur and

TABLE 9-2—*Maximum and Average Concentrations of Organic, Inorganic, and Radionuclide Contaminants in Soil on the Portsmouth Reservation [mg/kg dry weight (for chemical constituents) or pCi/kg dry weight (for radionuclides)]*

Constituent	Maximum Concentration	Constituent	Average Concentration
Acenapthene	1.20E+00	Acenapthene	2.08E-02
Acenapthylene	7.10E-03	Anthracene	6.60E-02
Acetone	3.90E-01	Aroclor 1260	1.50E-01
Anthracene	1.80E+00	Benzo(a)anthracene	1.52E-01
Aroclor 1254	2.10E-01	Benzo(a)pyrene	1.14E-01
Aroclor 1260	2.00E+03	Benzoic acid	2.50E-01
Benzene	5.10E-03	BEHP	5.20E-02
Benzo(a)anthracene	4.50E+00	Fluoranthene	2.49E-01
Benzo(a)pyrene	3.70E+00	Phenanthrene	1.79E-01
Benzo(b)fluoranthene	4.00E+00	Trichloroethene	4.06E-01
Benzo(g,h,i)perylene	2.50E+00	Vinyl chloride	8.92E-01
Benzo(k)fluoranthene	3.00E+00	Aluminum	1.16E+04
Benzoic acid	8.40E-01	Antimony	6.60E+00
BEHP	1.00E+02	Arsenic	3.35E+01
Bromodichloromethane	7.90E-03	Barium	6.98E+01
2-butanone	1.80E-02	Cadmium	1.08E+00
Butyl benzyl phthalate	2.70E-02	Chromium	1.34E+01
Carbon disulfide	1.20E+00	Cobalt	1.58E+01
Chlorobenzene	5.00E-03	Copper	2.07E+01
Chloroform	6.25E-01	Cyanide ion	3.20E+00
Chloromethane	6.60E-02	Iron	3.43E+04
4-chloro-3-methylphenol	4.60E-01	Lead	3.78E+01
2-chlorophenol	8.50E-01	Magnesium	7.34E+03
Chrysene	7.06E+00	Manganese	3.24E+02
Dibenzofuran	6.60e-01	Mercury	1.71E+00
Dibenzo(a,h)anthracene	6.10E-01	Nickel	5.71E+01
1,2-dichlorobenzene	3.50E-01	Potassium	1.42E+03
1,4-dichlorobenzene	2.40E-01	Selenium	7.80E+00
1,1-dichloroethane	2.05E-01	Silver	6.56E+00
1,1-dichloroethene	3.30E-03	Sodium ion	1.69E+02
cis-1,2-dichloroethene	3.80e-03	Thallium	1.30E+00
trans-1,2-dichloroethene	1.70E-03	Vanadium	3.94E+01
1,1-dichloroethylene	5.88E-02	Zinc	4.78E+01
2-trans-dichloroethylene	1.44E+00	Technecium-99	2.44E+02
2,4-dichlorophenol	2.40E-01		
4,4-DDT	1.60E-02		
2,4-dinitrotoluene	2.00E-01		
Diethyl phthalate	1.80E-01		
Dimethyl phthalate	4.30e-03		
Di-n-butyl phthalate	3.50E-01		
Di-n-octylphthalate	2.20E-02		
Ethylbenzene	2.30e-03		
Fluoranthene	1.30E+01		
Fluorene	1.40E+00		
Freon	3.59E+00		
indeno(1,2,3-cd)pyrene	2.10E+00		
Methylene chloride	1.32E-01		
2-methylnapthylene	6.60E-01		
2-methylphenol	8.50E-01		
Napthalene	5.00E-01		
4-nitrophenol	3.10E-01		
n-nitrosodi-n-propylamine	2.60E-01		

Table 9-2 (continued)

Constituent	Maximum Concentration	Constituent	Average Concentration
Phenanthrene	9.90E+00		
Phenol	1.97E+00		
Pyrene	1.30E+01		
Tetrachloroethene	4.30E-02		
Tetrachloroethylene	1.14E-01		
Toluene	3.07E+00		
1,2,4-trichlorobenzene	2.20E-01		
1,1,1-trichloroethane	7.44E-01		
1,1,2-trichloroethane	7.10E-03		
Trichloroethene	2.78E+01		
Vinyl chloride	8.92E-01		
Xylene	1.60E-02		
Aluminum	1.60E+04		
Antimony	4.50E+03		
Arsenic	6.60E+04		
Barium	1.99E+05		
Beryllium	2.40E+00		
Cadmium	1.10E+02		
Calcium	1.40E+05		
Chromium	7.76E+03		
Cobalt	4.20E+01		
Copper	2.39E+03		
Cyanide ion	3.20E+00		
Fluoride	1.20E+01		
Iron	1.10E+05		
Lead	8.36E+02		
Magnesium	1.10E+05		
Manganese	8.86E+02		
Mercury	7.60E+01		
Nickel	9.92E+03		
Potassium	1.58E+04		
Selenium	2.80E+01		
Silver	2.00E+01		
Sodium ion	3.24E+03		
Sulfite	1.70E+02		
Thallium	2.80E+00		
Vanadium	6.20E+01		
Zinc	2.44E+03		
Technecium-99	4.15E+05		
Uranium-238	2.63E+04		

TABLE 9-3—*Maximum and Average Concentrations of Organic, Inorganic, and Radionuclide Contaminants in Water at the Portsmouth Reservation [mg/L (for chemical constituents) or pCi/L (for radionuclides)]*

Constituent	Maximum Concentration	Constituent	Average Concentration
Acetone	5.20E-02	BEHP	2.70E-03
Aroclor 1260	2.00E-03	Vinyl chloride	4.00E-02
BEHP	2.70E-03	Aluminum	4.20E-01
Chloroform	2.90E-03	Arsenic	1.20E-02
Dibromochloromethane	3.20e-03	Barium	2.84E-02
1,1-dichloroethane	1.20E-02	Iron	9.40E-01
cis-1,2-dichloroethene	2.80e-02	Manganese	4.00E-01
1,4-dioxane	6.50E-04	Zinc	4.88E-02
Di-n-butyl phthalate	5.50E-04	Technicium-99	6.50E+01
Isobutyl alcohol	1.60e-01		
p-phenylendiamine	2.30E-03		
Trichloroethene	1.10E-01		
Vinyl chloride	4.00E-02		
Xylene	1.50E-03		
Aluminum	1.00E+00		
Arsenic	7.30E-02		
Barium	3.50E-01		
Cadmium	9.00E-03		
Calcium	2.70E+01		
Chromium	9.00E-03		
Cobalt	2.80E-02		
Copper	3.60E-02		
Fluoride	1.20E+00		
Iron	9.40E-01		
Lead	3.70E-02		
Magnesium	1.80E+01		
Manganese	4.00E-01		
Mercury	1.80E-03		
Nickel	5.50E-02		
Sodium ion	5.00E+01		
Tin	6.50E-02		
Vanadium	7.20E-02		
Zinc	2.20E-01		
Technecium-99	6.80E+01		
Uranium-238	2.43E-02		

TABLE 9-4—*Maximum and Average Concentrations of Organic, Inorganic, and Radionuclide Contaminants in Sediment at the Portsmouth Reservation [mg/kg (for chemicals) or pCi/kg (for radionuclides)]*

Constituent	Maximum Concentration	Constituent	Average Concentration
Acenapthene	3.90E+01	Acenapthene	1.22E+01
Acenapthylene	4.50E-01	Anthracene	2.13E+00
Acetone	9.70E-01	Aroclor 1260	3.89E+02
Anthracene	1.80E+01	Benzo(a)anthracene	5.23E+00
Aroclor 1260	8.30E+03	Benzo(a)pyrene	4.75E+00
Benzo(a)anthracene	2.60E+01	Benzoic acid	1.33E-01
Benzo(a)pyrene	2.10E+01	BEHP	3.11E+00
Benzo(b)fluoranthene	2.10E+01	Fluoranthene	9.83E+00
Benzo(g,h,i)perylene	9.20E+00	Phenanthrene	9.70E+00
Benzo(k)fluoranthene	1.90E+01	Aluminum	4.43E+03
Benzoic acid	1.10E+02	Arsenic	5.89E+00
BEHP	5.60E+00	Barium	1.96E+02
Bromoform	7.10E-04	Cadmium	2.04E+00
2-butanone	7.00E-03	Chromium	4.18E+01
Carbon disulfide	6.00E-03	Cobalt	1.34E+01
2-chlorophenol	1.50E-02	Copper	4.28E+00
Chrysene	2.90E+01	Iron	2.94E+04
Dibenzofuran	5.30E+04	Lead	2.11E+01
Dibenzo(a,h)anthracene	2.90E+00	Magnesium	3.60E+03
1,2-dichlorobenzene	2.40E-01	Manganese	4.86E+02
1,4-dichlorobenzene	2.40E-01	Mercury	9.71E-01
1,1-dichloroethene	4.20E-03	Nickel	1.30E+02
cis-1,2-dichloroethene	1.90E+00	Potassium	1.02E+03
trans-1,2-dichloroethene	4.80E-03	Silver	7.60E+00
4,4-DDT	3.40E-02	Sodium ion	8.20E+01
Dieldrin	1.10E+01	Vanadium	3.34E+01
Diethyl phthalate	5.70E-02	Zinc	3.60E+02
2,4-dimethylphenol	3.80E-02	Technecium-99	1.50E+05
Di-n-butyl phthalate	8.80E-03		
Di-n-octylphthalate	1.60E-01		
Fluoranthene	7.40E+01		
Fluorene	3.62E+02		
indeno(1,2,3-cd)pyrene	1.00E+01		
Methoxychlor	1.00E-01		
Methylene chloride	1.70E-02		
2-methylnapthylene	5.90E+03		
4-methylphenol	2.90E+02		
Napthalene	1.64E+00		
Phenanthrene	5.80E+01		
Pyrene	4.20E+01		
Toluene	2.90E-03		
1,2,4-trichlorobenzene	2.40E-01		
Trichloroethene	4.00E+00		
Xylene	1.60E-03		
Aluminum	1.50E+04		
Arsenic	1.08E+02		
Barium	4.00E+02		
Beryllium	9.90E-01		
Cadmium	3.80E+00		
Calcium	4.40E+04		
Chromium	4.96E+03		
Cobalt	3.90E+01		
Copper	7.70E+01		
Fluoride	1.20E+01		
Iron	7.60E+04		
Lead	5.50E+01		
Magnesium	1.50E+04		
Manganese	1.40E+03		
Mercury	1.90E+00		
Nickel	3.00E+02		
Potassium	1.80E+03		
Selenium	3.50E+00		

Table 9-4 (con't)

Constituent	Maximum Concentration	Constituent	Average Concentration
Silver	1.70E+01		
Sodium ion	2.30E+02		
Vanadium	8.10E+01		
Zinc	8.30E+02		
Technecium-99	4.61E+15		
Uranium-238	2.00E+04		

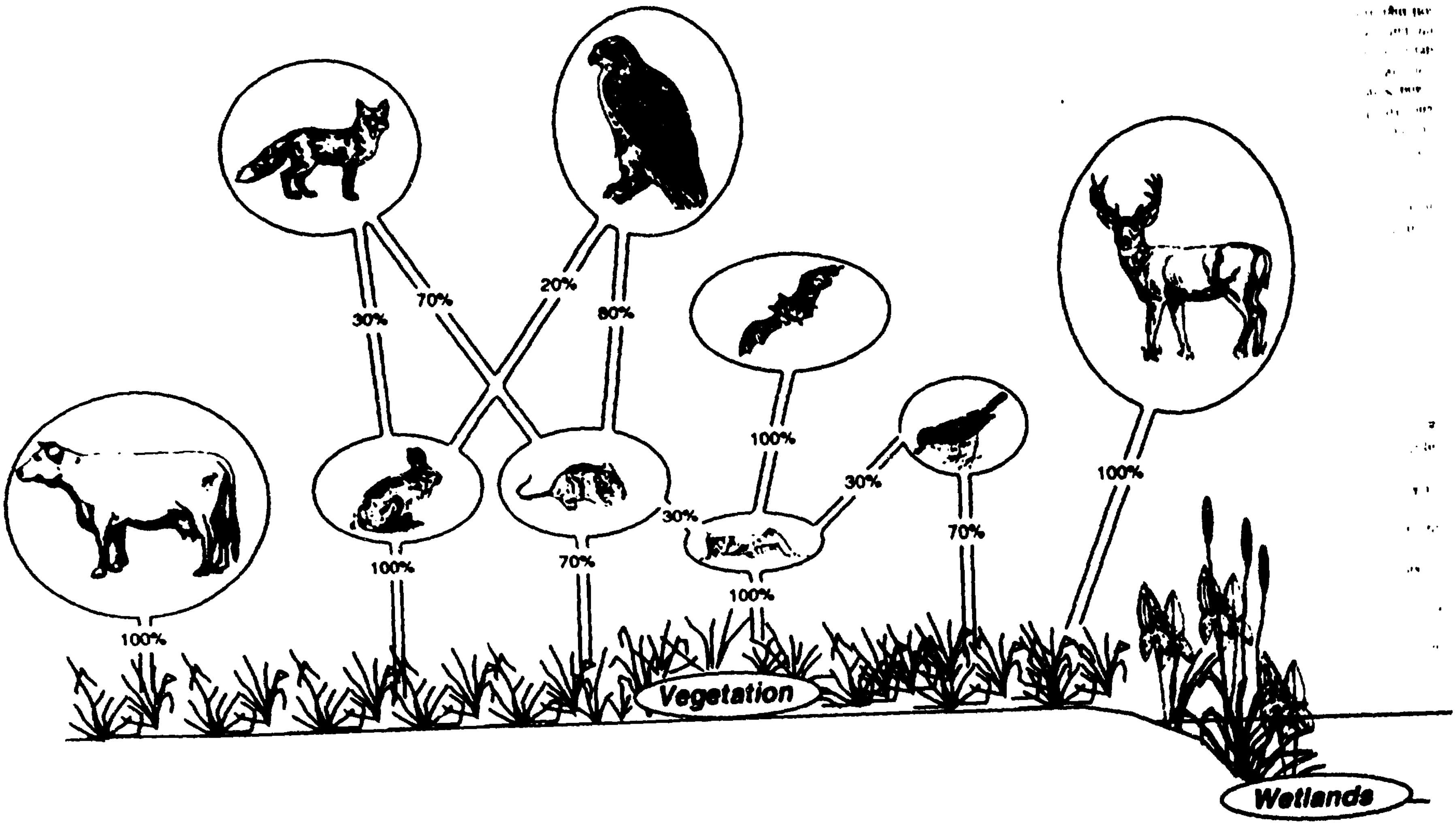


FIGURE 9-2. REPRESENTATION OF THE TERRESTRIAL FOOD WEB OF THE PORTSMOUTH RESERVATION

Alldredge 1979). The soil ingestion rates for the cow and mouse are 7% and 2% of the dry-matter intake, respectively (Mayland et al. 1977 and OHEA 1991). Since published values of soil ingestion rates were not found for the robin, it was conservatively estimated to be 10% of the dry-matter intake.

The estimated daily rates of food and water consumption (Q_v, Q_f, or Q_H, and Q_w, respectively) for each receptor species were calculated from allometric regression equations that are based on the weight of the organism (EPA 1988) (appendix A). These equations are based on the combined measurements for laboratory animals, livestock, and selected wildlife and bird species.

Because information on the specific habits and behaviors of most of the receptor wildlife species at Portsmouth is not well known, it is assumed that all species spend 100% of their time on the reservation. Therefore, the fraction of contaminated vegetation, fruit, prey, soil, and water consumed (FI_v, FI_f, FI_H, FI_s, and FI_w, respectively) is set at 100% (table 9-5).

Contaminant concentrations in vegetation, the first level in the foodchain, are estimated from source-term concentrations in the soils using published element-, or chemical-specific soil-to-plant transfer factors (Baes et al. 1984; Travis and Arms 1988) (table 9-6). Transfer factors for inorganic chemicals are available for both the vegetative and fruiting parts of plants (Baes et al. 1984); however, the transfer factors for organics do not make this distinction (Travis and Arms 1988). The methodology used to predict contaminant concentrations in vegetation does not make a distinction between different plant types or species. Therefore, all species ingest "generic" vegetation containing contaminant concentrations derived from soil concentrations by the use of transfer factors.

Transfer factors for contaminants of concern are applied to predict concentrations in the tissues of terrestrial mammalian receptors from consumption of vegetation, soil, and water (collectively termed B_b) (Baes et al. 1984; Travis and Arms 1988) (table 9-6). Data on transfer factors from vegetation or soil to insects and earthworms are very limited in the literature. Therefore, the concentration in insects was derived from vegetation concentrations, and a default, conservative one-to-one transfer between vegetation and insects was assumed. The rationale and limitations for applying these transfer factors are discussed in appendix B.

The consumption rates and the benchmark limit or no-observable-adverse-effect level (NOAEL) values are typically reported in wet weights, whereas the vegetation and soil concentrations are typically reported in dry weights. Therefore, conversion factors were applied to account for this difference. The wet- to dry-weight concentration conversion factor for the vegetative parts of plants at Portsmouth was assumed to be 0.32 (the average for meadow fescue, Kentucky bluegrass, wild bromegrass, and orchard grass (Morrison 1959). The wet- to dry-weight concentration conversion factor for the fruiting parts of plants at Portsmouth was assumed to be 0.17 (Morrison 1959). The wet- to dry-weight concentration conversion factor for soils was assumed to be 0.90 (Solid Wastes: Engineering Principles and Management Issues 1977).

For the base-line assessment of Portsmouth, the concentrations of radionuclides in animal tissues and the resulting doses were not decay-corrected. The doses are estimated for the current situation and not for some point in the future. The primary radionuclides of concern, ^{238}U and ^{99}Tc, have long half-lives (4.5×10^9 and 2.12×10^5, respectively) so this assumption is reasonable. The radionuclide concentrations in the source terms were decay-corrected by PNL to the time of disposal or release. To estimate dose to terrestrial receptors, all short-lived daughter products were included.

Aquatic organisms considered in the assessment included benthic macroinvertebrates and a generic fish species. For radiological analyses, emergent vegetation (i.e., cattails) and muskrats were included as well. All aquatic organisms, except for benthic macroinvertebrates, are exposed to contaminants in surface water. Benthic macroinvertebrates are assumed to be exposed only to the sediment pore water for calculation of internal radiation dose and exposure to chemicals. The external radiation dose from exposure to surface water was calculated for all organisms.

TABLE 9-5—*Body Weights and Consumption Rates[1] for Terrestrial Receptor Species[2] on the Portsmouth Reservation*

Parameter	White-footed Mouse	Eastern Cottontail rabbit	Deer	Cow	Robin	Indiana Bat	Red-Tailed Hawk	Red Fox
Body weight, BW (kg)	2.40E−02[3]	1.19E+00[4]	5.65E+01[5]	4.00E+02[6]	7.50E−02[7]	7.30E−03[8]	1.39E+00[9]	6.00E+00[10]
Water intake rate, Q_w (L/d)	6.40E−03	1.14E−01	2.63E+00	1.23E+01	1.43E−02	2.30E−03	1.41E−01	4.51E−01
Water ingestion fraction, FI_w	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00
Soil intake rate, Q_s (kg/d)	4.38E−05[11]	1.28E−03[12]	5.83E−03[13]	1.86E−01[14]	3.87E−04[15]	0.00	0.00	0.00
Soil ingestion fraction, FI_s	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	0.00	0.00	0.00
Vegetation intake rate, Q_v (kg/d)	0.00	3.73E−02[16]	7.93E−01[17]	7.47E+00	0.00	0.00	0.00	0.00
Vegetation ingestion fraction, FI_v	0.00	1.00E+00	1.00E+00	1.00E+00	0.00	0.00	0.00	0.00
Fruit/seeds intake rate, Q_f (kg/d)	3.36E−03[18]	3.73E−02	7.93E−01	0.00	5.80E−03[19]	0.00	0.00	0.00
Fruit/seeds ingestion fraction, FI_f	1.00E+00	1.00E+00	1.00E+00	0.00	1.00E+00	0.00	0.00	0.00
Prey 1 intake rate, Q_{p1} (kg/d)	1.40E−03 (insects)	0.00	0.00	0.00	2.50E−03 (insects)	1.30E−03 (insects)	7.92E−02[20] (mice)	1.88E−01[21] (mice)
Prey 1 ingestion fraction, FI_{p1}	1.00E+00	0.00	0.00	0.00	1.00E+00	1.00E+00	1.00E+00	1.00E+00
Prey 2 intake rate, Q_{p2} (kg/d)	0.00	0.00	0.00	0.00	0.00	0.00	1.98E−02 (rabbits)	8.06E−02 (rabbits)
Prey 2 ingestion fraction, FI_{p2}	0.00	0.00	0.00	0.00	0.00	0.00	1.00E+00	1.00E+00
Prey 3 intake rate, Q_{p3} (kg/d)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Prey 3 ingestion fraction, FI_{p3}	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

[1] All values are on a wet weight basis. For soils, the wet:dry ratio is 0.90 (Clark and Mausel 1977), for vegetation the ratio is 0.32 and for fruits/seeds, the ratio is 0.17 (Morrison 1959).
[2] Water and food consumption rates were computed by methods in (U.S. EPA 1988) (Table 8) unless otherwise noted.
[3] Lackey et al. 1985
[4] Chapman et al. 1980.
[5] Smith 1991.
[6] U.S. EPA 1988.
[7] Terres 1980.
[8] Thomson 1982.
[9] Brown and Amadon 1968.
[10] Opresko and Suter 1992
[11] Mouse soil ingestion rate is 2% of dry vegetation intake (Beyer et al. 1991).
[12] The eastern cottontail is assumed to have the same soil ingestion rate as the jackrabbit (6.3%) (Arthur and Gates 1988.)
[13] The white-tail deer is assumed to have a soil ingestion rate of 1.35% of dry matter intake (Arthur and Aldridge 1979)
[14] Cattle soil ingestion rate is about 7% of dry matter intake (Maryland et al. 1977).
[15] The robin soil ingestion rate is assumed to be 10% of dry matter intake
[16] The eastern cottontail rabbit is assumed to eat 50% fruit and seeds 5[illegible]% vegetation (Whitaker 1988.)
[17] The white-tailed deer is assumed to eat 50% vegetation and 50% fruit and seeds (Whitaker 1988.)
[18] The mouse is assumed to eat 70% fruit and seeds and 30% insects (Lackey et al. 1985)
[19] The robin is assumed to eat 70% fruit and seeds and 30% insects (Terres 1980).
[20] The red-tailed hawk is assumed to eat 80% mice and 20% rabbits (Terres 1980).
[21] The red fox is assumed to eat 70% mice and 30% rabbits (Whitaker 1988).

TABLE 9-6—*Soil to Vegetation, Soil to Fruit, and Plant to Beef Transfer Factors, and Fish Bioconcentration Factors for Constituents of Concern at the Portsmouth Reservation*

Constituent	Fish Bioconcentration Factor	Soil to Vegetation Transfer Factor	Soil to Fruit Transfer Factor	Vegetation to Beef Transfer Factor
Acenapthene	6.46E+02	2.16E-01	2.16E-01	2.00E-04
Acenapthylene	3.01E+02	2.16E-01	2.16E-01	2.00E-04
Acetone	3.89E-01	5.33E+01	5.33E+01	1.44E-08
Anthracene	1.42E+03	9.71E-02	9.71E-02	7.94E-04
Aroclor 1254	2.30E+04	2.24E-02	2.24E-02	1.00E-02
Aroclor 1260	1.60E+05	2.24E-02	2.24E-02	1.00E-02
Benzene	2.41E+01	2.37E+00	2.37E+00	3.16E-06
Benzo(a)anthracene	1.17E+04	1.97E-02	1.97E-02	1.26E-02
Benzo(a)pyrene	2.38E+04	1.32E-02	1.32E-02	2.51E-02
Benzo(b)fluoranthene	2.38E+04	1.19E-02	1.19E-02	3.02E-02
Benzo(g,h,i)perylene	NA	6.09E-03	9.55E-02	6.70E+04
Benzo(k)fluoranthene	2.38E+04	1.19E-02	3.02E-02	2.38E+04
Benzoic acid	1.55E+01	3.09E+00	3.09E+00	2.00E-06
BEHP	1.19E+07	4.37E-02	4.37E-02	3.16E-03
Bromodichloromethane	2.97E+01	2.37E+00	2.37E+00	3.16E-06
2-butanone	9.51E-01	2.63E+01	2.63E+01	4.90E-08
Butyl benzyl phthalate	3.54E+03	5.70E-02	5.70E-02	2.00E-03
Carbon disulfide	1.95E+01	NA	NA	NA
Chlorobenzene	6.45E+02	9.32E-01	9.32E-01	1.58E-05
Chloroform	1.85E+01	2.70E+00	2.70E+00	2.51E-06
Chloromethane	3.10E+00	1.15E+01	1.15E+01	2.04E-07
4-chloro-3-methylphenol	NA	6.25E-01	6.25E-01	3.16E-05
2-chlorophenol	6.40E+00	2.07E+00	2.07E+00	3.98E-06
Chrysene	1.08E+04	1.97E-02	1.97E-02	1.26E-02
Dibenzo(a,h)anthracene	1.13E+05	6.78E-03	6.78E-03	7.94E-02
Dibromochloromethane	NA	2.07E+00	2.07E+00	3.98E-06
1,2-dichlorobenzene	8.90E+01	4.20E-01	4.20E-01	6.31E-05
1,4-dichlorobenzene	6.00E+01	4.20E-01	4.20E-01	6.31E-05
1,1-dichloroethane	1.35E+01	3.53E+00	3.53E+00	1.58E-06
1,1-dichloroethene	1.47E+01	2.37E+00	2.37E+00	3.16E-06
1,1-dichloroethylene	1.47E+01	3.35E+00	3.35E+00	1.73E-06
2-trans-dichloroethylene	NA	2.37E+00	2.37E+00	3.16E-06
2,4-dichlorophenol	3.40E+01	4.79E-01	4.79E-01	5.01E-05
4,4-DDT	2.98E+04	7.74E-03	7.74E-03	6.31E-02
2,4-dinitrotoluene	1.95E+01	2.70E+00	2.70E+00	2.51E-06
1,4-dioxane	5.98E-01	5.55E+01	5.55E+01	1.35E-08
Dieldrin	4.87E+03	8.50E-02	8.50E-02	1.00E-03
Diethyl phthalate	4.36E+01	5.48E-01	5.48E-01	3.98E-05
2,4-dimethylphenol	1.50E+02	1.39E+00	1.39E+00	7.94E-06
Dimethyl phthalate	57	2.37E+00	2.37E+00	3.16E-06
Di-n-butyl phthalate	1.07E+04	3.82E-02	3.82E-02	3.98E-03
Di-n-octylphthalate	1.87E+07	1.86E-04	1.86E-04	3.98E+01
Ethylbenzene	146	5.48E-01	5.48E-01	3.98E-05
Fluoranthene	3.12E+03	5.70E-02	5.70E-02	2.00E-03
Fluorene	7.13E+02	1.44E-01	1.44E-01	4.02E-04
Indeno(1,2,3-cd)pyrene	5.13E+04	6.69E-03	6.69E-03	8.13E-02
Isobutyl alcohol	2.23	NA	NA	NA
Methoxychlor	8.30E+03	6.51E-02	6.51E-02	1.58E-03
Methylene chloride	5.74E+00	6.86E+00	6.86E+00	5.01E-07
2-methylnapthylene	5.05E+02	NA	NA	NA
2-methylphenol	1.85E+01	NA	NA	NA
4-methylphenol	1.72E+01	NA	NA	NA

TABLE 9-6 (continued)

Constituent	Fish Bioconcentration Factor	Soil to Vegetation Transfer Factor	Soil to Fruit Transfer Factor	Vegetation to Beef Transfer Factor
Napthalene	1.68E+02	3.22E-01	3.22E-01	1.00E-04
4-nitrophenol	1.26E+02	3.09E+00	3.09E+00	2.00E-06
Phenanthrene	1.44E+03	9.71E-02	9.71E-02	7.94E-04
Phenol	7.57E+00	5.26E+00	5.26E+00	7.94E-07
Pyrene	2.80E+03	3.35E-02	3.35E-02	5.01E-03
Tetrachloroethene	5.57E+01	4.20E-01	4.20E-01	6.31E-05
Tetrachloroethylene	5.57E+01	NA	NA	NA
Toluene	6.99E+01	1.07E+00	1.07E+00	1.26E-05
1,2,4-trichlorobenzene	1.09E+03	1.27E-01	1.27E-01	5.01E-04
1,1,1-trichloroethane	9.00E+00	1.39E+00	1.39E+00	7.94E-06
1,1,2-trichloroethane	3.90E+01	2.07E+00	2.07E+00	3.98E-06
Trichloroethene	3.79E+01	1.59E+00	1.59E+00	6.31E-06
Vinyl chloride	6.59E+00	6.01E+00	6.01E+00	6.31E-07
Xylene	1.77E+02	5.48E-01	5.48E-01	3.98E-05
Aluminum	1.00E+00	4.00E-03	6.50E-04	1.50E-03
Antimony	1.00E+00	2.00E-01	3.00E-02	1.00E-03
Arsenic	1.00E+00	4.00E-02	6.00E-03	2.00E-03
Barium	4.00E+00	1.50E-01	1.50E-02	1.50E-04
Beryllium	1.90E+01	1.00E-02	1.50E-03	1.00E-03
Cadmium	2.00E+02	5.50E-01	1.50E-01	5.50E-04
Calcium	0.00	3.50E+00	3.50E-01	7.00E-04
Chromium	2.00E+01	7.50E-03	4.50E-03	5.50E-03
Cobalt	5.00E+01	2.00E-02	7.00E-03	2.00E-02
Copper	5.00E+01	4.00E-01	2.50E-01	1.00E-02
Cyanide ion	3.79E-01	5.42E+01	5.60E-01	1.41E-08
Fluoride	1.00E+01	NA	NA	NA
Iron	1.00E+02	4.00E-03	1.00E-03	2.00E-02
Lead	1.00E+02	4.50E-02	9.00E-03	3.00E-04
Magnesium	5.00E+01	1.00E+00	5.50E-01	5.00E-03
Manganese	4.00E+02	2.50E-01	5.00E-02	4.00E-04
Mercury	2.00E+05	9.00E-01	2.00E-01	2.50E-01
Nickel	1.00E+02	6.00E-02	6.00E-02	6.00E-03
Potassium	1.00E+03	1.00E+00	5.50E-01	2.00E-02
Selenium	1.70E+02	2.50E-02	2.50E-02	1.50E-02
Silver	2.30E+00	4.00E-01	1.00E-01	3.00E-03
Sodium ion	1.00E+02	7.50E-02	5.50E-02	5.50E-02
Thallium	1.00E+04	4.00E-03	4.00E-04	4.00E-02
Tin	3.00E+03	3.00E-02	6.00E-03	8.00E-02
Vanadium	1.00E+01	5.50E-03	2.50E-03	2.50E-03
Zinc	2.00E+03	1.50E+00	1.00E-01	1.00E-01
Technecium-99	2.50E+01	5.50E-03	3.00E-02	3.50E-06
Uranium-238	1.00E+00	1.00E-02	4.00E-03	7.50E-04

NA = Transfer factor could not be calculated.

Source: For organics, the transfer factors were calculated from equations in Travis and Arms (1988) using K_{ow} values from the *Superfund Chemical Data Matrix* (1991). For inorganics and radionuclides, the transfer factors were taken from Baes et al. (1984). The K_{ow} for cyanide was taken from MEPAS and the transfer factors were calculated from equations in Travis and Arms (1988).

9.4 CONTAMINANT EFFECTS ASSESSMENT

Two pathways are used to determine the effects of contaminant exposure (chapter 9.3) on ecological endpoint receptors. For terrestrial receptors, consumption rates of contaminated food and water are compared with toxicological benchmarks. For aquatic receptors, contaminant concentrations in water or sediment pore water are compared with chemical-specific aquatic benchmarks.

To quantify risk to terrestrial receptors exposed to organic and inorganic contaminants, the daily consumption rate of contaminated food and water, normalized to body weight (in units of mg/kg/d), was compared to the NOAEL benchmark (mg/kg/d). Ratios greater than 1 are considered to pose a potential risk to organisms but do not necessarily indicate the severity of the effect(s). However, it is reasonable to assume that the higher the ratio, the greater the risk of adverse effects. Dose to terrestrial receptors, including vegetation, from internal and external exposure to radionuclides was also determined from calculated tissue concentrations, respectively. Doses that exceeded 0.1 rad/d were considered to pose a potential risk to terrestrial organisms (IAEA 1992). Methods used to calculate exposure and risk are described in appendix B.

Toxicological benchmarks for terrestrial organisms, excluding vegetation, were obtained from Opresko and Suter (1992) (table 9-7). For representative receptor species that were not listed in the data base, extrapolation techniques were employed to obtain the chronic NOAEL by adjusting for differences in body weight between the receptor and a test organism. If a NOAEL was available for a laboratory test species, the NOAEL for a receptor species could be calculated. Many of the NOAEL benchmarks were derived by extrapolation from small mammal laboratory data (Opresko and Suter 1992). No wildlife toxicity data were found for a few contaminants. For these cases, wildlife NOAELs were extrapolated from human noncarcinogenic toxicity data (i.e., RfD's) listed in the MEPAS constituent data base, normalized to the "standard man" body weight of 70 kg. Thus, for this report, wildlife species that weigh less than 70 kg would have a higher benchmark than humans, and the opposite would be true for wildlife species weighing more than 70 kg.

Literature sources for inorganic terrestrial phytotoxicity benchmarks were summarized and reported by Suter and Futrell (1993). Where applicable, the lowest source concentration in a soil medium that produced phytotoxically excessive effects was chosen from the data base. Several benchmarks were derived from experiments using nutrient solutions. However, uncertainty values were not applied to these data to account for differences in growth media. A methodology for deriving phytotoxicity benchmarks for organic constituents was developed by Eskew and Babb [as cited in the MMR Air National Guard Risk Assessment Handbook (1992)].

Risks to aquatic organisms from exposure to organic and inorganic contaminants in water and sediments (pore water) were calculated by comparing the water or sediment pore-water concentrations with the chemical-specific aquatic benchmark (Suter et al. 1992). To determine internal dose to aquatic plants, fish, and muskrats from exposure to radionuclides, the surface-water concentrations were multiplied by radionuclide and organism-specific aquatic (internal) dose conversion factors to produce a daily dose in rads (Killough and McKay 1976). To determine the internal dose to benthic macroinvertebrates and other bottom-dwelling organisms (e.g., fish larvae) from exposure to radionuclides, the sediment pore-water concentrations were multiplied by radionuclide and organism-specific aquatic (internal dose) conversion factors to produce a daily dose. The external dose to all organisms was determined by multiplying the surface-water concentration by the external radionuclide-specific dose conversion factor. Combined internal and external doses greater than 1 rad/d are considered to pose a potential risk to aquatic organisms (NCRPM 1991).

For contaminants and receptors that did not pass the average concentration screening (chapter 9-3), an attempt was made to further define exposure risks by comparing the home range sizes of receptor species with the potential fraction of the home range that is contaminated.

Receptor species at Portsmouth have home ranges or territories which range from small [e.g., one ha (2.5 acres) or less for very small animals such as the robin, mouse, and certain aquatic species] to hundreds of hectares for hawks and foxes (table 9-8). Small species have home ranges small enough to be contained within individual waste sites. Some species have such large home ranges that the waste sites would comprise only a part of the area they would occupy, if the waste sites were used at all. To further interpret results of this risk analysis, the following assumptions are made about contaminant exposure to receptors.

1. Burrowing small mammals, insects, and vegetation are known to move radiological contaminants from buried waste where it is presumably redistributed on the surface through the food chain, excrement, and soil dust (Arthur 1982; Markham 1987; Arthur and Markham 1983). The same is probably true for nonradiological contaminants. Because the waste sites are the original sources of contaminants, and data are lacking for contaminant levels outside of the waste sites, it is assumed that source terms outside waste sites are negligible.

2. It is assumed that species with home ranges of less than 10 ha (25 acres) (table 9-8 could receive as much exposure as the average screening in these analyses indicates.

3. For wider-ranging species, exposure may be less than the average screening indicates. Thus, for species with home ranges equal to or greater than the contaminated area of 40 ha (100 acres), it is assumed that the effective exposure is proportional to the ratio of the contaminated area to the area of the waste complex [i.e., about 400 ha (1000 acres)]. This ratio (i.e., 40/400 = 0.10) was applied as a correction factor to the calculated HIs presented in table 9-9 for the red fox, white-tailed deer, and red-tailed hawk to determine the effective HI. Because sufficient contaminant-specific distribution data are unavailable, an area of 40 ha (100 acres) is assumed for each contaminant.

4. About 2.5% of the surface area of Portsmouth is waste sites. Exposure of biota living in the other 97.5% of the reservation is limited to contaminants that have moved from waste sites in dust and from contaminated wildlife and plants. Although this contamination may be measurable, source terms are lacking; thus, it is assumed that the concentrations are negligible compared with the amounts and concentrations in the waste sites. Exposures could be higher if, for instance, the sole source of contaminants is a waste pond used as the only source of drinking water. However, for Portsmouth it is assumed that contaminants in soil, water, and sediment are evenly distributed among media.

5. Except for threatened and endangered species, for which the loss of an individual is considered a significant risk to the population, it is assumed other endpoints are at risk only at the small end of the home range scale represented by the 2.5% of the Portsmouth Reservation that is in waste sites.

6. Contaminated wetlands are waste ponds. It is assumed that aquatic biota receive the average exposure to contaminants if they occur in waste ponds. Similarly, it is assumed that biota in other wetlands are not exposed to contaminants.

7. Grazing livestock are not allowed into contaminated sites. Risks to livestock would be applicable only if livestock were allowed to graze in waste areas.

TABLE 9-7—*Criteria Benchmarks for Terrestrial[1] and Aquatic[2] Receptor Species at the Portsmouth Reservation*
(NOAELs listed in mg/kg/d for terrestrial benchmarks or mg/L for aquatic benchmarks)

Constituent	White-footed Mouse	Eastern Cottontail Rabbit	White-tail Deer	Cow	Indiana Bat	Robin	Red-tailed Hawk	Red Fox	Vegetation	Aquatic
Acenaphthene	NA	NA	NA	NA	NA	NA	NA	NA	1.28E+02	1.97E-01
Acenapthylene	NA	NA	NA	NA	NA	NA	NA	NA	1.28E+02	NA
Acetone	2.44E+01	6.65E+00	1.84E+00	9.56E-01	3.63E+01	1.67E+01	6.31E+00	3.88E+00	NA	2.37E+01
Anthracene	NA	NA	NA	NA	NA	NA	NA	NA	1.28E+02	8.20E-03
Aroclor 1254	1.41E-01	4.34E-02	1.73E-02	2.22E-01	2.10E-01	3.19E+00	1.20E+00	3.50E-02	1.00E+01	5.20E-04
Aroclor 1260	1.46E+00	2.92E-03	8.06E-04	4.20E-04	2.17E+00	9.96E-01	2.77E-03	1.70E-03	NA	2.10E-03
Benzene	6.11E+00	1.66E+00	4.59E-01	2.39E-01	9.08E+00	4.18E+00	1.58E+00	9.70E-01	NA	2.10E-02
Benzo(a)anthracene	NA	NA	NA	NA	NA	NA	NA	NA	1.26E+02	6.50E-04
Benzo(a)pyrene	2.44E-02	6.65E-03	1.84E-03	9.56E-04	3.63E-02	1.67E-02	6.31E-03	3.88E-03	1.28E+02	2.99E-03
Benzo(b)fluoranthene	NA	NA	NA	NA	NA	NA	NA	NA	1.28E+02	NA
Benzoic acid	NA	NA	NA	NA	NA	NA	NA	NA	NA	1.26E+00
BEHP	NA	NA	NA	NA	NA	NA	NA	NA	1.40E+01	3.00E-04
2-butanone	2.25E+01	6.12E+00	1.69E+00	8.80E-01	3.34E+01	1.54E+01	5.81E+00	3.57E+00	NA	NA
Chlorobenzene	NA	NA	NA	NA	NA	NA	NA	NA	NA	1.65E-01
Chloroform	2.20E+01	5.99E+00	7.84E-01	4.08E-01	3.27E+01	1.50E+01	5.68E+00	1.66E+00	NA	8.40E+00
Chrysene	NA	NA	NA	NA	NA	NA	NA	NA	1.28E+02	NA
1,1-dichloroethane	NA	NA	NA	NA	NA	NA	NA	NA	8.60E-01	1.59E+00
1,1-dichloroethene	2.20E+00	5.99E-01	1.65E-01	8.61E-02	3.27E+00	1.50E+00	5.68E-01	3.49E-01	NA	4.47E-01
1,1-dichloroethylene	2.20E+00	5.99E-01	1.65E-01	8.61E-02	3.27E+00	1.50E+00	5.68E-01	3.49E-01	NA	NA
Diethyl phthalate	NA	NA	NA	NA	NA	NA	NA	NA	NA	1.00E+00
Di-n-butyl phthalate	4.56E+01	1.24E+01	3.43E+00	8.09E-04	6.78E+01	1.41E-02	5.34E-03	7.23E+00	1.48E+04	2.70E-01
Di-n-octylphthalate	NA	NA	NA	NA	NA	NA	NA	NA	NA	3.10E-01
Fluoranthene	NA	NA	NA	NA	NA	NA	NA	NA	1.28E+02	3.20E-02
Methylene chloride	1.43E+01	3.89E+00	1.07E+00	5.60E-01	2.13E+01	9.78E+00	3.69E+00	2.27E+00	5.60E+00	4.10E-01
Phenanthrene	NA	NA	NA	NA	NA	NA	NA	NA	1.28E+02	1.10E-01
Phenol	NA	NA	NA	NA	NA	NA	NA	NA	NA	2.30E-04
Pyrene	NA	NA	NA	NA	NA	NA	NA	NA	1.28E+02	NA
Tetrachloroethene	1.51E+00	4.11E-01	1.13E-01	5.90E-02	2.24E+00	1.03E+00	3.90E-01	2.39E-01	1.57E+01	5.10E-01
Toluene	5.45E+01	1.48E+01	4.10E+00	2.13E+00	8.10E+01	3.73E+01	1.41E+01	8.65E+00	9.70E+00	2.60E-02
1,1,1-trichloroethane	8.55E+01	2.33E+01	6.43E+00	3.35E+00	1.27E+02	5.85E+01	2.21E+01	1.36E+01	6.10E+00	2.51E-01
1,1,2-trichloroethane	NA	NA	NA	NA	NA	NA	NA	NA	NA	1.30E+01
Trichloroethene	1.62E+02	4.99E+01	1.38E+01	7.17E+00	2.40E+02	1.11E+02	4.74E+01	2.91E+01	6.70E-01	5.76E+00
Vinyl chloride	3.18E-01	8.65E-02	2.39E-02	1.24E-02	4.72E-01	2.17E-01	8.21E-02	5.04E-02	NA	9.50E-04
Xylene	1.22E+03	3.33E+02	9.18E+01	4.78E+01	1.82E+03	8.36E+02	3.16E+02	1.94E+02	2.40E+01	2.68E+00
Aluminum	NA	NA	NA	NA	NA	NA	NA	NA	8.00E+00	8.70E-02
Antimony	1.21E+04	3.31E+03	9.13E+02	4.75E+02	1.81E+04	8.31E+03	3.14E+03	1.93E+03	5.00E+00	1.90E+00
Arsenic	1.02E-01	1.62E+00	7.60E-01	3.96E-01	1.52E-01	7.00E-02	1.54E+00	1.60E+00	1.50E+01	9.32E-01
Barium	1.25E+00	3.39E-01	9.37E-02	4.88E-02	1.85E+00	8.52E-01	3.22E-01	1.98E-01	5.00E+02	2.03E+01
Beryllium	1.32E+00	3.59E-01	9.92E-02	5.16E-02	1.96E+00	9.02E-01	3.41E-01	2.09E-01	1.00E+01	3.80E-03
Cadmium	2.35E-02	1.26E-02	1.77E-03	3.39E-04	3.50E-02	1.61E-02	5.44E-02	1.38E-03	3.00E+00	1.10E-03
Chromium	5.86E+00	1.60E+00	4.41E-01	2.30E-01	8.72E+00	4.01E+00	1.52E+00	9.31E-01	7.50E+01	1.10E-02
Cobalt	NA	NA	NA	NA	NA	NA	NA	NA	2.50E+01	4.40E-03
Copper	1.83E-01	2.21E+01	2.57E-01	3.17E+00	2.72E-01	1.25E-01	2.60E+01	1.29E+01	6.00E+01	1.20E-02
Cyanide ion	2.64E+01	7.18E+00	2.63E-02	1.37E-02	3.92E+01	1.80E+01	6.82E+00	5.55E-02	NA	5.20E-03

[1] The source for all terrestrial benchmarks except those for vegetation is Opresko et al. 1993. For vegetation, the source is Suter and Futrell 1993 and the Massachusetts Military Reservation Risk Assessment Handbook, 1992.

[2] The source for aquatic benchmarks in Suter et al. 1992.

TABLE 9-7 (continued)

Constituent	White-footed Mouse	Eastern Cottontail Rabbit	White-tail Deer	Cow	Indiana Bat	Robin	Red-tailed Hawk	Red Fox	Vegetation	Aquatic
Iron	NA	NA	NA	NA	NA	NA	NA	NA	1.00E+04	1.00E+00
Lead	7.09E-03	1.93E-03	5.33E-04	1.68E+00	1.05E-02	1.59E-02	1.11E+01	1.12E-03	1.00E+02	3.20E-03
Magnesium	2.33E+02	6.34E+01	1.75E+01	9.12E+00	3.46E+02	1.59E+02	6.02E+01	3.70E+01	NA	1.60E-04
Manganese	2.00E+00	5.44E-01	1.50E-01	7.83E-02	2.97E+00	1.37E+00	5.17E-01	3.18E-01	1.50E+03	3.10E+00
Mercury	1.43E+01	6.92E-03	2.15E-02	8.70E-02	2.13E+01	3.19E+00	1.20E+00	4.04E-03	3.00E-01	1.30E-03
Nickel	5.90E+01	1.61E+01	4.44E+00	2.39E-01	8.77E+01	4.17E+00	1.58E+00	9.37E+00	1.00E+02	1.60E-01
Potassium	NA	NA	NA	NA	NA	NA	NA	NA	NA	1.30E-04
Selenium	6.14E-02	1.67E-02	4.62E-03	1.43E-02	9.13E-02	2.51E-01	9.47E-02	9.75E-03	5.00E+00	3.50E-02
Silver	NA	NA	NA	NA	NA	NA	NA	NA	2.00E+00	2.00E-04
Sodium ion	NA	NA	NA	NA	NA	NA	NA	NA	NA	4.80E-01
Thallium	2.44E-02	6.65E-03	1.84E-03	9.56E-04	3.63E-02	1.67E-02	6.31E-03	3.88E-03	1.00E+00	6.40E-02
Tin	NA	NA	NA	NA	NA	NA	NA	NA	5.00E+01	NA
Vanadium	2.30E-01	6.26E-02	1.73E-02	9.01E-03	3.42E-01	1.57E-01	5.95E-02	3.65E-02	5.00E+01	4.10E-02
Zinc	2.37E+01	6.45E+00	1.78E+00	9.28E-01	3.52E+01	1.62E+01	6.13E+00	3.76E+00	7.00E+01	1.10E-01

NA = Benchmark not available.

9.5 Contaminant Hazard Assessment

The next step in the ecological risk assessment generates HIs that are representative of potential risk and that estimate the level of effects from exposure to contaminants. Risk to terrestrial and aquatic receptors from contamination at the Portsmouth Reservation was modeled. For terrestrial receptors, hazard indices (HIs) were generated from maximum and average contaminant concentrations for chemical constituents and maximum and average doses were generated for radiological constituents. For aquatic receptors, maximum and average doses were generated for chemical constituents and for radiological constituents.

9.5.1 Baseline

From the initial suite of 102 contaminants of concern, the two-stage screening process using maximum and then average contaminant values yielded 26 contaminants producing HIs equal to or greater than 1 (i.e., representing at least a moderate risk from contaminants) for at least one terrestrial or aquatic endpoint receptor as shown in tables 9-9, 9-10, 9-11, and 9-12. Hazard indices of radionuclides did not exceed one. Following the assumptions outlined in chapter 9.4, the approximate home range or territory size of receptors was determined in order to calculate the proportion of their range that could potentially encompass contaminated lands or surface water.

Four of the endpoint receptors included in the analyses, the white-footed mouse, the cottontail rabbit, the Indiana bat, and the American robin, occupy small enough areas (table 9-8) to potentially live their lives entirely within a contaminated area [e.g., less than 10 ha (25 acres)]. Vegetation obviously can occupy small areas. The remaining terrestrial receptor species, the red fox, the white-tailed deer, and the red-tailed hawk, have home ranges generally larger than the areas of the waste sites but less than the area of the waste complex and, therefore, require application of a correction factor to their average HIs to produce a more meaningful, effective HI. Aquatic receptors (fish, invertebrates, muskrats, and vegetation) are assumed to be fully exposed to contaminants measured in aquatic habitat.

9.5.1.1 Threatened and Endangered Species

As shown in table 9-13a, four inorganic contaminants pose moderate risk to Indiana bats that may forage near the contaminated sites. The HI for Pb is 9 and the HIs for Cu, Mg, and Mn are less than 2. However, Indiana bats are not known to live or forage on the Portsmouth Reservation. A site-specific analysis of individual waste sources and a survey to determine occurrence of bats or other threatened and endangered species would be necessary to determine actual risks.

9.5.1.2 Wetlands

Risks to wetlands receptors (e.g., benthic macroinvertebrates and fish) that might receive contamination from the waste sites are shown in table 9-13b. For purposes of this analysis, wetlands included most holding ponds but not creeks, ditches, swales, or other potentially contaminated wetlands because surface area data necessary for the analysis were lacking. Benthic macroinvertebrates (e.g., fly larvae, caddisflies, mayflies, stoneflies, snails, and beetles) would incur moderate and severe risks from 3 organic contaminants and 15 inorganic contaminants (probably mostly from the sediment pore water). There is less risk to fish from the inorganic contaminants but severe risk from vinyl chloride if fish inhabit the holding ponds.

9.5.1.3 Recreational Wildlife

Table 9-13c summarizes risks to recreationally desirable species on the Portsmouth Reservation. Base-line average HIs for terrestrial species (i.e., the eastern cottontail rabbit and the white-tailed deer) exceeded one for six contaminants. However, only lead posed severe risk to the rabbit. Fish in contaminated waters (table 9-13b) would incur severe risks from vinyl chloride and moderate risks from BEHP and aluminum.

9.5.1.4 Agriculture

Cattle are not allowed to graze in waste areas; therefore, potential risks to livestock are negligible. Vegetation, in the form of grass and planted pines, would incur a severe risk from exposure to aluminum and moderate risks from seven inorganic contaminants (table 9-13d).

TABLE 9-8—*Home Ranges[1] of and Hazard Index (HI) Correction Factors (CF)[2] for Terrestrial Receptor Species at the Portsmouth Gaseous Diffusion Plant*

Receptor Species	Home Range (ha) < 10	Home Range (ha) ≥ 10 but < 400	Correction Factor
White-footed mouse	X (0.2-0.6)		1.0
Eastern cottontail rabbit	X (1.0-2.8)		1.0
Indiana bat	X (1.5-4.5)		1.0
Red fox		X (260-520)	0.1
White-tailed deer		X (60-520)	0.1
American robin	X (0.1-2.0)		1.0
Red-tailed hawk		X (130-420)	0.1
Vegetation	X (<0.1)		1.0

[1]Burt and Grossenheider 1976; Chapman et al. 1980; Smith 1991; Schoener 1966.
[2]A CF of 1.0 was applied to HIs for each contaminant for each species having a home range less than 10 ha (25 acres). Other CFs were based on a ratio of area of contaminated land and water [i.e., 40 ha (100 acres)] to the total area of the waste complex [i.e., 400 ha (1000 acres)].

TABLE 9-9—*Baseline Hazard Indices for Terrestrial Organisms on the Portsmouth Reservation*

Hazard Indices Calculated Using Average Contaminant Concentrations									
	Mouse	**Rabbit**	**Deer**	**Cow**	**Robin**	**Ind. Bat**	**RT Hawk**	**Red Fox**	**Vegetation**
Acenapthene	NA	NA	NA	NA	NA	NA	NA	NA	1.46E-04
Anthracene	NA	NA	NA	NA	NA	NA	NA	NA	4.64E-04
Aroclor 1260	2.67E-04	6.74E-02	4.60E-02	1.97E-01	7.80E-04	8.86E-05	1.40E-05	2.02E-05	NA
Benzo(a)anthracene	NA	NA	NA	NA	NA	NA	NA	NA	1.07E-03
Benzo(a)pyrene	1.03E-02	2.01E-02	1.14E-02	5.93E-02	3.38E-02	2.36E-03	1.04E-05	1.50E-05	8.02E-04
BEHP	NA	NA	NA	NA	NA	NA	NA	NA	3.34E-03
Fluoranthene	NA	NA	NA	NA	NA	NA	NA	NA	1.75E-03
Phenanthrene	NA	NA	NA	NA	NA	NA	NA	NA	1.26E-03
Trichloroethene	1.74E-04	2.07E-04	3.25E-04	5.61E-04	1.56E-04	1.53E-04	2.84E-11	4.03E-11	5.46E-01
Vinyl chloride	7.55E-01	1.01E+00	1.63E+00	2.71E+00	6.42E-01	6.73E-01	5.00E-02	5.96E-02	NA
Aluminum	NA	NA	NA	NA	NA	NA	NA	NA	1.30E+03
Antimony	3.31E-06	6.26E-06	7.68E-06	2.24E-05	5.70E-06	4.17E-06	1.29E-10	1.87E-10	1.19E+00
Arsenic	8.61E-01	2.97E-02	1.34E-02	5.66E-02	2.50E+00	5.27E-01	8.00E-04	5.63E-04	2.01E+00
Barium	2.75E-01	5.33E-01	6.12E-01	1.90E+00	5.34E-01	3.27E-01	9.04E-03	1.08E-02	1.26E-01
Cadmium	7.10E-01	6.26E-01	1.78E+00	1.18E+01	8.38E-01	9.67E-01	1.58E-06	5.53E-05	3.24E-01
Chromium	4.33E-03	8.99E-03	4.19E-03	2.71E-02	1.60E-02	6.59E-04	1.01E-06	1.47E-06	1.61E-01
Cobalt	NA	NA	NA	NA	NA	NA	NA	NA	5.70E-01
Copper	1.70E+00	5.92E-03	2.00E-01	1.83E-02	2.01E+00	1.73E+00	1.02E-06	1.80E-06	3.10E-01
Cyanide ion	1.25E-01	2.44E-01	2.98E+01	7.59E+01	1.05E-01	2.52E-01	7.07E-11	7.75E-09	NA
Iron	NA	NA	NA	NA	NA	NA	NA	NA	3.09E+00
Lead	1.44E+01	2.88E+01	2.25E+01	1.54E-02	1.25E+01	9.20E+00	2.91E-08	2.57E-04	3.40E-01
Magnesium	1.05E+00	1.61E+00	2.47E+00	5.15E+00	1.04E+00	1.21E+00	1.72E-04	2.46E-04	NA
Manganese	1.27E+00	2.29E+00	3.00E+00	8.06E+00	1.94E+00	1.59E+00	7.94E-02	9.47E-02	1.94E-01
Mercury	2.77E-03	2.74E+00	3.68E-01	1.14E-01	9.06E-03	4.12E-03	7.79E-05	2.06E-02	5.14E+00
Nickel	4.06E-03	6.72E-03	6.51E-03	1.86E-01	8.31E-02	2.23E-03	8.21E-06	1.22E-06	5.14E-01
Selenium	3.44E-01	6.31E-01	4.47E-01	3.09E-01	1.63E-01	1.22E-01	3.29E-05	2.84E-04	1.40E+00
Silver	NA	NA	NA	NA	NA	NA	NA	NA	2.95E+00
Thallium	9.19E-02	1.97E-01	7.91E-02	6.01E-01	3.65E-01	8.16E-03	1.60E-04	2.34E-04	1.17E+00
Vanadium	3.09E-01	6.52E-01	2.81E-01	1.97E+00	1.18E+00	3.61E-02	3.32E-05	4.83E-05	7.09E-01

Hazard Indices Calculated Using Average Contaminant Concentrations									
	Mouse	Rabbit	Deer	Cow	Robin	Ind. Bat	RT Hawk	Red Fox	Vegetation
Zinc	6.51E-02	1.23E-01	1.91E-01	4.85E-01	6.53E-02	1.16E-01	1.07E-03	1.34E-03	6.15E-01

N/A=Benchmark not available, therefore hazard index could not be calculated.

TABLE 9-10—*Baseline Maximum Hazard Indices for Terrestrial Organisms on the Portsmouth Reservation*

	Hazard Indices Calculated Using Maximum Contaminant Concentrations								
	Mouse	**Rabbit**	**Deer**	**Cow**	**Robin**	**Ind. Bat**	**RT Hawk**	**Red Fox**	**Vegetation**
Acenapthene	NA	NA	NA	NA	NA	NA	NA	NA	8.44e-03
Acenapthylene	NA	NA	NA	NA	NA	NA	NA	NA	4.99e-05
Acetone	3.67e-02	4.88e-02	7.92e-02	1.32e-01	3.03e-02	3.31e-02	8.45e-04	1.01e-03	NA
Anthracene	NA	NA	NA	NA	NA	NA	NA	NA	1.27e-02
Aroclor 1254	3.86e-03	6.35e-03	2.99e-03	5.22e-04	3.41e-04	1.28e-03	4.50e-08	1.38e-06	1.89e-02
Aroclor 1260	3.57e+00	8.99e+02	6.13e+02	2.63e+03	1.04e+01	1.18e+00	2.60e-01	3.58e-01	NA
Benzene	8.53e-05	1.14e-04	1.82e-04	3.11e-04	7.45e-05	7.57e-05	7.89e-12	1.12e-11	NA
Benzo(a)anthracene	NA	NA	NA	NA	NA	NA	NA	NA	3.16e-02
Benzo(a)pyrene	3.34e-01	6.51e-01	3.70e-01	1.92e+00	1.10e+00	7.65e-0[illegible]	3.36e-04	4.88e-04	2.60e-02
Benzo(b)fluoranthene	NA	NA	NA	NA	NA	NA	NA	NA	2.81e-02
Benzo(g,h,i)perylene	NA	NA	NA	NA	NA	NA	NA	NA	NA
Benzo(k)fluoranthene	NA	NA	NA	NA	NA	NA	NA	NA	NA
Benzoic acid	NA	NA	NA	NA	NA	NA	NA	NA	NA
BEHP	NA	NA	NA	NA	NA	NA	NA	NA	6.43e+00
Bromodichloromethane	NA	NA	NA	NA	NA	NA	NA	NA	NA
Bromoform	NA	NA	NA	NA	NA	NA	NA	NA	NA
2-butanone	8.97e-04	1.19e-03	1.93e-03	3.23e-03	7.39e-04	8.08e-04	1.27e-12	1.81e-12	NA
Butyl benzyl phthalate	NA	NA	NA	NA	NA	NA	NA	NA	NA
Carbon disulfide	NA	NA	NA	NA	NA	NA	NA	NA	NA
Chlorobenzene	NA	NA	NA	NA	NA	NA	NA	NA	NA
Chloroform	3.35e-03	4.48e-03	1.51e-02	2.56e-02	2.91e-03	2.97e-03	5.23e-05	1.32e-04	NA
Chloromethane	NA	NA	NA	NA	NA	NA	NA	NA	NA
4-chloro-3-methylphenol	NA	NA	NA	NA	NA	NA	NA	NA	NA
2-chlorophenol	NA	NA	NA	NA	NA	NA	NA	NA	NA
Chrysene	NA	NA	NA	NA	NA	NA	NA	NA	4.96e-02
Dibenzofuran	NA	NA	NA	NA	NA	NA	NA	NA	NA
Dibenzo(a,h)anthracene	NA	NA	NA	NA	NA	NA	NA	NA	NA
Dibromochloromethane	NA	NA	NA	NA	NA	NA	NA	NA	NA
1,2-dichlorobenzene	NA	NA	NA	NA	NA	NA	NA	NA	NA
1,4-dichlorobenzene	NA	NA	NA	NA	NA	NA	NA	NA	NA
1,1-dichloroethane	NA	NA	NA	NA	NA	NA	NA	NA	2.15e-01
1,1-dichloroethene	1.53e-04	2.06e-04	3.27e-04	5.58e-04	1.34e-04	1.36e-04	1.42e-11	2.01e-11	NA
cis-1,2-dichloroethene	NA	NA	NA	NA	NA	NA	NA	NA	NA
trans-1,2-dichloroethene	NA	NA	NA	NA	NA	NA	NA	NA	NA
1,1-dichloroethylene	3.85e-03	5.15e-03	8.23e-03	1.40e-02	3.30e-03	3.43e-03	1.95e-10	2.76e-10	NA
2-trans-dichloroethylene	NA	NA	NA	NA	NA	NA	NA	NA	NA
2,4-dichlorophenol	NA	NA	NA	NA	NA	NA	NA	NA	NA
4,4-DDT	NA	NA	NA	NA	NA	NA	NA	NA	NA

TABLE 9-10 (continued)

	Hazard Indices Calculated Using Maximum Contaminant Concentrations								
	Mouse	Rabbit	Deer	Cow	Robin	Ind. Bat	RT Hawk	Red Fox	Vegetation
2,4-dinitrotoluene	NA	NA	NA	NA	NA	NA	NA	NA	NA
1,4-dioxane	NA	NA	NA	NA	NA	NA	NA	NA	NA
Dieldrin	NA	NA	NA	NA	NA	NA	NA	NA	NA
Diethyl phthalate	NA	NA	NA	NA	NA	NA	NA	NA	NA
2,4-dimethylphenol	NA	NA	NA	NA	NA	NA	NA	NA	NA
Dimethyl phthalate	NA	NA	NA	NA	NA	NA	NA	NA	NA
Di-n-butyl phthalate	2.83E-05	4.81E-05	4.38E-05	3.01E-01	1.45E-01	1.38E-05	1.06E-02	5.72E-06	2.13E-05
Di-n-octylphthalate	NA	NA	NA	NA	NA	NA	NA	NA	NA
Ethylbenzene	NA	NA	NA	NA	NA	NA	NA	NA	NA
Fluoranthene	NA	NA	NA	NA	NA	NA	NA	NA	9.14E-02
Fluorene	NA	NA	NA	NA	NA	NA	NA	NA	NA
Freon	NA	NA	NA	NA	NA	NA	NA	NA	NA
indeno(1,2,3-cd)pyrene	NA	NA	NA	NA	NA	NA	NA	NA	NA
Isobutyl alcohol	NA	NA	NA	NA	NA	NA	NA	NA	NA
Methoxychlor	NA	NA	NA	NA	NA	NA	NA	NA	NA
Methylene chloride	2.71E-03	3.61E-03	5.81E-03	9.78E-03	2.27E-03	2.43E-03	3.95E-11	5.60E-11	2.12E-02
2-methylnaphthylene	NA	NA	NA	NA	NA	NA	NA	NA	NA
2-methylphenol	NA	NA	NA	NA	NA	NA	NA	NA	NA
4-methylphenol	NA	NA	NA	NA	NA	NA	NA	NA	NA
Naphthalene	NA	NA	NA	NA	NA	NA	NA	NA	NA
4-nitrophenol	NA	NA	NA	NA	NA	NA	NA	NA	NA
n-nitrosodi-n-propylamine	NA	NA	NA	NA	NA	NA	NA	NA	NA
Phenanthrene	NA	NA	NA	NA	NA	NA	NA	NA	6.96E-02
Phenol	NA	NA	NA	NA	NA	NA	NA	NA	NA
p-phenylenediamine	NA	NA	NA	NA	NA	NA	NA	NA	NA
Pyrene	NA	NA	NA	NA	NA	NA	NA	NA	9.14E-02
Tetrachloroethane	5.55E-04	7.76E-04	1.13E-03	2.13E-03	6.10E-04	4.58E-04	1.06E-09	1.51E-09	2.46E-03
Tetrachloroethylene	NA	NA	NA	NA	NA	NA	NA	NA	NA
Toluene	2.64E-03	3.59E-03	5.56E-03	9.76E-03	2.4[illegible]E-03	2.30E-03	9.82E-10	1.40E-09	2.85E-01
1,2,4-trichlorobenzene	NA	NA	NA	NA	NA	NA	NA	NA	NA
1,1,1-trichloroethane	5.28E-04	7.13E-04	1.12E-03	1.94E-03	4.80E-04	4.63E-04	1.23E-10	1.75E-10	1.10E-01
1,1,2-trichloroethane	NA	NA	NA	NA	NA	NA	NA	NA	NA
Trichloroethene	1.21E-02	1.43E-02	2.26E-02	3.89E-02	1.09E-02	1.06E-02	2.38E-04	2.84E-04	3.73E+01
Vinyl chloride	7.55E-01	1.01E+00	1.63E+00	2.71E+00	6.42E-01	6.73E-01	5.00E-02	5.96E-02	NA
Xylene	6.53E-07	8.82E-07	1.43E-06	2.20E-06	6.81E-07	5.35E-07	4.87E-07	5.81E-07	6.00E-04
Aluminum	NA	NA	NA	NA	NA	NA	NA	NA	1.[illegible]E+03
Antimony	2.26E-03	4.27E-03	5.24E-03	1.53E-02	3.89E-03	2.84E-03	8.81E-08	1.28E-07	8.10E+02

TABLE 9-10 (continued)

Hazard Indices Calculated Using Maximum Contaminant Concentrations									
	Mouse	Rabbit	Deer	Cow	Robin	Ind. Bat	RT Hawk	Red Fox	Vegetation
Arsenic	1.63E+03	5.70E+01	2.49E+01	1.10E+02	4.86E+03	9.89E+02	7.19E-03	5.42E-03	3.96E+03
Barium	7.67E+02	1.50E+03	1.70E+03	5.36E+03	1.50E+03	9.18E+02	1.16E-01	1.40E-01	3.58E+02
Beryllium	3.39E-03	7.19E-03	3.42E-03	2.22E-02	1.27E-02	6.97E-04	1.46E-07	2.13E-07	2.16E-01
Cadmium	7.25E+01	6.38E+01	1.82E+02	1.20E+03	8.54E+01	9.86E+01	1.71E-02	4.97E-01	3.30E+01
Calcium	NA	NA	NA	NA	NA	NA	NA	NA	NA
Chromium	2.50E+00	5.19E+00	2.42E+00	1.57E+01	9.26E+00	3.81E-01	1.19E-03	1.57E-03	9.31E+01
Cobalt	NA	NA	NA	NA	NA	NA	NA	NA	1.51E+00
Copper	1.97E+02	6.84E-01	2.31E+01	2.11E+00	2.33E+02	2.00E+02	2.60E-04	4.19E-04	3.59E+01
Cyanide ion	1.25E-01	2.44E-01	2.98E+01	7.59E+01	1.05E-01	2.52E-01	7.07E-11	7.75E-09	NA
Fluoride	NA	NA	NA	NA	NA	NA	NA	NA	NA
Iron	NA	NA	NA	NA	NA	NA	NA	NA	9.90E+00
Lead	3.20E+02	6.38E+02	5.00E+02	3.42E-01	2.76E+02	2.05E+02	3.42E-04	2.48E+00	7.52E+00
Magnesium	1.58E+01	2.42E+01	3.71E+01	7.72E+01	1.56E+01	1.81E+01	3.32E-02	4.02E-02	NA
Manganese	3.37E+00	6.16E+00	7.99E+00	2.18E+01	5.22E+00	4.29E+00	7.94E-02	9.47E-02	5.32E-01
Mercury	1.23E-01	1.21E+02	1.63E+01	5.06E+00	4.02E-01	1.83E-01	3.61E-03	9.48E-01	2.28E+02
Nickel	7.05E-01	1.17E+00	1.13E+00	3.23E+01	1.44E+01	3.87E-01	5.00E-03	6.53E-04	8.93E+01
Potassium	NA	NA	NA	NA	NA	NA	NA	NA	NA
Selenium	1.23E+00	2.27E+00	1.61E+00	1.11E+00	5.85E-01	4.37E-01	1.18E-04	1.02E-03	5.04E+00
Silver	NA	NA	NA	NA	NA	NA	NA	NA	9.00E+00
Sodium ion	NA	NA	NA	NA	NA	NA	NA	NA	NA
Sulfite	NA	NA	NA	NA	NA	NA	NA	NA	NA
Thallium	1.98E-01	4.25E-01	1.70E-01	1.30E+00	7.86E-01	1.76E-02	3.46E-04	5.04E-04	2.52E+00
Tin	NA	NA	NA	NA	NA	NA	NA	NA	0.00
Vanadium	5.70E-01	1.14E+00	6.37E-01	3.35E+00	1.95E+00	1.23E-01	1.24E-01	1.48E-01	1.12E+00
Zinc	3.30E+00	6.26E+00	9.69E+00	2.47E+01	3.31E+00	5.92E+00	1.66E-02	2.31E-02	3.14E+01

N/A=Benchmark not available, therefore hazard index could not be calculated

TABLE 9-11—*Baseline Hazard Indices for Aquatic Organisms on the Portsmouth Reservation*

Constituent	Average Surface Water HI (fish)	Benthic Macroinvertebrate HI
Acenapthene	NA	7.82E-01
Anthracene	NA	8.23E-01
Aroclor 1260	NA	4.66E+01
Benzo(a)anthracene	NA	1.61E+00
Benzo(a)pyrene	NA	1.59E-01
BEHP	9.00E+00	8.23E+00
Fluoranthene	NA	3.87E-01
Phenanthrene	NA	2.79E-01
Vinyl chloride	4.21E+01	NA
Aluminum	4.83E+00	3.39E+01
Arsenic	1.29E-02	3.16E-02
Barium	1.39E-03	1.61E-01
Cadmium	NA	2.85E+02
Chromium	NA	4.48E+00
Cobalt	NA	6.78E+01
Copper	NA	1.02E+01
Iron	9.40E-01	1.18E+03
Lead	NA	7.34E+00
Magnesium	NA	5.00E+06
Manganese	3.64E-01	6.80E+00
Mercury	NA	7.47E+01
Nickel	NA	5.43E+00
Potassium	NA	1.42E+06
Silver	NA	8.44E+02
Sodium ion	NA	2.63E+01
Vanadium	NA	8.15E-01
Zinc	4.43E-01	8.18E+01

N/A = Benchmark not available, therefore hazard index could not be calculated.

TABLE 9-12—*Baseline Maximum Radiological Doses for Terrestrial Organisms on the Portsmouth Reservation*

Radiological Doses (rad/d) Calculated Using Maximum Contaminant Concentrations									
	Mouse	Rabbit	Deer	Cow	Robin	Indiana Bat	RT-Hawk	Red Fox	Vegetation
Technecium-99	1.93E-03	1.93E-03	1.98E-03	2.35E-03	1.93E-03	1.93E-03	1.93E-03	1.93E-03	8.45E-03
Uranium-238	1.10E-03	1.10E-03	1.10E-03	1.10E-03	1.10E-03	1.10E-03	1.10E-03	1.10E-03	1.13E-03
Total dose	3.03E-03	3.03E-03	3.08E-03	3.45E-03	3.03E-03	3.03E-03	3.03E-03	3.03E-03	9.58E-03
Radiological HI	3.03E-02	3.03E-02	3.08E-02	3.45E-02	3.03E-02	3.03E-02	3.03E-02	3.03E-02	9.58E-02

TABLE 9-13—*Baseline Average Radiological Doses for Terrestrial Organisms on the Portsmouth Reservation*

Radiological Doses (rad/d) Calculated Using Average Contaminant Concentrations									
	Mouse	Rabbit	Deer	Cow	Robin	Indiana Bat	RT-Hawk	Red Fox	Vegetation
Technecium-99	1.13E–06	1.13E–06	1.17E–06	1.41E–06	1.13E–06	1.13E–06	3.36E–07	3.37E–07	4.96E–06
Total dose	1.13E–06	1.13E–06	1.17E–06	1.41E–06	1.13E–06	1.13E–06	3.36E–07	3.37E–07	4.96E–06
Radiological HI	1.13E–05	1.13E–05	1.17E–05	1.41E–05	1.13E–05	1.13E–05	3.36E–06	3.37E–06	4.96E–05

Potentially adverse effects, however, would be limited to the relatively small areas (totaling less than 32 ha) within and around the waste sites. With respect to aluminum, however, the geometric mean concentration for soils in the eastern United States (33,000 mg/kg) reported by Shacklette and Boerngen (1984) is greater than the 11,600 mg/kg average concentration used in this assessment. Therefore, it is quite possible that the extremely low benchmark (8.0 mg/kg) used in this assessment represents a plant species unusually sensitive to aluminum and that would not grow in most soils found throughout the United States, including those at Portsmouth.

9.5.1.5 Public Lands

There are no parks or public lands on the Portsmouth Reservation. State and private recreation areas are all more than 16 km (10 miles) in various directions from the Portsmouth Reservation. Wayne National Forest is adjacent to the reservation on the east and souteast.

9.5.1.6 Biodiversity

As noted previously, biodiversity on and around the reservation reflects modern human activities. The original forests have given way to agriculture (crops and cattle) and second-growth forest. Nevertheless, the area supports desirable ecological communities that could be affected by harmful contaminants on the reservation, as indicated in table 9-13e (see, also, tables 9-13a, b, c, and d). The mouse, robin, and bat incur moderate risks from each of several contaminants, whereas lead poses potentially severe risk to the mouse and robin. Hazard indices for the red-tailed hawk and red fox are less than one; therefore, risks to these elements of biodiversity are considered negligible.

9.6 HABITAT DISTURBANCE ASSESSMENT

The natural mesophytic and oak-hickory forests that dominated Ohio before the arrival of Europeans have given way to managed agriculture and timber production and residential and industrial development. Although the reservation and environs are substantially altered ecosystems, they nevertheless support fairly rich plant and animal communities that are typical of much of rural Ohio and Kentucky today.

9.6.1 Baseline

About 400 ha (1000 acres) or 25% of the reservation possesses little or no habitat value to wildlife because of the presence of waste sites, production areas, and ancillary facilities. The base-line alternative does not, by definition, include any additional disturbance from restoration activities. Thus, no additional risks to plant or animal habitat are anticipated as a result of the base-line alternative.

9.7 CUMULATIVE ASSESSMENT

9.7.1.1 On-Site

Based on the assumptions and calculations used in this assessment, the base-line alternative clearly poses moderate to severe risks from a suite of contaminants to selected receptor species in the endpoint categories, particularly wetlands. Table 9-14 shows which contaminants pose risks to one or more receptor species in five of the six endpoints. Public recreation lands and parks do not occur on the reservation; hence, no adverse effects on this endpoint would be expected.

For 25 contaminants, HIs suggest potential risks to organisms inhabiting waste sites. Of these contaminants, four pose potential risks to federally listed threatened, endangered, or candidate species (table 9-13a); 19 pose potential risks to species in wetlands; six pose potential risks to recreational wildlife species (table 9-13c); eight pose potential risks to vegetation; and six pose potential risks to important food web components and species important to biodiversity (table 9-13e).

9.7.2 Off-Site

Determining cumulative risks to endpoints and receptors that do not occur at waste sites is more problematic. Data were not available to determine reservation-wide or regional contaminant levels. For some contaminants, it is possible that the source terms reflect naturally-occurring concentrations rather than contamination (e.g., aluminum, see chapter 9.5.1). Even when background levels are known, interpretation of hazard indices for inorganic substances is often difficult because most analytical techniques do not distinguish between

TABLE 9-13A—*Baseline Potential Risks[1] to Federally Listed Threatened, Endangered, or Candidate Receptor Species[2] that Occupy Waste Sites on the Portsmouth Reservation*

Contaminant	Receptor
	Indiana Bat[2]
Copper	M[3]
Lead	M
Magnesium	M
Manganese	M

[1]Potential risk based on assumptions described in Section 9.4. Risks to individuals that do not occupy waste sites are negligible. Waste sites account for about 2.5% of the surface area of the Portsmouth Reservation.
[2]The Indiana bat has been reported in the Portsmouth area (Houlberg et al. 1992); however, suitable habitat (i.e., caves) does not exist on the Portsmouth Reservation and the bat is not expected to be an inhabitant of the reservation.
[3]M = moderate risk, where HI is equal to or greater than 1.0, but less than 10; S = severe risk, where HI is equal to or greater than 10.

TABLE 9-13B—*Baseline Potential Risks[1] to Wetlands Associated With Waste Sites[2] on the Portsmouth Reservation*

Contaminant	Receptor	
	Fish	Benthic Invertebrates
Aroclor 1260		S
Benzo(a)anthracene		M
BEHP	M[3]	M
Vinyl chloride	S	
Aluminum	M	S
Cadmuim		S
Chromuim		M
Cobalt		S
Copper		S
Iron		S
Lead		M
Magnesium		S
Manganese		M
Mercury		S
Nickel		M
Potassium		S
Silver		S
Sodium ion		S
Zinc		S

[1]Potential risk based on assumptions described in Section 9.4.
[2]For purposes of this analysis, wetlands included holding ponds but not creeks, ditches, swales or other potentially contaminated wetlands because surface area data were lacking.
[3]M = moderate risk, where HI is equal to or greater than 1.0, but less than 10; S = severe risk, where HI is equal to or greater than 10.

TABLE 9-13C—*Baseline Potential Risks[1] to Recreational Wildlife That Occupy Waste Sites on the Portsmouth Reservation*

Contaminant	Receptor	
	Eastern Cottontail Rabbit	**White-tailed Deer**
Vinyl chloride	M[2]	
Cyanide ion		M
Lead	S	M
Magnesium	M	M
Manganese	M	M
Mercury	M	

[1]Potential risk based on assumptions described in Section 9.4. Risks to individuals that do not occupy waste sites are negligible and overall risks to populations of wildlife on the reservation are negligible. Waste sites account for about 2.5% of the surface area of the Portsmouth Reservation.
[2]M = moderate risk, where HI is equal to or greater than 1.0, but less than 10; S = severe risk, where HI is equal to or greater than 10.

TABLE 9-13D—BASELINE POTENTIAL RISKS[1] TO VEGETATION[2] ON THE PORTSMOUTH RESERVATION

Contaminant	Receptor
	Vegetation
Aluminum	S[3]
Antimony	M
Arsenic	M
Iron	M
Mercury	M
Selenium	M
Silver	M
Thallium	M

[1]Potential risk based on assumptions described in Section 9.4. Risks to populations that do not occupy waste sites are negligible. Terrestrial waste sites account for about 2% of the surface area of the Portsmouth Reservation.
[2]Vegetation includes grasses and pine.
[3]M = moderate risk, where HI is equal to or greater than 1.0, but less than 10; S = severe risk, where HI is equal to or greater than 10.

TABLE 9-13E—*Baseline Potential Risks[1] to Important Food Web and Biodiversity Components That Occupy Waste Sites on the Portsmouth Reservation*

Contaminant	Receptors				
	Mouse	American Robin	Bats	Red-tailed[2] Hawk	Red Fox[2]
Arsenic		M[3]			
Copper	M	M	M		
Lead	S	S	M		
Magnesium	M	M	M		
Manganese	M	M	M		
Vanadium		M			

[1]Potential risk based on assumptions described in Section 9.4. Risks to individuals that do not occupy waste sites and risks to populations are negligible. Waste sites account for about 2.5% of the surface area of the Portsmouth Reservation.

[2]Baseline average hazard indices for the red-tailed hawk and the red fox are all below 1 indicating negligible risk to these biodiversity endpoint receptors.

[3]M = moderate risk, where HI is equal to or greater than 1.0, but less than 10; S = severe risk, where HI is equal to or greater than 10.

chemical forms that are available for uptake by organisms (e.g., dissolved in soil pore water or loosely bound to particles) and those that are biologically unavailable (e.g., insoluble salts).

The waste sites are mostly highly developed areas that do not provide suitable habitat for many organisms. Thus, actual risks associated with these sites are probably lower than indicated by the HIs. However, for biota that live in (e.g., macroinvertebrates) or use the wetlands (e.g., waterfowl in ponds), contaminant exposure may be substantial. Exposure of benthic macroinvertebrates to average sediment pore-water concentrations resulted in HIs over one for 15 inorganic contaminants. Risk to receptors was greatest from inorganic contaminants (21 with HIs greater than 1). Organic contaminants (4 with HIs greater than 1) posed a risk mainly to receptors in wetlands. Risks from radionuclides were negligible (all HIs less than 1). An alternative that involves closure of the Portsmouth facility without restoration might result in reoccupation of the waste sites by plants and animals: risks similar to those indicated in tables 9-13a, b, c, d, and e would then be expected.

The only currently known mechanism for off-site transport of contaminants from the waste sites is via ingestion by wide ranging wildlife (e.g., migratory waterfowl or deer). Of the three classes of contaminants in waste sites (i.e., organics, inorganics, and radionuclides), the only source of radionuclides in the region would be the Portsmouth Reservation waste sites. Therefore, any regional (off-site) cumulative risks from radionuclides would be the same as on-site risks which are considered negligible (i.e., HI less than 1). At the time of our analyses no regional date for organics or inorganics were available, and cumulative risks off-site could not be estimated.

TABLE 9-14—*Comparative Summary of Alternatives for Onsite Risks[1] to Ecological Endpoints[2] on the Portsmouth Reservation*

Source of Risk	Endpoints[4]	
	Baseline	ARAR[5]
Construction[3]		
Aroclor 1260	W	
Benzo(a)anthracene	W	
BEHP	W	
Vinyl chloride	W, R	
Aluminum	W, F	
Antimony	F	
Arsenic	F, B	
Cadmium	W	
Chromium	W	
Cobalt	W	
Copper	E, W, B	
Cyanide ion	R	
Iron	W, F	
Lead	E, W, R, B	
Magnesium	E, W, R, B	
Manganese	E, W, R, B	
Mercury	W, R, F	
Nickel	W	
Potassium	W	
Selenium	F	
Silver	W, F	
Sodium ion	W	
Thallium	F	
Vanadium	B	
Zinc	W	

[1]Only those contaminants are listed which our analyses showed could pose severe or moderate risks to some endpoints.
[2]Risks are for endpoints associated with waste sites or contaminated waters. Otherwise, risks to endpoints are assumed to be negligible.
[3]These are short-term risks. Long-term risks could be reduced with successful restoration of appropriate habitat.
[4]Ecological endpoints: E = threatened, endangered and candidate species; W = wetlands; R = recreational fish and wildlife; F = agricultural or timber production; P = parks and other public lands, and B = biodiversity.
[5]Source terms for alternatives were unavailable for this ecological risk assessment.

CHAPTER 10: COMPARISON OF ALTERNATIVES

Programmatic alternatives for environmental restoration are described in Chapter 4 of the DOE Implementation Plan for the PEIS. Under the *No Action* alternative, DOE would undertake no further remedial actions at ER sites. Although this alternative is not consistent either with DOE policy or with CERCLA, it provides a baseline of potential impacts for comparison to other alternatives. *Alternative 1*, which reflects DOE's current ER program, emphasizes compliance with applicable laws and regulations. The principal laws in question include CERCLA, the Resource Conservation and Recovery Act (RCRA), and the Atomic Energy Act (AEA). These laws are implemented in facility-specific agreements negotiated with Federal, state, and local regulatory agencies. Environmental standards specified in other regulations, termed Applicable or Relevant and Appropriate Requirements (ARARs), are often adopted as remedial action goals. The use of ARARs as remedial action goals emphasizes reduction of local public risks from residual contamination, but may involve unrealistic assumptions about future land use and also fails to account for risks to remedial action workers and risks related to transportation of contaminated material.

Under *Alternative 2*, likely future land use would be given explicit emphasis early in the site evaluation process to better reflect potential risks which are likely to occur. The PEIS Implementation Plan describes three "bounding land use" options. For unrestricted land use, contaminant exposures associated with all six major human exposure pathways (groundwater for drinking, surface water, air inhalation, atmospheric deposition, soil ingestion, and direct radiation) would be reduced to levels that would permit any future land use. For "somewhat restricted land use," groundwater would not be remediated, and future land use would be restricted to activities not involving the use of groundwater as drinking water. For "totally restricted land use," only the minimum remediation performed to stabilize contamination and prevent future spread. Only future land uses consistent with prevention of public access (e.g., hazardous waste management facilities, military test facilities) would be permitted.

Under *Alternative 3*, remedial and waste management worker and remedial waste transportation risks would be equally emphasized with the risks to a site's surrounding population. Remedial actions that would result in greater risks than posed by the current contamination would not be implemented, even though ARARs might have to be waived. Feasible future land uses and necessary engineering or institutional controls at each site would be determined by the condition of the site following completion of remediation.

Under *Alternative 4*, alternatives 2 and 3 would be combined to emphasize both early evaluation of likely future land uses and minimization of worker and transportation risks.

Estimates of (1) degrees of reduction in human health risk and (2) areas of land disturbed for each alternative were developed by PNL. These results were used to roughly compare the ecological benefits and impacts caused by implementation of each alternative at INEL, Fernald, Rocky Flats, Hanford, and Oak Ridge. Analyses of health risk reductions were not performed for Portsmouth, consequently, no comparisons can be made for that site.

Several assumptions were required to extrapolate the human health risk results to ecological risks. First, radionuclides were selected as reference contaminants. Estimates of the aggregate radiological doses for all radionuclide sources on ech reservation were calculated for on-site workers, the off-site public, and for a farm family residing on the site. It was assumed for our analysis that (1) radionuclide risk reduction would be qualitatively similar to reductions in risks from chemical contaminants, and (2) reductions in exposure of on-site farmers would be qualitatively similar to reductions in risk to on-site biota.

Table 10-1 presents results of these analyses. It is apparent from this table that most of the above alternatives are quite similar with respect to ecological risk reductions and disturbance impacts. The No Action alternative and the Totally Restsricted Land Use alternative involve little or no contaminant risk reduction and also little or no habitat disturbance. All of the other alternatives involve large (2-4 orders of magnitude or more) reductions in contaminant risks and similar degrees of habitat disturbance. With the exception of Rocky Flats, the areas disturbed were estimated to be on the order of 500 acres or less. These values represent 1% or less of the total areas of large reservations such as INEL, Hanford, and Oak Ridge. From a complex-wide programmatic perspective, none of the environmental remediation alternatives appear to have major ecological consequences. Impacts of land use changes associated with opening up these reservations for residential, agricultural, or commercial development would likely be much greater than the impacts of any of the remediation alternatives examined in this report.

On a facility-specific level, there may be substantial differences between the alternatives. For smaller sites, (e.g., Rocky Flats and Fernald), contaminated areas requiring remediation may be a much larger fraction of the total facility area than is the case on large facilities. Differences between removal-oriented and land-use oriented remediation approaches could be substantial for these facilities. For example, the disturbed areas of Rocky Flats listed in Table 10-1 range from 6% for the Totally Restricted Land Use alternative to 26% for the ARAR alternative. Moreover, ecological impacts of restoration activities that disturb equal areas can vary significantly depending on the remediation technology employed. Although the immediate ecological impacts of soil removal/remediation are large (i.e., complete destruction of all ecological resources on the site), the long-term impacts may be small if the site is properly restored. Capping involves an initially similar degree of disturbance, but the potential for ecological restoration is severly limited because of the need to insure integrity of the cap.

For any facility, the ecological importance of the specific areas selected for remediation (e.g., wetlands, habitat for endangered species) must be evaluated prior to any action. These determinations would best be addressed in facility-specific assessments. If adequate facililty-specific data on contaminant distributions and biological resource distributions are available, the technical approach employed in this report can be directly applied to facility-level assessments.

10.1 Uncertainties

The results presented in Table 10-1 are predicated on several key assumptions. The assumption that exposures to an on-site farmer are similar to exposures to biota was necessitated because the ARAM model used to calculate risk estimates for the various alternatives does not permit direct calculation of ecological exposures. Reductions in exposures to farmers eating vegetables grown on contaminated soil or consuming beef/milk from cattle grazing on contaminated pastures would be expected to be similar to reductions in exposure to wildlife consuming natural vegetation growing on the same soil. However, farmers might drink treated tapwater or be exposed to well-water that is not consumed by wildlife and they may not ingest surface water at all. The farm scenario is, therefore, less realistic for the surface-water pathway than for the soil pathway. However, for INEL and Fernald, no surface-water remediation is included in any of the alternatives and so for those sites the difference between surface-water exposure to farmers vs. wildlife is unimportant.

Radionuclides were used as reference contaminants because (1) radiological doses due to different isotopes are summed to caluclate human exposures in the same way they are summed to calculate ecological exposures (this is not true for cancer risk estimates for chemical carcinogens), and (2) the environmental transport of radionuclides is similar to the transport of many chemical contaminants. This assumption could produce misleading estimates of ecological risk reductions if (1) chemical contaminants are the dominant source of ecological risks, and (2) the remediation alternatives emphasize radionuclides over chemical contaminants. The results in chapters 4-9 suggest that chemical contaminants may, in fact, often be of more concern than radionuclides, but insufficient information was available to evaluate whether the remediation alternatives preferentially emphasize radionuclides.

TABLE 10-1—*Ecological Risks and Benefits of ER Alternatives*

Facility	Total Area (acres)	Resources at Risk	Alternative[2]	% Risk Reduction[3]	Acres disturbed (% of reservation)[4]
INEL[1]	570,000	Soil: none Water (waste ponds): wildlife, endangered species	No Action	Soil: NR[6] Water: 0	0 (0%)
			ARAR	Soil: 99.94% Water: 0	188 (0.03%)
			Unrestricted land use	Soil:99.94% Water: 0	188 (0.03%)
			Semi-restricted land use	Soil:99.94% Water: 0	188 (0.03%)
			Totally restricted land use	Soil: NR Water: 0	[illegible] (<0.01%)
			Health-risk driven	Soil:99.94% Water:NA[7]	188 (0.03%)
			Combination	Soil: Not available Water:NA	188 (0.03%)
Hanford[8]	365,700	Soil: none Water (waste ponds): wildlife, endangered species	No Action	Soil: NR Water: 0	0
			ARAR	Soil: NR Water: 98%	453 (0.1%)
			Unrestricted land use	Soil: NR Water: 98%	453 (0.1%)
			Semi-restricted land use	Soil: NR Water: 0	234 (0.06%)
			Health-risk driven	Soil: NR Water: 98%	597 (0.16%)
			Combination	Soil: NR Water:98%	596 (0.16%)

TABLE 10-1 (continued)

Fernald[9]	1050	Soil: wildlife, endangered species, biodiversity Water: fish	No action	Soil: 0 Water: 0	0
			ARAR	Soil: 99.95% Water:0%	201 (19%)
			Unrestricted land use	Soil: 99.95% Water: 0	201 (19%)
			Semi-restricted land use	Soil: >99.9% Water: 0	201 (19%)
			Totally restricted land use	Soil: 0 Water: 0	200 (19%)
			Health-risk driven	Soil: >99.9% Water: 0	201 (19%)
			Combination	Soil: NA Water: NA	201 (19%)
Oak Ridge Reservation[10]	37,500	Soil: wildlife, endangered species, biodiversity Water: fish, wetlands	No action	Soil: 0 Water. 0	0
			ARAR	Soil: 99.99% Water: 99.5%	421 (1.1%)
			Unrestricted land use	Soil:99.9% Water: 99.5%	421 (1.1%)
			Semi-restricted land use	Soil:99.9% Water: 99.5%	421 (1.1%)
			Totally restricted land use	Soil: 0 Water: 0	314 (0.8%)
			Health-risk driven	Soil: 99.9% Water: 99.5%	420 (1.1 %)
			Combination	Soil: NA Water: NA	421 (1.1 %)

TABLE 10-1 (continued)

Rocky Flats[11]	6550	Soil: wildlife, endangered species, biodiversity Water: wetlands	No action	Soil: 0 Water: 0	0
			ARAJ.	Soil:99.99% Water:>99.99%	1695 (26%)
			Unrestricted land use	Soil: 99.9% Water: >99.9%	
			Semi-restricted land use	Soil: 99.9% Water: >99.9%	1694 (26%)
			Restricted land use	Soil: 0 Water: 0	373 (6%)
			Health-risk driven	Soil: >99.9% Water: >99.9%	NA
			Combination	Soil: NA Water: NA	1694 (26%)

[1]Resources at risk are defined separately, by principal exposure medium. Resources were determined to be "at risk" if (1) the are present on the facility and possibly present in known contaminated areas, and (2) comparison of estimated contaminant concentrations to regulatory criteria or other toxicological benchmarks indicates a moderate or severe risk to organisms inhabiting contaminated areas.

[2]Alternatives are defined in the PEIS Implementation Plan.

[3]% reduction in contaminant exposure, as approximated by % reduction in risk to on-site farmers. Radionuclides were used ans reference contaminants.

[4]% of total facility area either temporarily or permanently disturbed by remedial activities. Estimates include adjustments for access roads and soil borrow areas.

[5]major areas of INEL containing contaminated soil (e.g., the Radioactive Waste Management Complex) are already heavily disturbed and provide poor habitat for terrestrial biota, hence, terrestrial resources are not at risk. Contaminated waste ponds are utilized by wildlife, hence these resources are considered to be at risk for purposes of the PEIS. None of the remediation alternatives for INEL include remediation of waste ponds.

[6]NR = no resources at risk

[7]NA = no estimate available

[8] major areas of Hanford containing contaminated soil are already heavily disturbed and provide poor habitat for terrestrial biota, hence, terrestrial resources are not at risk. Contaminated waste ponds are utilized by wildlife, hence these resources are considered to be at risk for purposes of the PEIS.

[9]Wildlife have free access to contaminated areas; aquatic resources at risk include waste ponds and statutory wetlands. None of the remediation alternatives for Fernald include remediation of waste ponds or wetlands.

[10]This facility has many widely-dispersed contaminated areas; wildlife have free access to many of these. Contaminated aquatic resources include both on-site waste ponds and on- and off-site streams.

[11]Wildlife have free access to some contaminated areas. Small wetlands are widely dispersed over the site.

Additional uncertainties limiting this assessment include (1) the validity of source-term estimates, (2) the actual distribution of receptor species on the facilities relative to sites where contamination is present, (3) the unknown degree of conservatism of the transfer coefficients and toxicity benchmarks used in the hazard assessment. The first two uncertainties can be addressed in facility-specific assessments that focus on optimizing the balance between remediation and habitat preservation based on reservation-wide distributions of contaminants and ecological resources. The third uncertainty is a function of the state-of-the-science of environmental toxicology. It can be reduced by performing (1) periodic updates of the toxicological data base as new information becomes available from the scientific community, and (2) field studies at the DOE facilities to generate site-specific exposure and effects data. Such studies are now being performed at many DOE facilities to support CERCLA Baseline Ecological Risk Assessments.

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APPENDIX A: EXPOSURE AND EFFECTS ASSESSMENT METHODOLOGY

A.1 Exposure Assessment

The baseline (no-action) exposure assessment focuses on chemical stresses and any existing physical stresses to the endpoints as a result of preremediation activities. Baseline exposures to chemical stresses were assessed from the current, existing contaminant profile in the environmental media in which organisms may be exposed. Physical stresses are defined in terms of alteration or destruction of ecosystems during and after remediation. The baseline (no-action) assessment of contaminant exposures involves the following tasks: (1) determining representative receptor species composition and distribution within the ecological endpoints, (2) defining the contaminant transport and exposure pathways from the sources to the biotic receptors, (3) determining the average and maximum contaminant levels in the media to which the receptors are exposed, (4) calculating the daily intake or tissue concentrations of contaminants from each exposure pathway for each receptor, and (5) characterizing the risks to each receptor for each contaminant by comparing the total daily intake or exposure of a contaminant to the contaminant-specific benchmark (figure A-1). Assessment of ecological exposures associated with remediation alternatives involves (1) reassessment of residual contaminant exposures, and (2) evaluation of habitat disturbance (Appendix B).

Exposure scenarios were determined for each of the representative receptors for all ingestion-related pathways (e.g., food and water consumption; grooming or preening) and for external exposure. Inhalation exposures were not included because (1) air concentrations of contaminants were not available, and (2) preliminary calculations showed that risks from inhalation are minor compared to risks from food and water ingestion. To determine how contaminants are transferred through components of successive trophic levels within terrestrial ecosystems, a food web was formulated for each reservation and used to assess contaminant ingestion by terrestrial receptors.

The fate and transport model used for the human health risk assessment by Oak Ridge National Laboratory is the Multimedia Environmental Pollutant Assessment System (MEPAS) (Pacific Northwest Laboratories, 1989). MEPAS was developed to prioritize contaminated waste sites based on their potential hazard to the public. The assessment framework for MEPAS addresses the migration, fate, exposure and human health impact from radionuclides and chemical contaminants, accounting for complex chemical processes and intermedia transfer among the atmospheric, groundwater, surface water, and overland runoff pathways. MEPAS-derived contaminant concentrations in surface water were used as exposure estimates for aquatic receptors. Soil-to-plant and plant-to-animal transfer coefficients were used to translate MEPAS-derived soil concentrations into food-chain exposures to terrestrial receptors.

The primary exposure routes for terrestrial vegetation is root uptake from soil. Published soil-to-plant transfer factors were be applied to obtain concentrations of radionuclides, organics, and inorganics in the vegetative parts of plants and concentrations of radionuclides and inorganic chemicals in fruits (Baes et al. 1984; Travis and Arms 1988). Travis and Arms (1988) reported that for organic chemicals, the bioconcentration factors for vegetation were inversely proportional to the square root of the octanol-water partition coefficient. This transfer factor takes into account all exposure routes responsible for the contaminant burden measured in plant tissues. Transfer factors do not take into account, however, the bioavailability of a chemical in the soil, the biodegradation rate, weathering factors, or chemical transformations within the tissues. Therefore, the transfer factor is conservative in that it does not factor for these loss mechanisms. The equation used to estimate concentrations of contaminants in vegetation is:

$$C_V = C_S * TF , \qquad (A.1)$$

where

C_V = concentration in vegetation (vegetative or fruits) (mg/kg; pCi/kg dry weight),

C_S = concentration in soils (mg/kg; pCi/kg dry weight),

TF = soil to plant transfer factor (vegetative or fruits) = <u>concentration in vegetation</u> (unitless).

The primary exposure routes for terrestrial wildlife species are ingestion of food, external exposure to radionuclides, and drinking water. The incidental ingestion of soils is also considered for some herbivorous species such as deer, mice, and rabbits. The daily intake of a nonradiological contaminant by ingestion is estimated by the following equation:

$$intake = [(C_V * Q_V)FI_v + (C_S * Q_S)FI_s + (C_W * Q_W)FI_w + (C_f * Q_f)FI_f + (C_H * Q_H)FI_h]/BW , \qquad (A.2)$$

where

intake = daily intake of contaminated source (mg kg^{-1} day^{-1}),

C_V = concentration in vegetation (vegetative parts of plants) (mg/kg wet weight),

C_S = concentration in soils (mg/kg wet weight),

C_W = concentration in water (mg/L),

C_H = concentration in (prey) (mg/kg wet weight),

C_f = concentration in fruits, nuts, or seeds (mg/kg wet weight),

Q_V = consumption rate of vegetation by animal (kg/day),

Q_f = consumption rate of fruits, nuts, or seeds (kg/day)

Q_S = consumption rate of soils by animal (kg/day),

Q_W = consumption rate of water by animal (L/day),

Q_H = consumption rate of prey by animal (kg/day),

$FI_{v,s,w,h,f}$ = fraction of source ingested or inhaled that is contaminated (unitless),

BW = body weight of the organism (kg).

Typical consumption rates of food sources and water were obtained from the literature, where available, or determined from calculations by using allometric regression equations based on the body weight of the organism (Opresko and Suter 1992; EPA 1988;).

The contaminated fraction (FI) of each food source ingested was estimated for each organism based on the animals home range, time spent on the reservation, and the amount of food and water consumed from contaminated areas.

To determine the exposure of terrestrial organisms to radionuclides, tissue concentrations were estimated by using the following equation:

$$C_A = B_B\,[(C_V * Q_V)FI_v + (C_S * Q_S)FI_s + (C_W * Q_W)FI_w + (C_I * Q_I)FI_i + (C_H * Q_H)FI_h], \quad (A.3)$$

where

C_A = concentration in animal tissue (pCi/kg or mg/kg wet weight),

B_B = plant to muscle transfer factor (day/kg).

The other variables were defined in Eq. (A.2); the units for concentration in food sources and drinking water containing radionuclides are pCi/kg or pCi/L, respectively. The plant-to-muscle transfer factors for inorganics and radionuclides can be obtained from various literature sources, such as Baes et al. (1984), and for organic compounds, the biotransfer factor can be estimated by using allometric regression equations (Travis and Arms 1988). Travis and Arms (1988) found that the biotransfer factor for organic chemicals in muscle tissue (and milk) was directly proportional to the octanol-water partition coefficient. Although the muscle biotransfer factor was originally derived for cattle, as a reference herbivore, it can be applied to other animals that are consumed as food. Even though (1) the amount of dry matter ingested per body weight of the animal, (2) the fraction assimilated by muscle, and (3) turnover rate differ among species, the relationship between food ingested and concentration in muscle should not vary substantially among species (IAEA 1982). The transfer factor can also be applied to ingestion of water and soil. However, the chemical forms of the contaminant in soils and water may be different from that in meat, and care should be taken when applying these transfer factors. Biotransfer from food to muscle for organic chemicals assumes that fresh meat is 25% fat (Travis and Arms 1988). Although some predators ingest the whole organism, it is assumed that bone will not be digested. Thus, concentrations in an organism ingested whole are expected to be similar to those in muscle tissue.

Contaminant-specific fish bioconcentration factors (BCFs) were used to estimate the concentration of contaminants in fish tissue for consumption by fish-eating receptor organisms. The BCF is simply the ratio of literature-derived measurements of contaminant concentrations in fish tissue to corresponding contaminant concentrations in ambient surface water.

The internal dose to terrestrial organisms from exposure to radionuclides is estimated by converting the concentrations in organisms [Eq. (A.3)] to an internal whole-body dose rate for alpha-, beta- and gamma-emitting radioisotopes (IAEA 1982; Turner 1986):

$$\text{dose (rad/year)} = 0.01867\ (E_i)\ (C_i)\ , \quad (A.4)$$

where

E_i = average energy of decay (MeV) for isotope i (includes all short-lived daughter products),

C_i = concentration of radionuclide in the organism (pCi/g wet weight),

This relatively simple dose estimation of a semi-infinite absorbing medium assumes that the radionuclide is distributed uniformly throughout the organism.

To estimate external ground dose from gamma radiation and skin dose from beta radiation, the soil concentration can be substituted for the organism concentration in Eq. (A.4) (IAEA 1982).

Exposure of aquatic organisms may occur via several pathways: (1) direct ingestion of water and sediments, (2) foliar or root uptake by aquatic plants, (3) indirect exposure via uptake through the food chain, and (4) external exposure from contaminated water and sediments. Chronic exposures of aquatic organisms to contaminants in surface water and sediments were determined for fish and benthic macroinvertebrates, and radionuclide exposures are determined for wetland emergent plants and muskrats, as well. Because muskrats are semiaquatic, estimated radiation doses, which are based on criteria established for strictly aquatic species that spend the entire lives submerged in water, are conservative.

Exposures of bottom-dwelling fish, benthic macroinvertebrates, and fish larvae were determined from the sediment pore-water concentrations. Organisms that reside on or in the sediments are primarily exposed to chemicals in the pore-water. If pore-water measurements are not available, they can be estimated for organic chemicals by using the following equation (Suter 1991):

$$P = S/(K_{ow})(F) \quad (A.5)$$

where

P = pore-water concentration (mg/L)
S = sediment concentration (mg/L)

K_{OW} = octanol-water partition coefficient,

F = 0.01, the assumed organic fraction of the sediments.

It was assumed that equilibrium partitioning occurs between the organic matter in the sediments and the pore-water. The K_{ow} is used in place of the organic matter–water partitioning coefficient (K_{oc}) because K_{oc} values are not generally available. The organic fraction of the sediments was conservatively assumed to be 1%, unless otherwise known. For radionuclides and inorganic chemicals, the K_d can be substituted for the K_{ow} and the organic fraction of the sediments in the denominator can be omitted.

Internal and external chronic radiation doses to aquatic organisms from exposure to water were estimated by applying published dose conversion factors derived from generic bioaccumulation factors for freshwater fish, invertebrates, plants, and muskrats (Killough and McKay 1976). Internal radiation doses for combined alpha, beta, and gamma energies of a radionuclide are estimated by the following equation:

internal radiation dose (mrad/year) = exposure concentration (pCi/L) x internal dose conversion factor (mrad/year per pCi/L). (A.6)

The external dose from exposure to gamma rays, or both gamma rays and beta particles in water, were calculated in the same way, except that the external dose conversion factor is used.

The estimated daily rates of food and water consumption (Q_v or Q_h, and Q_w, respectively) for each representative species were calculated from allometric regression equations that are based on the weight of the organisms (EPA 1988.) These equations (Table A-1) are based on the combined measurements for laboratory animals, livestock, and selected wildlife and bird species.

A.1.1 Uncertainties in Model Predictions

All models used to predict the fate and effects of contaminants on the environment are inherently uncertain. At best, they can only approximate the real-world situation. Model predictions contain many potential sources of errors. Major sources include (1) improper parameter estimation (or parameter bias), (2) improper model formulation (or model bias), and (3) stochastic effects due to random measurement and sampling errors or natural variability (Till and Meyer 1983).

The models used to estimate doses to receptor organisms are limited by the lack of site-specific data for model parameters. Most of the reservations considered in the PEIS lack sufficient environmental databases to allow detailed and specific predictions of contaminant exposures. Transfer factors and dose conversion factors are not determined on a site-specific basis, even though these parameters are the most variable and exhibit the most uncertainty. Consumption rates, body weights, and behaviors

TABLE A-1—*Allometric Equations for Estimating Water Consumption (C in L/d) and Food Consumption (F in kg/d) from Data on Body Weight (U.S. EPA 1988*

Animal Group	Allometric Equation	r^2
Water Consumption Rates		
All species combined	$C = 0.11\ W^{0.7872}$	0.93
Primates	$C = 0.09\ W^{0.7945}$	0.95
Laboratory mammals	$C = 0.10\ W^{0.7377}$	0.88
Chickens	$C = 0.13\ W^{0.7555}$	0.74
Food Consumption Rates		
All species combined	$F = 0.065\ W^{0.7919}$	0.95
Laboratory mammals	$F = 0.056\ W^{0.6611}$	0.87
Rabbits	$F = 0.041\ W^{0.7898}$	0.73
Chickens	$F = 0.075\ W^{0.8449}$	0.97

of representative species are also generally not site-specific, however, these values are much less variable and exhibit less overall uncertainty. The consistent use of the same contaminant- and organism-specific parameters for all reservations permits comparisons between reservations on a relative scale. Because most of the parameters used in the models are conservative (i.e., they represent the upper-most value on the range of possible values), the models can be used to identify contaminants that clearly pose negligible risks to exposed organisms.

There are additional uncertainties concerning the fate and effects of radionuclides and toxic contaminants that are currently unaccounted for even in site-specific assessment models. These include antagonistic or synergistic interactions between chemicals and influences of environmental conditions such as pH, temperature, and redox potential on contaminant mobility, bioavailability, or toxicity. Although potentially significant to site-specific assessments, these uncertainties are unlikely to affect estimates of the relative risks of broadly defined programmatic alternatives such as those addressed in the PEIS.

A.2 EFFECTS ASSESSMENT

Characterization of ecological effects from contaminant exposures begins with an evaluation of the toxicity effects data that are relevant to the particular contaminants and species of interest. Aquatic and terrestrial chemical effects databases for the primary contaminants that occur at representative DOE reservations have been compiled and consist of toxicological benchmark concentrations to which the exposure concentration is compared (Suter et al. 1992; Suter et al. 1994; Opresko et al. 1994). If the exposure concentration exceeds the benchmark, there is considered to be a risk that the contaminant may adversely affect the population (or individual organisms in the case of threatened or endangered species) organism and would require further measurement and evaluation.

However, if the benchmark is greater than the exposure concentration, no adverse effects to populations are expected to occur and further assessment is not necessary. The ratio of the exposure concentration to the benchmark is termed the hazard index (HI). In evaluating the total exposure to an organism from multiple contaminants, the individual HIs for each contaminant are summed together to account for potential additive effects. Although several HIs may be less than 1 and individually would not be expected to pose any adverse effects, the sum of the HIs could be greater than one, potentially posing cumulative adverse effects. (The media concentrations considered are at or above background concentrations, so the sum of HIs greater than 1 would not include exposures to natural trace elements in the environment.) Cumulative impacts to endpoints from exposure to contaminants are discussed in Chapter 3.

For radionuclides, the available evidence indicates that a combined internal and external chronic dose rate from all radionuclides of no greater than 1 rad per day to the most sensitive aquatic species or the maximally exposed individuals in a population would not measurably affect aquatic populations (NCRP 1991). For terrestrial organisms, the upper dose limit is set at 100 mrad per day (IAEA 1992). If the total dose received from all exposure pathways and radionuclides exceeds the limit (i.e., the HI is greater than 1), there is a risk that the contaminant may adversely effect the population (or individual organism in the case of threatened or endangered species) and would require further measurement and evaluation.

The aquatic benchmarks chosen from the chemical effects data base are, in order of priority, the (1) Environmental Protection Agency (EPA) Ambient Water Quality Criteria from the state in which the reservation is located, if available, (2) Environmental Protection Agency (EPA) National Ambient Water Quality Criteria for Protection of Aquatic Life (NAWQC), where available; or (3) the lowest effective concentration (EC_{20}) test results for fish and invertebrates reported in the literature (Suter et al. 1992). The latter benchmark may be lower than the NAWQC for various reasons and is thus considered to be more conservative. The NAWQC benchmarks are set at limits that are intended to protect most of the aquatic species most of the time (Suter et al. 1992). Thus, lower benchmark values should offer even more protection. The rationale for the selection of benchmarks for specific chemicals will be discussed in the reservation-specific reports.

The benchmarks for determining effects in terrestrial species from exposure to chemicals is the chronic no-observed-adverse-effects level (NOAEL) in units of milligrams per kilogram per day. The HI is determined by comparing the benchmark NOAEL with the daily intake of a contaminant per unit body weight of the animal. The information on the toxicological effects of chemicals on wildlife is limited; most toxicity studies are conducted on laboratory animals and may only report the acute LD_{50} (the dose at which the contaminant is lethal to 50% of the organisms), the LOAEL (lowest-observed-adverse-effects level), or a subchronic NOAEL. For receptor organisms that are not listed in the data base or for which the chronic NOAEL is not available, extrapolation techniques that use uncertainty factors and adjust for differences in body weight (BW) are employed to estimate the chronic NOAEL for wildlife species from laboratory animal data or other wildlife species within the same phylogenetic class (Opresko et al. 1994). If a NOAEL is available for a laboratory test species ($NOAEL_t$), the NOAEL for a receptor species ($NOAEL_r$) can be calculated according to the following equation (Opresko et al. 1994):

$$NOAEL_r = NOAEL_t * (BW_t / BW_r)^{1/3}. \qquad (A.7)$$

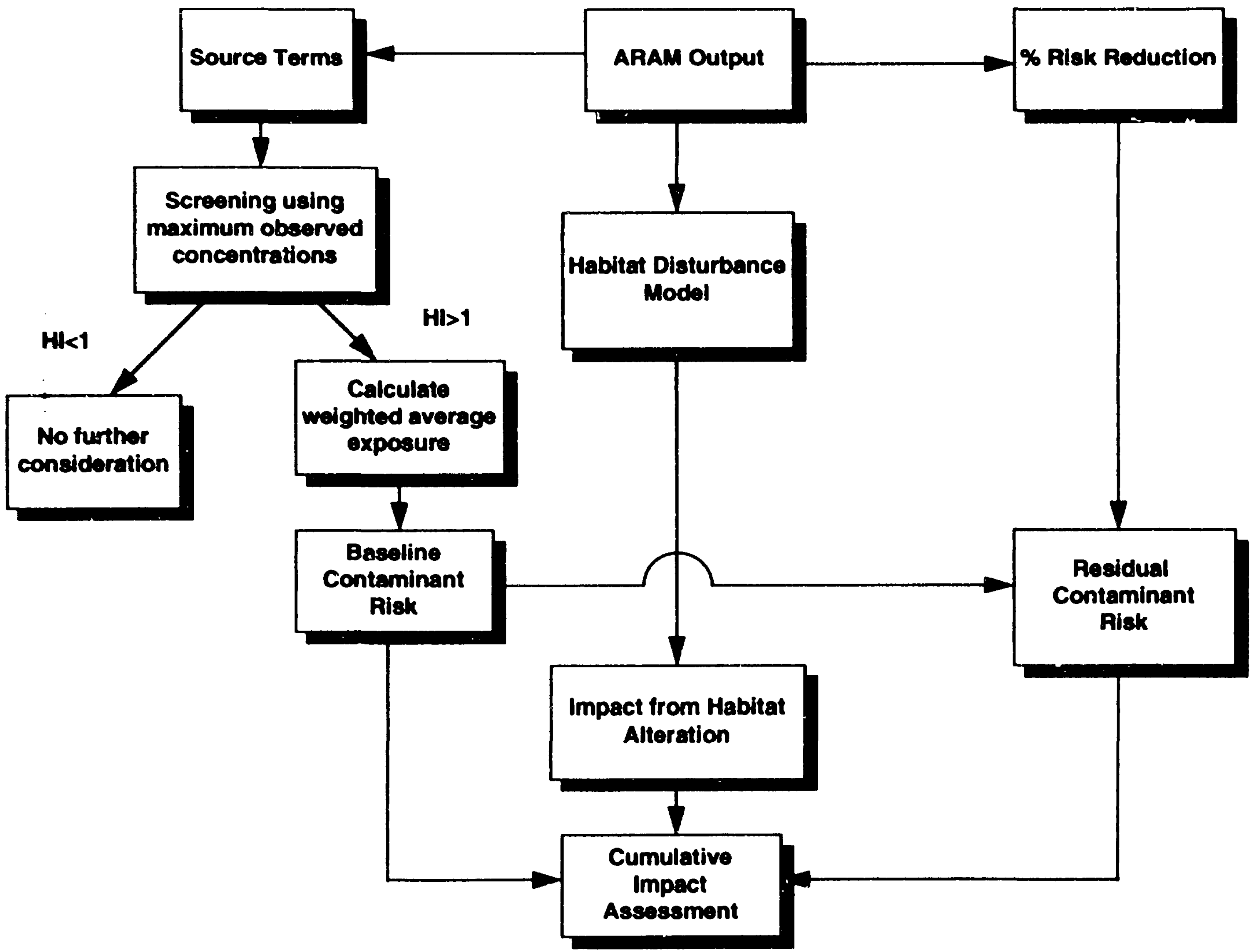
If the body weight of the test species is not reported, a more conservative approach can be taken that does not adjust for differences in body size. A multiplicative factor of 0.1 is applied to account for intraclass differences (e.g., from quail to hawk), and a factor of 0.05 is applied to account for interclass differences (e.g., mammal to bird) (EPA 1989). A factor of 0.1 is used to extrapolate from the LOAEL or a subchronic (NOAEL) study to the NOAEL (Opresko et al. 1994).

Literature sources for inorganic terrestrial phytotoxicity benchmarks were summarized by Suter et al. (1994). Where applicable, the lowest source concentration in a soil medium that produced phytotoxically excessive effects was chosen from the database. Several benchmarks were derived from experiments using nutrient solutions. However, uncertainty values were not applied to these data to account for differences in growth media. A methodology for deriving phytotoxicity benchmarks for organic constituents was developed by Eskew and Babb (Air National Guard Risk Assessment Handbook 1992). The organic fraction of the soil is the primary factor in determining bioavailability of organic compounds to plant roots. Therefore, estimated critical concentrations (mg/kg wet weight) for soil were calculated from experimental data on the uptake of compounds from nutrient solution or vapor phase by using octanol-water partitioning coefficients (K_{ow}) to estimate the distribution of compounds between the solution phase (soil pore water) and the solid phase (organic soil particles). Assumptions used to derive toxicity benchmarks were (1) a soil organic content of 1%, (2) a bulk soil density of 1.3 g/cm^3, and (3) a soil water content of 18%. Uncertainty factors were applied to adjust the data from acute to chronic effects and from 50% inhibition of growth to lowest toxic effect levels.

A.3 POSTREMEDIAL ASSESSMENT

For the baseline (no-action) risk assessment, the only environmental stressors considered are exposures to chemical contaminants and radionuclides. For the postremedial assessments, habitat disturbance resulting from each respective remedial alternative action (Appendix B), as well as the associated exposure to residual contaminant levels, were considered (figure A-1). Contaminants that do not elicit effects in the baseline assessment are not expected to cause effects after remediation, assuming that contaminant loading into the environment remains the same or is reduced after remediation.

Descriptions of remedial alternatives were supplied by PNL. These descriptions contain estimates of the reduction in contaminant inventory expected from each alternative, as well as estimates of the total area disturbed. The resultant environmental concentration at a given location should be directly proportional to the release rate from a particular source (although, depending on the environment, this may occur over a relatively long period of time). It follows that if the release rate were reduced by a given amount by remediation, the environmental concentration will be reduced proportionately. Therefore, the percentage reductions of contaminants from each source were directly applied to the contaminants in the media of interest to determine the degree reduction of the HIs. In the case of multiple sources of a particular contaminant, attempts were made to eliminate those not contributing to the environmental concentrations by examining the transport pathways from the sources to all potential receptors. Once the major contributing sources of a particular contaminant were identified, the average percentage reductions were applied to the environmental concentrations.


Source Terms
ARAM Output
% Risk Reduction
Screening using maximum observed concentrations
Habitat Disturbance Model
HI<1
HI>1
No further consideration
Calculate weighted average exposure
Baseline Contaminant Risk
Residual Contaminant Risk
Impact from Habitat Alteration
Cumulative Impact Assessment

APPENDIX B: GENERATION OF HAZARD INDICES, HOME RANGE ESTIMATES, EXPOSURE CORRECTION FACTORS, AND HABITAT DISTURBANCE ESTIMATES

B.1 INTRODUCTION

This appendix describes the methodologies used to (1) develop hazard indices and (2) calculate habitat disturbance caused by remedial actions. This information is needed to determine how DOE ER activities will affect ecological resources at DOE facilities. In sections B.2 and B.3 of this appendix, the methodology for generating ER PEIS source terms is explained. Section B.4 discusses determination of home ranges for potentially exposed organisms. Section B.5 explains the habitat disturbance calculations.

B.2 INITIAL HAZARD SCREENING

B.2.1 ER PEIS Data Bases

Source terms used for the ecological risk assessment were derived from the ER PEIS source term data base developed by Pacific Northwest Laboratory (PNL). Six contaminated media types are included in the data base: solid waste, contaminated soil, liquid containment structures, groundwater, facilities, and surface water. Groups of data are further associated by site names within reservation operable units.

The ecological risk assessment focused on soil and surface water; groundwater was addressed only to the extent that, through linkages to surface water, it influenced surface water quality. The initial stage of source term generation, then, is one of determining which data are appropriate for the ecological risk assessment. Table B-1 lists assumptions made during source term development.

B.2.2 Data Screening Based on Sitewide Maxima

Generation of ER PEIS hazard indices is a two-step process. The first stage is a conservative screening assessment based on the absolute maximum contamination levels possible across each reservation. In the second stage a more realistic estimation of contaminant exposure is attempted. This task presents several difficulties, some of which will be discussed later. Figure B-1 describes the process by which hazard indices are generated.

The information compiled for a given facility can list many different concentrations for the same contaminants in the same medium at different spatial locations. For example, ^{238}U could be found in soil at several different sampling locations on a reservation, and each one of these sampling locations could have different surface area associated with it. In the initial screening stage, the absolute sitewide maxima for each combination of contaminant and medium is determined. These maxima are used as inputs to the exposure and effects assessment models described in appendix A. Contaminants shown to have a negligible risk under these extremely conservative assumptions are eliminated from further assessment. Remaining contaminants are analyzed using the methods described in the next section.

B.3 AREA-AVERAGED HAZARD SCREENING

B.3.1 Concentration Averaging Scheme

Source terms reported by PNL are generally representative of samples collected at known sites of contamination and are not representative of reservation-wide levels of contamination. Knowledge of the areas occupied by burial grounds or other contamination sources was used to develop a scheme for estimating the contaminant exposures *within these contaminated areas*. Where possible, based on knowledge of the local ecosystems, surface water used solely for drinking was treated separately from surface water that provides aquatic habitat.

The averaging scheme is shown in figure B-2. In this hypothetical case, data are available for contaminated sites A, B, and C. A weighted mean contaminant exposure is calculated by (1) averaging all of the contaminant measurements within each area, and (2) computing an overall mean from the site means, each weighted by its area.

The weighted mean applies only to the fraction of a reservation within which samples have been collected. It is assumed that contamination of the remainder of each reservation is negligible compared to contamination of the areas that have been characterized. Exposure estimates for receptor species are corrected to account for (1) the fraction of an individual organism's home range that might include contaminated sites, and (2) the fraction of the total range of receptor species or community types occupied by contaminated sites.

The source term data base does not include area estimates for all contaminated sites. Estimates of the total contaminated area on each reservation were adjusted to account for the fraction of contaminated sites for which areas were provided. If, for example, surface areas are provided for 50% of the contaminated sites at a particular reservation, all known surface areas are summed and then multiplied by two to compensate for the missing data.

B.4 Home Ranges of Receptor Species

For contaminants and receptors for which detailed analysis was required, an attempt was made to further define contaminant exposures by comparing the home range sizes of receptor species with the potential fraction of the home range that was contaminated.

Receptor species at the six DOE reservations have home ranges or territories which range from small [e.g., one hectare (about 2.5 acres) or less for very small animals such as songbirds and mice] to very large [e.g., thousands of hectares (acres) for some bats and coyotes (table B-2)].

Food webs of receptor species were developed for each DOE reservation (appendix A). An effort was made to include prey species, game mammals, birds, and predators in these food webs. Also, where possible, receptor species were selected that were common to multiple DOE sites and that included state and federally listed, threatened, endangered, and candidate species for each of the six sites.

Species home ranges may vary from reservation to reservation depending on food availability. Larger home ranges are typically found in the arid western reservations where animals must forage over greater distances to find sufficient food.

Table B-2 lists the bird and mammal receptor species used for the six DOE reservations, their home ranges, and the sources of the data. Where data were lacking, home ranges for birds were estimated based on regression of home range size as a function of body weight [i.e., $Y = -1.16 + 1.19X$, where $Y = \log_{10}$ area (acres) and $X = \log_{10}$ body weight (grams); $r^2 = .65$ with 94 observations in the sample size]. Generally, home range area was assumed to be circular or square. In some cases however, (e.g., some bats, mink, osprey), home range is reported as a linear stream distance or as a distance of linear travel to feeding areas.

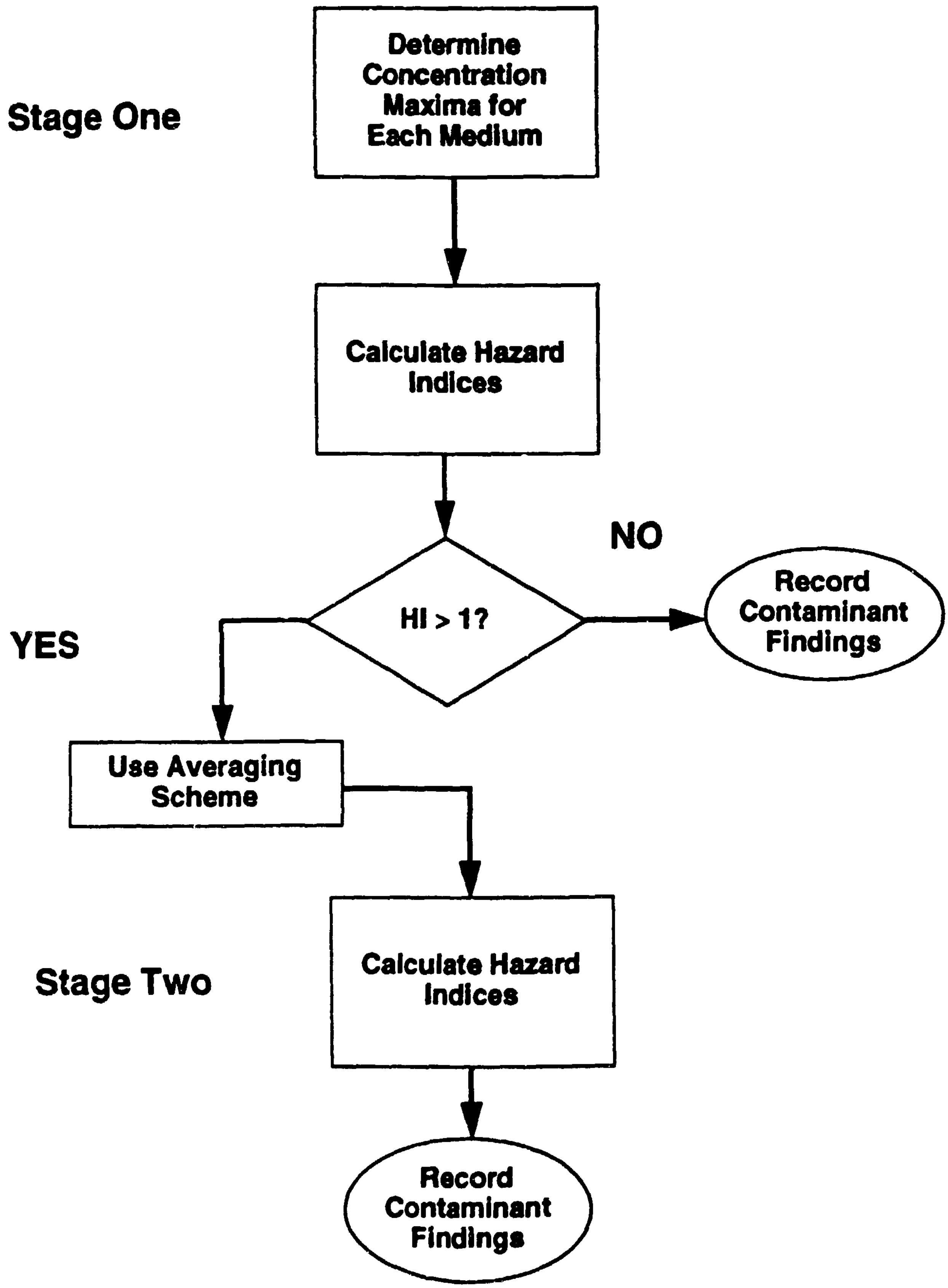
Home range data were used to further define exposure risks by comparing the home range sizes of receptor species with the potential fraction of the home range that is contaminated.

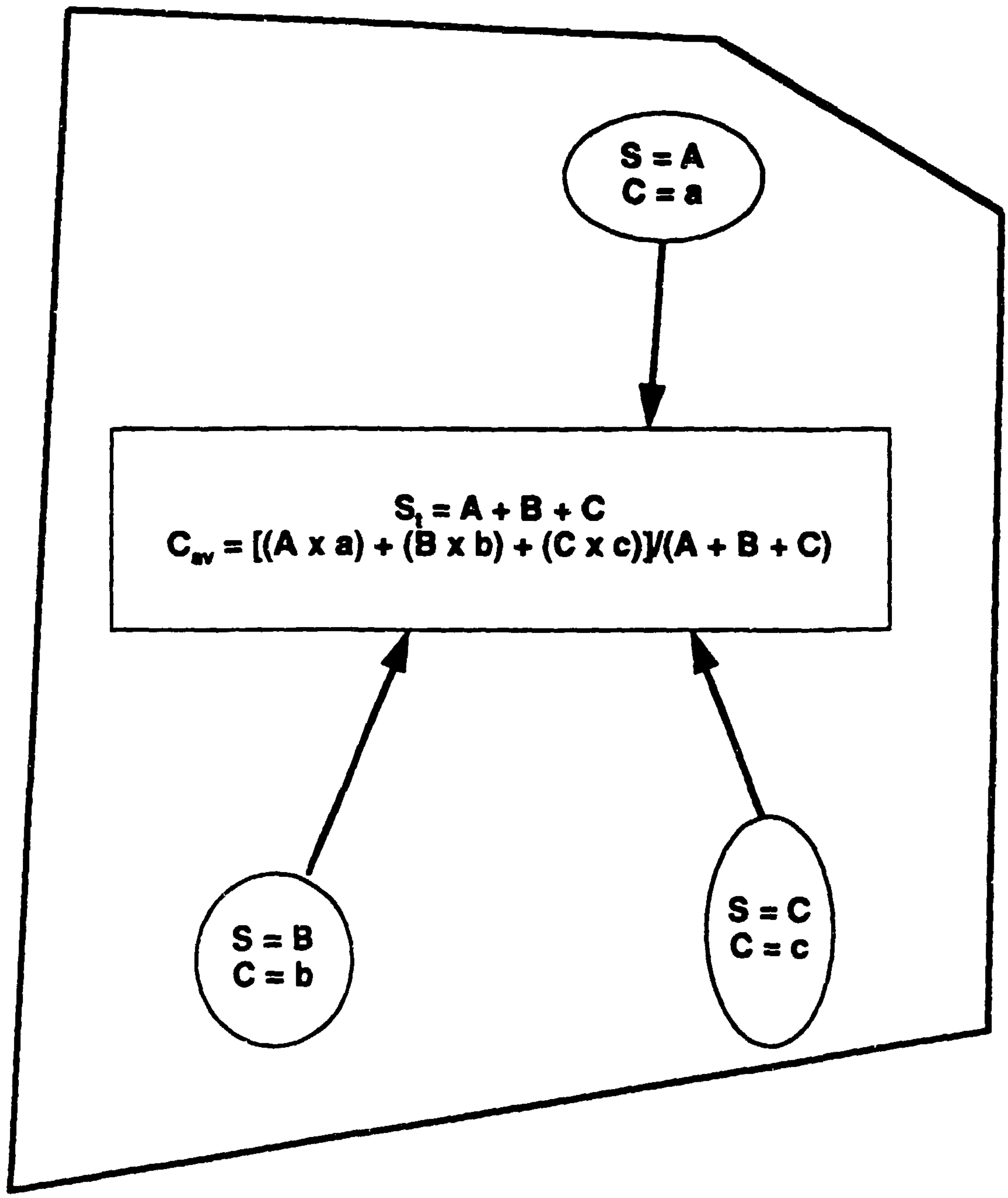
B.4.1 Theoretical Basis for Estimating Correction Factors

The following discusses the theoretical basis for applying correction factors to the calculated risks (i.e., HIs). The DOE reservations described in the ER PEIS have numerous contaminated areas (e.g., burial grounds, scrap yards, contaminated ponds and streams) yet many animals and birds will not spend all of their time in a contaminated area. Thus, it is important to determine the

TABLE B-1—*Assumptions Made in the First Stage of Source Term Generation*

General	• When isotopes are not specifically stated, uranium is assumed to be ^{238}U, plutonium is assumed to be ^{239}Pu, and strontium is assumed to be ^{90}Sr. • Measurements not associated with specific contaminants will not be used (e.g., gross alpha and total suspended solids).
Solid Waste	• Solid waste sources will be considered only if surface soils surrounding the solid waste storage areas have become contaminated.
Contaminated Soil	• Only contamination in the top 2 ft of surface soil will be used, because it is assumed that deeper soils do not contribute to contaminant exposure to biota.
Liquid Containment Structures	• Liquid containment structures (LCS) will be considered only if biota could use water contained in the structure for habitat or drinking water.
Groundwater	• Groundwater contamination will not be considered.
Surface Water	• Surface water and sediments will be treated as separate media. • Where appropriate, the surface water category will be divided into water used solely for drinking and water used for aquatic habitat.


Stage One
Determine Concentration Maxima for Each Medium
Calculate Hazard Indices
HI > 1?
NO
Record Contaminant Findings
YES
Use Averaging Scheme
Stage Two
Calculate Hazard Indices
Record Contaminant Findings



S = surface area
S_t = total surface area
C = contaminant concentration
C_{av} = weighted average contaminant concentration

TABLE B-2—*Home Range Data and References for Bird and Mammal Receptor Species at the Six DOE Reservations*[1]

Receptor Species	Home Range hectares (acres)	References
American robin (large generic songbird)	0.24 (0.6) HN 0.1-0.24 (0.2-0.6) RF 4 (10) IN, OR	Terres 1980; based on regression of home range size as a function of body weight (Schoener 1968)
Bald eagle	5500 (14,000) HN 520-940 (1300-2300) RF 1200 (3000) IN	Based on regression of home range size as a function of body weight (Schoener 1968); Terres 1980
Canada goose	980 (2400) HN 500 (1200) OR	Fitzner and Gray 1991; based on regression of home range size as a function of body weight (Schoener 1968)
Cooper's hawk	230 (560) OR	Schoener 1968
Ferruginous hawk	7200 (18,000) HN 210 (520) IN	Fitzner and Gray 1991; based on regression of home range size as a function of body weight (Schoener 1968)
Loggerhead shrike	8 (20) HN 2 (5) IN	Schoener 1968; based on regression of home range size as a function of body weight (Schoener 1968)
Mallard duck	4 (10) RF 170 (410) IN	Based on regression of home range size as a body weight (Schoener 1968)
Osprey	200 (500) OR	Based on regression of home range size as a function of body weight (Schoener 1968)
Peregrine falcon	2600 (6400) HN 65-31,000 (160-77,000) RF	Brown and Amadon 1968; based on regression of home range size as a function of body weight (Schoener 1968)
Sage grouse	8 (20) HN 350-410 (880-1000) IN	Based on regression of home range size as a function of body weight (Schoener 1968); Connelly and Markham 1983
Small generic songbird	0.24 (0.6) IN, OR	Based on regression of home range size as a function of body weight (Schoener 1968)
Red-tailed hawk	190-240 (480-1000) FN	Brown and Amadon 1968; Schoener 1968
Western meadowlark	1.2-6.1 (3.0-15) RF	Terres 1980

TABLE B-2 (continued)

Receptor Species	Home Range hectares (acres)	References
Black-tailed jackrabbit	20 (49) HN 7.3-160 (18.0-400) RF 16-20 (40-50) IN	Chapman and Feldhamer 1982; Chapman et al. 1980; Lim 1987
Coyote	8800 (22,000) HN 2100-8000 (5100-20,000) RF 4100 (10,000) IN 1000-6800 (2500-16,800) OR	Fitzner and Gray 1991; Bekoff 1977; Bekoff 1982; ORR staff observation
Eastern cottontail rabbit	1.0-2.8 (2.5-6.9) FN 2-6 (5-15) OR	Chapman et al. 1980; McNabb 1963
Generic mouse (as in various species of *Peromyscus*)	0.12-2.4 (0.3-6) IN, OR	McNabb 1963
Great Basin pocket mouse	0.2 (0.5) HN	Nowak and Paradiso 1983
Indiana bat	1.5-4.5 (3.7-11) 0.82 km linear stream distance FN OR	Thomson 1982; Humphrey et al. 1977
Mink	8-20 (20-49) OR 2-5 km linear stream distance	Chapman and Feldhamer 1982; Linscombe et al. 1982; ORR staff observation
Mule deer	3000 (7400) HN 36-240 (90-600) RF	Anderson and Wallmo 1984; Burt and Grossenheider 1976
Pallid bat	196,000 (485,000); 25 km foraging distance HN	Hermanson and O'Shea 1983
Prairie dog	2.4-2.8 (5.9-6.9) RF	Clark et al. 1971
Preble's meadow jumping mouse	0.08-1.1 (0.19-2.7) RF	Whitaker 1972
Pronghorn antelope	300-2300 (740-5700) IN	O'Gara 1978
Pygmy rabbit	2 (5) IN	Green and Flinders 1980
Red fox	260-520 (640-1300) RF	Burt and Grossenheider 1976
Townsend's big-eared bat	2-14,000 (5-35,000); 64 km foraging distance IN	Kunz and Martin 1982
White-footed mouse	0.2-06 (0.5-1.5) OR RF	Burt and Grossenheider 1976
White-tailed deer	60-520 (150-1300) RF	Burt and Grossenheider 1976; Smith 1991

[1] HN = Hanford Reservation; FN = Fernald Environmental Management Project; IN = Idaho National Engineering Laboratory; OR = Oak Ridge Reservation; RF = Rocky Flats Plant; PM = Portsmouth Reservation.

proportion of contaminated area to the total area of an animal's or bird's home range or territory. Waste sites and adjoining contaminated areas are usually clustered in waste area groups or operable units. On large reservations such as ORR, INEL, and Hanford, waste sites are generally concentrated near major facilities or groups of facilities. We refer to the area containing most of the contaminated sites as the "waste complex." At facilities where a small proportion of waste sites are widely dispersed, a representative waste complex was defined which contained most of the waste sites. The relationships between a waste complex, individual waste sites or contaminated areas, and home ranges of various species of wildlife are shown in figure B-3. This conceptual relationship was used to develop correction factors for hazard indices in order to produce more realistic estimates of risks to receptors.

For purposes of this programmatic risk assessment, all waste sites are assumed to be the same size and randomly distributed throughout the waste complex. This may not be a realistic assumption as waste sites range in size and often their distribution is clumped. It is also assumed that the area surrounding waste sites within the waste complex is suitable habitat for wildlife.

As shown in figure B-3, some species have home ranges small enough to be entirely within waste sites. For these species no correction factor was used. For species with home ranges larger than a representative waste site but smaller than the entire waste complex, a correction factor is used that is equal to the ratio of the sum of the area of the individual waste sites divided by the total area of the waste complex. For species with home ranges larger than the waste complex, a correction factor is used that is equal to the ratio of the sum of the area of the individual waste sites divided by the area of the home range or territory.

B.5 Habitat Disturbance

Remedial activities can cause adverse impacts on plant and animal communities through (1) the removal and treatment of soil or sediment, and (2) the building of roads, decontamination facilities, and other infrastructure associated with remediation. For the ER PEIS, a stochastic analysis of habitat disturbance risks was performed using the @RISK software package, a supplement to the Lotus 1-2-3 spreadsheet program.

Information on the areas expected to be disturbed by remedial activities is derived from the Analysis of Remedial Alternatives Model (ARAM) output for each reservation. Site codes provided in ARAM are cross-referenced to site codes, site names, and site areas contained in the source term data base. For each remediation alternative, the specific sites to be remediated are identified from the ARAM output and the areas of those sites are extracted from the source term data base.

It is unlikely that the entire area of each site will be disturbed. For example, a 100-m^2 trench may have significant contamination throughout only 80% of its area. It is assumed that only this 80% will be disturbed by remediation. There is no way, however, to determine from the ER PEIS source term data the exact fraction of each site that might require remediation. Therefore, the @RISK program is used to generate probability distributions of disturbance fractions for each site. A triangular distribution with a minimum of 50% disturbance, a maximum of 100%, and a mode of 90% is used to generate these estimates.

Roads, buffer zones, and storage facilities are generally constructed at remediated sites. It is assumed that the amount of habitat disturbance from these sources is directly proportional to the area to be remediated.

In many instances, remediation activities will require that some volume of clean soil be used to fill in pits created when contaminated soil is taken to remediation or waste management facilities. Borrow pits either on- or off-site must be excavated to provide this soil. The general term "off-site effects" is used to describe the impacts of these activities as they relate to habitat disturbance. The percentage of each remediated site requiring clean soil from a borrow pit is assumed to be a function of surface area. This fraction is modeled as a triangular probability distribution with a minimum of 50%, a maximum of 100%, and a mode of 80%. When borrow pits are constructed, the surface area affected is expected to be somewhat less than the actual surface area requiring borrowed soil because pits are likely to be dug deeper to generate the necessary volumes of soil. The area estimates are therefore adjusted by an additional area ratio having a minimum value of 10%, a maximum of 100%, and a mode of 50%.

The total area of habitat disturbed is summed over all of the remediation sites included in the ARAM output. In most cases, the sites included in this output represent a sample of all of the sites at a reservation requiring remediation. To scale up the habitat disturbance estimates to the reservation level, it is assumed that the sites included in the ARAM analysis are representative of the full suite of contaminated sites. For example, if 20% of the known contaminated sites at a reservation are included in the ARAM output, the total area disturbed is adjusted by a factor of five.

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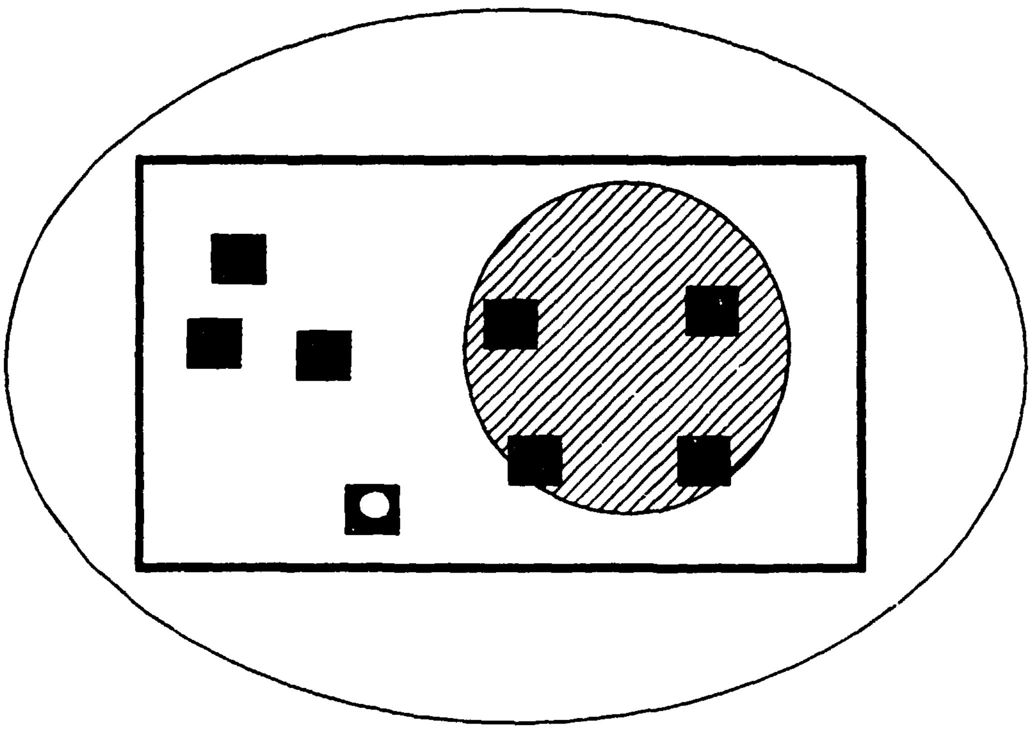

- Waste complex (Y acres)
- Typical (representative) waste site (X acres)
- Small home range (<X acres); Correction Factor (CF) = 1
- Intermediate home range (more than X but less than Y); $CF = \frac{\text{sum X}}{\text{Y}}$
- Large home range (more than Y); $CF = \frac{\text{sum X}}{\text{home range}}$