Environmental Risk Characterization Work Plan
Yankee Nuclear Power Station
Rowe, Massachusetts

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1 Introduction

This document presents a work plan for performing an environmental risk assessment to support the environmental site closure underway at the Yankee Nuclear Power Station (YNPS). A work plan for the human health risk assessment was submitted as a separate document (Gradient, 2006). The YNPS is located in the town of Rowe, situated in northwestern Massachusetts along the Deerfield River adjacent to Sherman Dam (Figure 1-1). Yankee Atomic Electric Company (YAEC) owns YNPS and surrounding lands, which comprise approximately 1,800 acres, of which approximately 12 acres is occupied by the nuclear plant itself.

The YNPS began operations in 1961 and ceased operation in 1992. The plant is in the process of being dismantled and YAEC is terminating the YNPS federal license with the Nuclear Regulatory Commission (NRC). In order to terminate its nuclear operating license, YAEC must complete a process of radiological cleanup defined by the NRC and set forth in YAEC's License Termination Plan (LTP). In addition, YAEC will comply with the Massachusetts Department of Public Health (MADPH) requirements for meeting radiological dose guidelines.[1] Both the NRC and MADPH require compliance with radiological "dose-based" requirements for the protection of human health.

In parallel with the license termination, YAEC is conducting a comprehensive environmental closure that will ensure that the property poses no adverse human or environmental impacts once YAEC transfers title of the property.[2] The environmental site closure is being performed as a voluntary action that will adhere to guidelines established by the Massachusetts Department of Environmental Protection (MADEP) as well as guidelines established by the U.S. Environmental Protection Agency (USEPA), in addition to the requirements noted above established by NRC and MADPH.

Because the NRC and MADPH standards or guidelines only address the possible impacts of radiological constituents to humans, this additional assessment of human health and environmental risks associated with non-radiological constituents (for convenience and clarity non-radiological constituents will be referred to here as "chemicals" or "chemical risk assessment") will be conducted by YAEC following MADEP and USEPA guidelines. In addition, both MADEP and USEPA require the assessment of "cumulative," or additive risks associated with both radionuclides and chemicals. This

[1] MADPH guidelines apply to humans only.

[2] Future uses are not currently defined, although likely will include open space/recreational uses. However, a portion of the site constituting the former industrial area will have Activity Use Limitations (AULs) and/or deed restrictions on future uses that will prevent development (including preventing residential uses), installation of wells, *etc*...

work plan presents the procedures that will be adopted to evaluate cumulative chemical and radiological risks to the environment, or an "ecological risk assessment" (ECORA). A separate work plan (Gradient, 2006) describes the companion human health risk assessment for combined chemical and radiological risks.

1.1 Risk Assessment Goals

Although the assessment methods and standards for radiological and chemical risk assessment may differ somewhat in their approach (*e.g.*, dose *versus* risk), both share the common purpose of ensuring protection of human health and the environment. The overall goal of the cumulative risk assessment approach described herein is to establish whether post-closure site conditions (*e.g.*, existing structures removed, remediation of radionuclides and chemicals as necessary, and site restoration) meet environmental conditions that do not pose a significant risk to the environment. Should the cumulative risk assessment identify potential risks above background risks and beyond risk guidelines established by MADEP and USEPA, this will serve as the basis for identifying additional remedial measures or environmental controls to reduce these potential risks.

The cumulative risk assessments will evaluate potential ecological risks (or hazards) above those associated with exposure to naturally occurring or ubiquitous constituents in the environment. This is particularly important for naturally occurring radionuclides, inorganic constituents (*e.g.*, metals), and other chemicals associated with ubiquitous anthropogenic sources. Thus, as described below, one element of the ECORA will include an evaluation of background levels of radionuclides and chemicals in the environment in general, as well as within the vicinity of the site, in order to assess incremental risks above background risks.

In addition to this work plan for the cumulative ecological risk assessment for the overall site closure, a focused risk assessment in support of the Toxic Substances Control Act (TSCA) Risk-Based Disposal Approval Application (RBDAA) for PCB cleanup in Sherman Reservoir was prepared pursuant to a request by USEPA Region I. That assessment, along with subsequent revisions based on comments received from the USEPA, was completed and approved by the USEPA September 28, 2004. As outlined in this ECORA work plan, the cumulative risk assessment for the site includes an evaluation of any residual PCBs in Sherman Reservoir sediments, and other possible chemicals of potential concern (COPCs), after the sediment remediation has been completed under USEPA and MADEP oversight.

1.2 Risk Assessment Framework

This work plan has been prepared in accordance with the requirements of a MADEP Method 3 Risk Characterization pursuant to Section 310 CMR 40.0900 of the MCP. The cumulative ecological risk assessment will be conducted primarily according to MCP Risk Characterization guidance for performing a Method 3 Environmental Risk Characterization, found in Chapter 9 of the Guidance for Disposal Site Risk Characterization (MADEP, 1996). It should be noted that MADEP and USEPA ecological risk assessment guidelines share a common framework and foundation such that the approaches adopted here following MADEP guidelines are consistent with USEPA methods. Furthermore, MADEP does not have any published radiological risk assessment guidance. Thus, the assessment of radiological risks will rely primarily on guidance from U.S. Department of Energy's "A Graded Approach for Evaluating Radiation Doses to Aquatic and Terrestrial Biota" (USDOE, 2002).

A Method 3 Environmental Risk Characterization is a site-specific risk characterization taking into account site-specific ecological exposure patterns, the distribution of constituents of potential concern, as well as exposures to multiple constituents. The principal ecological concern at YNPS is the potential effects to ecological receptors associated with exposures to metals, organic constituents, and radionuclides in soil, sediment, and surface water along with possible accumulation of site-related chemicals and radionuclides into biological tissues (*e.g.*, plant, invertebrates, mammals, fish, and birds).

The MCP divides the Environmental Risk Characterization into two stages: Stage I Environmental Screening and Stage II Environmental Risk Characterization. This approach is also recommended by USEPA. Both stages of the environmental risk characterization are illustrated in Figure 1-2. It should be noted that the Stage I Environmental Screening is not intended to estimate actual hazard (*e.g.*, adverse effects) to ecological receptors. The conservative methods and assumptions used in the Stage I evaluation are intended to identify possible hazards and are designed so that potential risks to ecological receptors are not underestimated. If the results of the Stage I evaluation indicate a potential hazard cannot be ruled out using conservative approaches, then a Stage II quantitative evaluation will be required to assess hazards to potential ecological receptors at the Site in more detail.

A Stage I Environmental Screening will be performed pursuant to Section 310 CMR 40.0995 in order to evaluate the risks to biota and habitats at the site and its vicinity. The steps followed in the screening evaluation will include:

- Identify constituents of potential concern (COPC) based on site chemical use history and monitoring data.
- Identification of potential receptors and exposure pathways.
- Comparison of maximum detected COPC concentrations in media with applicable "screening" benchmarks to determine whether a Stage II environmental risk characterization is needed to evaluate potential site-related risks further.

Should a Stage II environmental risk characterization be necessary, the assessment will be conducted following MADEP (1996) ecological risk assessment guidance including other established Agency guidance summarized below:

- Ecological Assessment at Hazardous Waste Sites: A Field and Laboratory Reference (USEPA, 1989a)
- Eco Updates (USEPA, 1991; 1992a), which supersede earlier guidance for conducting environmental evaluations for the baseline risk assessment (USEPA 1989b)
- Framework for Ecological Risk Assessment (USEPA, 1992b)
- Wildlife Exposure Factors Handbook (USEPA, 1993)
- Ecological Risk Assessment Guidance for Superfund: Process for Designing and Conducting Ecological Risk Assessments (USEPA, 1997)
- Guidelines for Ecological Risk Assessment (USEPA, 1998)
- A Graded Approach for Evaluating Radiation Doses to Aquatic and Terrestrial Biota (USDOE, 2002)
- Methodology for Estimating Radiation Dose Rates to Freshwater Biota Exposed to Radionuclides in the Environment (Blaylock *et al*., 1993)
- Methods and Tools for Estimation of the Exposure of Terrestrial Wildlife to Contaminants (Sample *et al*., 1997)

The ecological characterization for the Site will be performed in accordance with methodology recommended by MADEP (1996) that was modified from the approach developed by the National Academy of Sciences for assessing human health risks (NRC, 1983), outlined below.

- **Problem Formulation**: This component of the assessment defines the ecological assessment's objectives and involves a thorough description of the potentially impacted areas. The focus will be on collecting information to conduct the exposure and ecological effects assessments. Assessment and measurement endpoints will be defined. The end product will be a conceptual model of the site that outlines sources of constituents and potential pathways of exposure.

- **Analysis**: The analysis aspect of the assessment sets forth the "Exposure Assessment" and "Biological Effects Assessment" components. *Exposure Assessment* refers to the magnitude and type of actual and/or potential exposure of receptors to constituents released from the site, with emphasis on characterizing receptors and quantifying exposure point concentrations of constituents. *Biological Effects Assessment* refers to the quantitative evaluation of the link between concentrations of constituents in environmental media to potential adverse effects in receptors. It involves evaluating toxicology information from literature, field and/or laboratory studies that link the concentrations of constituents in various environmental media to adverse biological effects in organisms.
- **Risk Characterization**: Risk characterization compares the results of the exposure assessment with the results of the biological effects assessments to evaluate whether adverse effects are occurring or will occur as a result of constituents present at the Site. An interpretation of the ecological significance and uncertainties in the assessment are components of the risk characterization step.

The sections that follow describe the Stage I and Stage II environmental risk characterization approach that will be implemented at the YNPS.

2 Stage I Environmental Screening

The purpose of the Stage I Environmental Screening will be to address whether constituents released to soil and groundwater, with subsequent migration to surface water and sediment in Sherman Reservoir, may pose a potential hazard to ecological receptors. This type of screening is not intended to estimate actual hazard (*e.g.*, adverse effects) to ecological receptors. The methods and assumptions used in the Stage I evaluation are designed so that potential risks to ecological receptors at various exposure areas are not underestimated. As specified in the MCP, a subsequent Stage II environmental risk characterization is required only if COPCs exceed conservative "Stage I" screening benchmarks.

As mentioned earlier, YNPS sits on approximately 1,800 acres most of which are undeveloped eastern hardwood and pine forest. The YNPS is situated adjacent to two prominent water bodies, Sherman Reservoir and the Deerfield River, which provide human recreation and habitat typical of eastern coldwater streams. YAEC has conducted a natural resource survey to identify the ecological resources associated with the Site. The survey identified vegetation composition and habitat types (*e.g.*, wetland, upland forest), characterized wildlife habitat (*e.g.*, availability of foraging and nesting habitat), identified the presence of wildlife species and endangered species (based on available habitat), and assessed forest health and value (Woodlot, 2004). The natural resource survey will provide the basis for establishing site habitat conditions to be evaluated in the environmental risk assessment.

2.1 Site Background

Originally designed as a 145-megawatt electric generating plant and later increased to 185 megawatt, YNPS was built between 1958 and 1960 as a prototype plant intended to operate for six years. The plant ultimately operated for over 30 years, from 1961 until 1992. On February 26, 1992, the YAEC Board of Directors decided to cease power operations permanently at YNPS and decommission the facility.

The YNPS plant used a variety of materials/chemicals in the course of routine operations, a summary of which is provided in the Phase II Comprehensive Site Assessment Report (ERM, 2005b). As summarized in that report, historical chemical and radiological releases from the plant are attributed to:

- painted surfaces (historically painted with PCB-containing paints) released flaking paint chips impacting soils, groundwater in several locations, the stormwater system, and sediments of Sherman Reservoir and the WSD;
- permitted cooling water and waste discharges (*e.g.*, to Sherman Reservoir and the WSD);
- occasional leaks or spills or unplanned releases from the plant; and
- oil or fuel-related materials from automobile traffic/parking areas, and other occasional leaks or spills.

Since the initiation of plant decommissioning activities in 1992, YAEC has conducted numerous environmental sampling programs to support the decommissioning efforts. These investigations have included sampling of building surfaces and materials, soil, groundwater, stormwater systems, surface water, sediments and fish. Samples have been analyzed for both radiological and chemical parameters. YAEC is presently conducting comprehensive environmental investigations of soil, sediment, surface water, and fish at the site to support the environmental site closure. These historical and current environmental sampling efforts will provide the body of data and information that will be used for the environmental risk assessment. Data collected from the most recent site characterization efforts will be used preferentially, augmenting these data with historical data as necessary.

Plant decommissioning and demolition is currently underway, and nearing completion. All radiological systems with the exception of the Spent Fuel Pool systems have been removed from the plant. The spent nuclear fuel is being stored in the Independent Spent Fuel Storage Installation (ISFSI), an on-site dry cask storage facility, until the Department of Energy satisfies its obligations to remove the spent fuel to a Federal facility. The ISFSI is fenced and protected by surveillance 24-hours a day. Upon completion of the environmental site closure, all site structures, with the exception of the ISFSI, will be removed and the site will be re-graded and seeded with natural vegetation. The environmental assessment will evaluate these "post closure" conditions and evaluate whether residual chemicals and radionuclides in environmental media pose a potential threat to the environment.

One element of the site closure will be the institution of an Activity Use Limitation (AUL) over that portion of the site constituting the former industrial area. In addition, as a component of the final site restoration/grading plan, up to 3-feet of overburden will be in place in the former industrial area. The AUL would preclude excavation, without a DEP-approved soil management plan and would occur only under the oversight of a Licensed Site Professional (LSP).

Since decommissioning activities commenced in 1992, YAEC has collected environmental data as necessary to support the dismantling/decommissioning of the plant. Data collected in support of decommissioning since 1997 for soil, groundwater, storm sewer/catch basin sediments, and Sherman Reservoir sediments, have been compiled into an electronic database. In addition, in the Spring of 2000, paint chips associated with lead-based paint were observed flaking from certain plant structures and subsequent investigations determine the paint chips to contain PCBs. The investigation of the paint chip release was reported to MADEP and EPA. Additional sampling has been conducted to support remediation of the PCB paint chip release under the MCP and TSCA. These data collected since 2000 have also been compiled into the electronic database for the site. Finally, on-going environmental sampling in support of the Site Closure Plan (as set forth in the Field Sampling Plans) has been conducted by YAEC. These Site Closure data are also compiled in the electronic site database.

In addition to these chemical data, radiological constituents have also been measured to support the LTP. Radiological data compiled in the Historical Site Assessment (HSA) are maintained in the electronic database for the site. These data include radiological data for soils, sediments, and groundwater. As set forth in the LTP, additional radiological data will be collected for the FSS to support license termination, and these FSS data will be incorporated into the YNPS database.

The chemical and radiological data in the YNPS electronic database will form the foundation for data used in the risk assessments. The geographical extent of the chemical and radiological data currently in the electronic database is shown in Figure 11 and Figure 12 of the Baseline Environmental Report (ERM, 2004). In addition, historical Radiological Environmental Monitoring Program (REMP) data collected by YAEC will be used as necessary to identify local and regional background levels of radionuclides in environmental media.

The site data collected as part of the above-mentioned sampling efforts (including on-going efforts), will provide the data that will be used in the environmental risk characterization.

2.2 Constituents of Potential Concern

Constituents of potential concern, or COPCs, will be identified based on a combination of past history of materials/chemical usage, and environmental monitoring data collected at the site. As part of the environmental site closure, YAEC has prepared a Site Closure Project Plan (YAEC, 2004), a Quality

Assurance Project Plan (QAPP) (Gradient, 2005), and field sampling plans for sediment, soil and groundwater (ERM, 2003a,b,c).

Based on the operations and materials used at the plant, samples from environmental media have been analyzed for the following constituents as described in the QAPP (Gradient, 2005):

- volatile organic compounds (VOCs);
- semivolatile organic compounds (SVOCs);
- petroleum hydrocarbons[3]
- priority pollutant 13 metals, plus boron and lithium;
- hexavalent and trivalent chromium;
- total cyanide and cyanide amenable to chlorination;
- chlorinated herbicides;
- polychlorinated biphenyls (PCBs);
- dioxins and furans;
- hydrazine; and
- radiological constituents.

As specified in the MCP, all constituents detected in soil, sediment, and surface water will be retained as COPCs if both of the following conditions are met:

1. constituents are detected in greater than 5% of environmental samples, and
2. constituent concentrations exceed background or local conditions.

MADEP (1995) defines background as "those levels of oil and hazardous material that would exist in the absence of the disposal site of concern that are:

(a) ubiquitous and consistently present in the environment at and in the vicinity of the disposal site of concern; and

(b) attributable to geologic or ecologic conditions, atmospheric deposition of industrial process or engine emissions, fill materials containing wood or coal ash, releases to ground water from a public water supply system, and/or petroleum residues that are incidental to the normal operation of motor vehicles."

[3] Depending on the levels of total petroleum hydrocarbons found, additional extractable petroleum hydrocarbon/volatile petroleum hydrocarbon (EPH/VPH) analyses may be performed (MADEP, 2002a).

Given their ubiquitous presence in the environment, MADEP (2002a) has developed statewide background levels for metals and PAHs in both "natural" soil and soil containing fill material. Site-specific information will be used to characterize local conditions and identify constituents of concern, for soils, surface water, and sediment for inorganics, SVOCs, petroleum hydrocarbons, and radionuclides. The site-specific information may be supplemented with statewide and literature background values for comparative purposes. Median and maximum detected concentrations of constituents in specific media will be compared to the site background levels for the above media following MADEP protocols.. In addition, for constituents with sufficiently robust background and site data (*e.g.*, radionuclides), distributional methods and statistical plotting methods will also be used to assess background conditions. Constituents present at levels consistent with background levels will not be retained as constituents of concern (COPCs) for the risk assessment. Only those site-related radionuclides, which exceed background, will be evaluated in the environmental assessment.

A preliminary evaluation of the environmental data conducted according to the MCP guidelines identified the following chemical COPCs (see Table 2-1 for detailed chemical listing):

COPCs – Chemical Constituents	
Soils	Total Petroleum Hydrocarbons (TPH), Volatile Organic Compounds (VOCs), Semi-Volatile Organic Compounds (SVOCs), PCBs, dioxins, Inorganics
Sediment	TPH, VOCs, SVOCs (including PAHs), PCBs, Inorganics
Surface Water	VOCs and Inorganics
Groundwater	TPH, VOCs, SVOCs, PCBs, Inorganics, Alcohols

In addition to environmental sampling for chemical constituents, YAEC conducted regular radiological monitoring for personnel protection, waste classification and disposal, as well as a Radiological Environmental Monitoring Program (REMP) to evaluate possible environmental impacts. The REMP program, which was initiated in 1961, included samples of soil, vegetation, water, air, fish, and milk. Methods used to analyze radiological constituents included gross alpha, gross beta, gamma spectroscopy, liquid scintillation, and alpha spectroscopy, depending on the specific media. The historical monitoring data from the YNPS were presented in the Historical Site Assessment (HSA) report.

The radionuclide COPCs identified at the YNPS Site are summarized in Table 2-2. These represent the only radionuclides expected to be present in any area of the Site due to plant operations (*i.e.*, are plant-related rather than naturally occurring). The criteria used to determine that a radionuclide is a COPC included:

- whether the radionuclide is a fission product (including activation products);
- whether the radionuclide is present above local background;
- the radionuclide half-life;
- the estimated abundance in the plant waste streams; and
- the relative dose potential.

For instance, a radionuclide with a long half-life was not listed as a COPC if it was never identified in any of the plant's waste streams during operations or in the comprehensive Radiological Environmental Monitoring Program (REMP).

YAEC is currently conducting the Final Status Survey (FSS) to support the LTP under the program defined by the NRC. These FSS data will be used to support the ecological risk assessment for the Site. It should be noted that during the FSS sampling, should radionuclides be detected that are not on the COPC list, their presence will be evaluated in the ECORA. Based on discussions with MADEP uranium (metal) has been added as a COPC, although it is not anticipated to be present above background, and it is not a radionuclide being evaluated in the LTP and FSS.

2.3 Stage I Screening

For a Stage I evaluation, the available data will be evaluated to determine whether plants and/or animals are currently exposed, or could potentially be exposed, to contamination at or from the site. An exposure pathway is the link between a source of a constituent release and a receptor in any medium and by any route. For the aquatic habitats (*e.g.*, Wheeler Brook, Sherman Reservoir), aquatic and benthic organisms could be potentially exposed to constituents in sediment or surface water. For terrestrial habitats, comparison benchmarks for chemicals in soils are published and will be used for the screening.

Any media or area of concern for which all site-related COPCs fall below these Stage I Environmental Screening levels, will not require a subsequent Stage II Environmental Risk Characterization. The Stage I assessment will adopt the MADEP-endorsed area-based screening approach (MADEP, 2006b).

2.3.1 Chemical Constituents

Criteria that will be considered for Stage I screening include, but are not limited to the following published sources:

Surface Water:

- National Recommended Water Quality Criteria - Ambient Water Quality Criteria (USEPA, 2002)
- Tier II Great Lakes Water Quality Initiative values (Suter and Tsao, 1996)

Sediment:

- NOAA Effects Range - low/Effects Range - median: ER-L/ER-M (Long et al. 1995; Smith et al. 1996)
- The Environmental Residue-Effects Database (ERED), 2003. U.S. Army Corps of Engineers, Dredging Operations Technical Support (DOTS) Program (USACE, 2003)
- Assessment and Remediation of Contaminated Sediments (ARCS) Sediment Effects Concentrations (Jones *et al.*, 1997)
- Ontario Ministry of Environment (MOE) Freshwater Sediment Values (Persaud *et al.*, 1993)
- Equilibrium Partitioning (EqP) Sediment Benchmark Values (Jones *et al.*, 1997)
- Consensus-Based Sediment Quality Guidelines (SQGs) developed by MacDonald *et al*. (2000)
- MADEP Technical Updates to Section 9 of the MCP Environmental Risk Characterization (MADEP, 2006a, b, c)[4]

Terrestrial/Soil:

- Toxicological benchmarks for screening potential constituents of concern for effects on soil and litter invertebrates and heterotrophic process (Efroymson *et al*., 1997a)
- Toxicological benchmarks for screening potential constituents of concern for effects on terrestrial plants (Efroymson *et al*., 1997b)
- Soil screening guidance (USEPA, 2000).

2.3.2 Radiological Constituents

[4] The MADEP sediment screening benchmarks adopt the MacDonald *et al*. (2000) consensus SQGs

The MCP does not specifically address requirements and procedures for addressing environmental risks due to radionuclides. An approach developed by the U.S. Department of Energy (USDOE), one that shares a common framework with the chemical assessment, will be used for this assessment.

Guidelines to protect humans from the harmful effects of radiation are generally considered adequate to protect ecological organisms. There may be scenarios where human-based guidelines do not address environmental/ecological conditions and pathways (USDOE, 2002). For example, scenarios that limit human access to contact with contaminated areas may not restrict ecological receptors. Animals and plants may encounter contaminants due to exposure pathways that are not considered in human assessments. In addition, an evaluation of rare and endangered species, or other unique ecological considerations for the plant or animal populations may not be captured by evaluations of human health (USDOE, 2002). For these reasons, an environmental assessment for radionuclides will be conducted at the YNPS.

The ecological risk assessment for radiological COPCs adopts an approach analogous to the assessment for chemical COPCs. The approach adopts a 2-stage process that is based on the "graded approach" defined by USDOE (2002). The first step is a comparison of the maximum measured concentration for each radionuclide COPC in environmental media to the radionuclide-specific biota concentration guidelines (BCG).[5] The radionuclide results for surface soil and sediment will be screened against soil and sediment biota concentrations guides (BCGs) from the current U.S. Department of Energy (USDOE) Biota Dose Assessment Committee (BDAC) A Graded Approach for Evaluating Radiation Doses to Aquatic and Terrestrial Biota (USDOE, 2002). These BCGs are now available in the RESRAD-BIOTA web-based model, and RESRAD-BIOTA will be used as the source of BCGs.[6]

The intent of the graded approach is to protect populations of aquatic and terrestrial animals, and terrestrial plants from the effects of exposure to ionizing radiation. Because certain ecological receptors are more sensitive to ionizing radiation than others, it is generally assumed that protecting the more sensitive receptor will adequately protect other less sensitive individuals. Thus, receptors should be selected that:

- are important to the structure and function of the community,

[5] The BCGs are analogous to soil screening levels (SSLs)
[6] Available at: http://homer.ornl.gov/oepa/public/bdac/

- are expected to receive a comparatively high degree of exposure; and
- have a comparatively high degree of radiosensitivity (*e.g.*, radiation effects occur at relatively low doses in comparison with other receptors in the same community).

USDOE's graded approach consists of a step-wise process that is designed to proceed from an initial conservative screening to, if needed, a more rigorous analysis using site-specific information. The process, which is similar to the two-stage process for chemical risk assessment, is summarized below (USDOE, 2002).

(1) Data Assembly
Knowledge of sources, receptors, and routes of exposures for the area to be evaluated. Measured radionuclide concentrations in water, sediment, and soil are assembled for subsequent screening.
(2) General Screening
Maximum measured radionuclide concentrations in environmental media are compared with a set of Biota Concentration Guides (BCGs). Each radionuclide-specific BCG represents the limiting radionuclide concentration in an environmental medium that should not result in exceedance of recommended dose standards.
(3) Site-Specific Analysis
This phase consist of three increasingly more detailed steps of analysis: *(a) Site-specific Screening*: Uses more realistic site-representative lumped parameters (*e.g.*, bioaccumulation factors) in place of conservative default parameters. Use of mean radionuclide concentrations in place of maximum values, taking into account time dependence and spatial extent of accumulation, may be considered. *(b) Site-specific Analysis:* Uses a modeling tool that incorporates multiple parameters representing contributions to the organism's internal dose (*e.g.*, body mass, consumption rate of food/soil, inhalation rate, lifespan, biological elimination rates) that represent site and organism-specific characteristics. The model employs allometric equations relating body mass to these internal dose parameters. *(c) Biota Dose Assessment*: Involves an actual site-specific biota dose assessment using collected and analysis of biota samples. The dose assessment would involve a problem formulation, analysis, and risk characterization protocol consistent with the ecological risk assessment methodology.

Soil, sediment, and surface water BCGs have been derived for aquatic and riparian plants and animals based on exposure to radionuclides in soil, sediment, surface water; also accounting for dietary intake of radionuclides. A BCG represents the limiting radionuclide concentration in soil, sediment, or surface water that is conservatively estimated such that the corresponding dose to the plant or animal receptor exactly equals the "allowable dose.".

The general equation for calculating the BCG is given by (USDOE, 2002):

$$BCG \quad = \quad \frac{Dose_{limit}}{AF \times \left(UF \times DCF_{int} + DCF_{ext}\right)} \qquad (2\text{-}1)$$

where

BCG	=	Biota concentration guideline (pCi/g) soil/sediment, or (pCi/L) water
$Dose_{limit}$	=	Acceptable dose (0.1 rad/day terrestrial animals; 1 rad/day aquatic animals and terrestrial plants)
DCF_{int}	=	Dose conversion factor for internal radiation (rad/day)/(pCi/g)
DCF_{ext}	=	Dose conversion factor for external radiation (rad/day)/(pCi/g) for soil/sediment, or (rad/day)/(pCi/L) for water
UF	=	Media to biota empirical uptake factor (pCi/g-biota)/(pCi/g-media) for soil/sediment, or (pCi/g-biota)/(pCi/L-media) for water – accounts for dietary intake
AF	=	Area correction factor to account for biota habitat/foraging area and residence time (default set to 1.0 for screening level BCGs)

Note that the default screening BCGs assume 100% absorption for radionuclides and also do not correct for the foraging area relative to the size of the impacted habitat for the receptors (*e.g.*, default AF = 1.0). Both assumptions lead to a conservative estimate of the BCG.

For the Stage I screening, exposure concentrations of radionuclide COPCs in surface soil, sediment, and surface water will be compared to the corresponding plant and animal BCGs using a sum of fractions approach. The sum of fractions is similar to summing hazard quotients for multiple compounds, where the hazard quotient is the ratio of the measured radionuclide concentration in either soil, sediment, or surface water to its corresponding BCG. The sum of these "fractions" across all radionuclides is the "sum of fractions." When the sum of fractions is less than 1.0, then the screening indicates that the total radiation dose from all radionuclides is below the acceptable level. The radionuclide COPCs and the corresponding BCGs (where available) for plants and wildlife exposed to radionuclides in surface soil and sediment are presented in Table 2-2.

If the initial conservative screening against BCGs indicates no unacceptable risk in an exposure area, no additional analysis will be performed. If any radionuclide COPC exceeds the corresponding BCG, or the sum of fractions is above 1.0, a more detailed analysis will be conducted. This second stage is a site-specific evaluation of radionuclide doses in ecological receptors using site-representative parameters (*e.g.*, bioaccumulation factors, receptor species, foraging ranges, *etc.*) in place of default parameters and mean radionuclide concentrations in place of maximum values. The time dependence and spatial extent of accumulation (a correction factor for the receptor residence time) will also be considered.

Based on a comparison of the radionuclide DCGLs (to protect human health) and BCGs (Table 2-2), the need for a site-specific ecological analysis (or "Stage II") that models site and organism-specific characteristics is not anticipated. In order to achieve NRC and MADPH dose limits, soils will be remediated as necessary to achieve the DCGLs. As summarized in Table 3-2, the BCGs for ecological risk protection are much higher (less restrictive) than the corresponding DCGLs for human health protection. Thus, it is anticipated that protection of human health will lead to more restrictive remediation requirements for radionuclides as compared to ecological endpoints.

3 Stage II Environmental Risk Characterization

A Stage II Environmental Risk Characterization is a quantitative, site-specific characterization of hazard to ecological receptors. The approach used in performing the Stage II Environmental Risk Characterization consists of a process by which measured or estimated concentrations or doses of constituents in environmental samples are compared to criteria considered protective of ecological receptors. Thus, the Stage II assessment will evaluate whether the constituent concentrations at the Site pose a threat to ecological receptors. For those media or areas of concern that exceed Stage I screening level benchmarks, if any, the Stage II risk characterization process will develop a more detailed site-specific environmental risk characterization that will identify:

- species-specific exposure pathways and constituent exposure concentrations, and
- likelihood of adverse effects to individuals and populations in the environment.

The methods and assumptions that will be used in this evaluation are intended to identify possible hazards and are designed so that potential risks to ecological receptors are not underestimated. The discussion below follows the four steps for a Stage II environmental risk characterization.

3.1 Problem Formulation

The first step of a quantitative Stage II evaluation is the Problem Formulation. The outcome of this step is the selection of assessment endpoints (*e.g.*, endpoints that address biological stress or potential harm) that are subsequently quantified in the risk characterization through specific measurement endpoints (*e.g.*, specific quantitative measures that relate chemical concentration or intake to possible biological harm). The Problem Formulation step includes the following components:

- an ecological assessment/natural resource inventory of local ecological habitats and communities;[7]
- identification of chemicals of potential concern (COPCs) and their fate and transport characteristics;
- identification of exposure pathways and receptors of concern; and
- definition and selection of ecological assessment and measurement endpoints.

[7] YAEC has conducted this natural resource inventory (Woodlot, 2004).

Using information developed from these components of the analysis, the conceptual site model (CSM) presented in Figure 3-1 was developed to guide the site-specific environmental assessments. The CSM represents pathways by which constituents move through the environment to potential exposure points and through the food web to higher trophic level consumers. In addition to providing a basis for identifying key receptors, the conceptual model also provides a reference point for selecting measurement methods that can be used to evaluate the effects of possible concern.

3.1.1 Ecological Habitats

The Site is located along the eastern shore of the Deerfield River adjacent to Sherman Dam, one of several dams along the Deerfield River used for hydroelectric power generation (see Figure 3-2). Yankee Atomic Electric Company (YAEC) owns YNPS and the surrounding lands. The Site is divided into the two following parcels, separated by the Deerfield River.

- Rowe Parcel – Approximately 1,648 acres located in the northwest corner of Rowe, Massachusetts, to the east of the Deerfield River. The former nuclear plant itself occupied approximately 12 of the 1,648 acres of the Rowe Parcel.
- Monroe Parcel – Approximately 89 acres located in Monroe, Massachusetts, to the west of the Deerfield River.

In 2003, Woodlot Associates conducted a Natural Resource Inventory of the Site. The inventory identified vegetation composition and habitats (*e.g.*, wetland, upland forest), characterized wildlife habitat (*e.g.*, availability of foraging and nestling habitat), identified the presence of wildlife species and endangered species (based on available habitat), and assessed forest health and value (Woodlot, 2004). The natural resource survey is the basis for establishing site habitat conditions to be evaluated in the environmental risk assessment.

3.1.1.1 Observed Habitats and Species

The Site consists of an assemblage of upland terrestrial areas, freshwater wetland areas, and lotic ("flowing") and lentic ("still") water bodies (Woodlot, 2004). The former nuclear plant is surrounded predominantly by forest. Along the eastern shore of the Deerfield River, the forest is primarily a hardwood community of high density. Trees are typically 40-60 feet tall with approximately 80-100 percent crown closure. To the west of the Deerfield River, the forest is comprised of mixed hardwoods and softwoods 40-60 feet tall with approximately 80-100 percent crown closure. South of the former nuclear plant, the forest is predominantly hardwoods, trees measuring 20-40 feet in height with greater than 80 percent crown closure.

The former nuclear plant is adjacent to two prominent water bodies, Deerfield River and Sherman Reservoir, both Class B water bodies. These surface water bodies provide a habitat for fish, other aquatic life, and wildlife, as well as a place for recreational activities (ERM, 2004a). Three perennial streams appear on the USGS topographic map on the Rowe parcel: Wheeler Brook, Shippee Brook, and Lord Brook (see Figure 3-2). These streams are typically steep and very rocky. Cobbles and boulders are typical substrates on moderate to steep hillsides and finer mineral substrates, such as gravel and coarse sand occur amid boulder and cobble where gradients are less steep. A number of intermittent stream channels also occur across the property. These streams occur in topographic settings similar to perennial streams, and consequently, have similar substrates. However, because these stream channels do not contain water during parts of the year, substrates are often covered by mosses and upland vegetation occasionally grows within them (Woodlot, 2004).

In addition to natural stream channels, the YNPS has a storm drainage system that carries runoff from the Site. This system consists of a series of catch basins connected by buried pipe, which is divided into east and west drainage systems. The outlet for the East Storm Drain (ESD) empties into Sherman Reservoir. The West Storm Drain (WSD) outlet empties into the unnamed tributary which in turn flows into the Deerfield River downstream of Sherman Reservoir (see Figure 3-3). Both discharges are episodic in nature and the WSD frequently has a low flow water regime (often no water) during parts of the year.

The Site fauna was found to be dominated by aquatic and terrestrial invertebrates, birds, mammals, reptiles, and amphibians, which use the on-Site habitat for cover, feeding, nesting and a migratory stopover point (Woodlot, 2004). In the aquatic habitats of Sherman Reservoir, freshwater fish species such as Yellow Perch (*Perca flavescens*), White Sucker (*Catostomus commersoni*), Brown Bullheads (*Ameiurus nebulosus*), Chain Pickerels (*Esox niger*), Fallfish and Rock Bass (*Ambloplites rupestris*) were observed (Woodlot, 2004). Numerous avian species (terrestrial and semi aquatic, as well as migratory and residential) observed on the Site include Canada goose (*Branta canadensis*), Mallard (*Anas plyrhynchos*), Red-tailed hawk (*Buteo jamaicensis*), Downy woodpecker (*Picoides pubescens*), and Eastern kingbird (*Tyrranus tyrranus*). Observed mammalian species include Snowshoe hare (*Lepus americanus*), Beaver (*Castor canadensis*), Red fox (*Vulpes vulpes*), and Coyote (*Canis latrans*). Reptiles and amphibians include, but are not limited to Common Snapping Turtle (*Chelydra serpentina*), Painted Turtle (*Chrysemys picta*), Northern Redbelly Snake (*Storeria occipitomaculata*), Eastern Garter Snake

(*Thamnophis sirtalis*), Red-spotted Newt (*Notophthalmus virdiescens*), Northern Redback Salamander (*Plethodon cinereus*), and Green frog (*Rana clamitans*) (Woodlot, 2004). A complete list of 210 species observed and expected to occur on site based on a complete ecological habitat assessment is presented in the YNPS National Resources Inventory and Management Plan (Woodlot, 2004).

3.1.1.2 Threatened and Endangered Species and Species of Special Concern

Portions of the Site are mapped as "Priority Habitats of Rare and/or Endangered Species" under the National Heritage and Endangered Species Program (NHESP) based on the presence of habitat for the American Bald Eagle (*Haliaeetus leucocephalus*) (Woodlot, 2004). Suitable nesting, feeding and roosting habitats for bald eagles are identified along the Sherman Reservoir, however none are presently known to be used (Woodlot, 2004). Field personnel discovered a northern spring salamander (*Gyrinophilus porphyriticus*), an NHESP species of special concern. One late-stage larva was observed in the headwaters of Wheeler Brook located on the northwestern border of the Site approximately 5,000 feet from the former nuclear plant (Woodlot, 2004). Bristly black currant (*Ribes lacustre*), an NHESP species of special concern, was found outside the fence line of the former plant footprint (Woodlot, 2004). It was observed in a wet drainage area located along the Wheeler Brook Divertment, just southeast of the former nuclear plant. These areas of interest are identified in Figure 3-2.

3.1.1.3 Study Areas

Given the large area of the YNPS Site, it is divided into the following terrestrial and aquatic study areas (see Figures 3-2 and 3-3).

Terrestrial Habitats

- **Former Industrial Area (FIA)** – This terrestrial habitat is located adjacent to Sherman Reservoir and is approximately 17 acres. The FIA includes 12-acres of the industrial footprint of the former nuclear plant, Furlon House, Furlon House Parking Area, ABC Parking Area and the 4-acre fenced Independent Spent Fuel Storage Installation (ISFSI). This area has limited habitat for terrestrial wildlife, only available to small mammals, birds, small burrowing mammals, and terrestrial invertebrates with high tolerance for human contact due to the fence and highly trafficked area. After site restoration is complete, the human activity will decrease dramatically and likely be limited to continuous security of the fenced ISFSI. As part of the final site restoration/grading plan, a 3-foot overburden will be in place in the former industrial area, further limiting contact with remediated areas.
- **Non-Impacted Area (NIA)** – The majority of the remaining 1,648 acres surrounding the Former Industrial Area of the Rowe Parcel, consists of Northern Hardwoods Hemlock

and White Pine Forest. The characteristic steep terrain of this area limits the development of wetland and aquatic communities. This undeveloped woodlands area is not anticipated to be impacted by historical plant operations. The ASTM Phase I Investigation (ERM, 2005a) indicates no evidence of waste disposal or other industrial impacts in this area.

- **West Storm Drain (WSD)** – The WSD is an intermittent drainage channel that receives stormwater runoff from parking areas and a portion of the Former Industrial Area during storm events. The WSD starts at the western portion of the Former Industrial Area, and flows under the paved access road and into the Deerfield River, south of Sherman Reservoir. This ECORA considers the WSD primarily as a terrestrial habitat due to the low flow water regime (often no water) during parts of the year and limited aquatic ecological habitat (it is a very narrow ditch, only several feet wide in most areas). In addition, as part of the decommissioning and site restoration process, much of the stormwater collection system in the current 12-acre plant Site footprint has been or will be removed or sealed, thereby likely further reducing runoff flows in the WSD. In Fall 2004, sediment/soil with PCB concentrations above 1 mg/kg was removed from the WSD (ERM, 2004b).

Aquatic Habitats

- **Deerfield River** – The Deerfield River starts in Vermont and travels through the northwestern portion of Massachusetts. The river abuts the Site along its eastern shore for over a mile. The river flows rapidly immediately downstream of the Sherman Reservoir and then flows moderately to the Monroe Bridge Dam.
- **Sherman Reservoir** – Several lakes and ponds are a part of Deerfield River, most of which are created or enlarged by dams. One such impoundment area is Sherman Reservoir. Sherman Reservoir, the impoundment behind the dam, was used as the source of circulating water during plant operation. The reservoir is about 2 miles long, a quarter mile wide, and up to 75 feet deep along its central channel with steep, heavily forested shorelines. Sediment remediation for PCBs in the vicinity of the ESD outfall was completed in 2004 (ERM, 2004b).
- **Wheeler Brook** – Wheeler Brook and associated wetlands, is a perennial stream that transects the northwestern corner of the YNPS Site and flows into Sherman Reservoir, directly north of the Former Industrial Area. This perennial brook may dry up or reduce in size during the dry season, making it an ill-suited habitat for fish. The Wheeler Brook Divertment was constructed by YAEC in 1980 to divert stormwater/surface water from uplands, around the Industrial Area and into Wheeler Brook (ERM, 2004a).

The Monroe Parcel will not be evaluated in the ecological risk assessment. As confirmed in the ASTM Phase I Investigation, historical activities from the former nuclear plant are not expected to have impacted this area (ERM, 2005a).

In addition, the smaller perennial and intermittent streams in the Rowe Parcel (Shippee Brook, Lord Brook, and smaller unnamed streams and tributaries of these two brooks) will not be evaluated in the risk assessment. These streambeds are covered with mosses and upland vegetation, due to the intermittent water flow throughout the year. As shown on Figure 3-2, these streams do not intersect the former industrial area and are not expected to be a part of Site's fate and transport pathway.

3.1.2 Current and Future Conditions Affecting Fate and Transport Characteristics of COPCs

The ECORA will evaluate Site conditions as they will exist after the demolition of the YNPS power plant (nearly complete) and restoration of the industrial area. Under these foreseeable future Site conditions, it is expected that with the exception of the ISFSI, the YAEC property remain in its current state of undeveloped woodlands, essentially similar to present conditions (of course without the power plant). The Site restoration plan calls for up to 3 feet of grading over the former industrial areas of the Site, re-vegetation of the Site, and a surface water drainage plan. With the exception of possible direct radiation exposure from residual radionuclides beneath the overburden (a pathway that will be evaluated), the 3-feet of graded material/overburden will effectively eliminate ecological exposures in this area (*e.g.*, surface contact would be eliminated and burrowing deeper than 3-feet is unlikely). Thus, the ecological risk assessment will evaluate exposure to COPCs in soil based on shallow (1-3 feet) data collected from those areas of the Site beyond the former industrial area, as well as possible direct radiation exposure for residual radionuclides beneath the up to 3-foot graded area.[8]

With the demolition and removal of plant structures, the reduction in impervious services will return the Site to conditions that are more "natural" and reduce surface runoff. Furthermore, as part of the decommissioning and site restoration process, much of the stormwater collection system in the current 12-acre plant Site footprint has been or will be removed or sealed (the stormwater drainage will remain in place for the ISFSI area), thereby likely reducing the runoff from this engineered migration pathway from the plant Site to Sherman Reservoir and the Deerfield River.

The current and future remediation activities as necessary (*e.g.*, to achieve PCB, chemical, and radionuclide cleanup goals) are designed to either remove contamination or reduce potential for contact and/or future migration.

Historically, surface water runoff resulted in migration of PCB-containing paint chips from the Site through the storm drain system, depositing paint chips and sediment in areas of the Sherman

[8] If cover depths are adjusted based on agreements with MADEP, the exposure will be assessed based on actual graded overburden depths.

Reservoir and WSD. To date, PCB remediation has included road sand removal, catch basin maintenance and sediment removal, exterior building paint characterization and abatement, and a building inspection-monitoring program. In addition, sediments in Sherman Reservoir near the ESD outfall have been dredged. Soil/sediment up to a depth of 2 feet was removed along 500 linear feet of the WSD ditch from the outfall to the culvert (ERM, 2004b).

Planned future remediation activities will remove residual PCBs in soil and radionuclides to achieve NRC and MADPH guidelines. Upon completion of the remedial activities, the portions of the former industrial area will receive up to 3-feet of grading material. The completed and planned remediation activities are expected to eliminate future migration *via* the surface runoff pathway.

3.1.3 Exposure Pathways

An exposure pathway is the link between a source of a constituent release and a receptor *via* a particular environmental medium and route of contact or intake. Thus, an exposure pathway defines the mode of COPC transport from the source of contamination to the point of intake by receptors, whereas an exposure route refers to the methods by which COPCs enter the body of the receptor. For an exposure pathway to be complete, a constituent must be able to migrate from the source to ecological receptors and be taken up by the receptors *via* one or more exposure routes (*e.g.*, ingestion, direct contact, inhalation, *etc.*). The food web diagrams (Figure 3-4) illustrate the potential exposure pathways and exposure routes of possible concern for aquatic and terrestrial receptors at the Site. For chemical and radiological COPCs, the potential exposure routes to be evaluated for ecological receptors at the Site will be the following:

- ingestion of COPCs in soil, sediment, or surface water
- transfer of COPCs into plant or prey items that are subsequently ingested
- direct contact with COPCs in soil, sediment, or surface water
- direct radiation exposure (radionuclide COPCs)

As depicted in Figure 3-4, the environmental media of concern for the terrestrial higher vertebrate receptors will be surface soils through the ingestion of prey items and incidental soil ingestion. These terrestrial prey items are exposed through direct contact and uptake from soils. The exposure pathways of concern for the freshwater ponds/wetlands receptors are exposure through the direct contact of aquatic life with COPCs in surface water and sediments. Higher semi-aquatic vertebrate species are primarily exposed through the ingestion of sediment-exposed prey and incidental ingestion of soils or sediments. Contact with groundwater will be evaluated through the surface water pathway. Incidental ingestion of surface water by higher order receptors is not considered a significant pathway relative to other pathways of exposure. Additionally, data are not available in the literature for an estimate of daily incidental consumption of this environmental media. The surface water ingestion pathway for higher vertebrate species is expected to be minimal due to the limited number of COPCs observed in surface water. Incidental ingestion of sediment and surface soils will be evaluated for higher trophic level vertebrate receptors.

3.1.4 Ecological Endpoints

Environmental risk characterization guidance distinguishes between two types of ecological endpoints: assessment and measurement endpoints (MADEP, 1996). Assessment endpoints are defined as the environmental attributes upon which the ecological risk assessment focuses, whereas measurement endpoints are defined as the measurable, observable changes used to estimate whether adverse impacts as defined by the assessment endpoints might exist. Selection of appropriate endpoint receptors that specifically address the assessment endpoint is key such that the endpoint receptors evaluated must be amenable to the measurement endpoints (*i.e.*, easily testable or measurable).

Assessment Endpoints

Potential adverse effects on the reproductive success, growth, or survival of receptor species will be used as assessment endpoints for this evaluation. As outlined in MADEP guidance (MADEP, 1996), the following five key characteristics define assessment endpoints.

- **Operational definition**, which provides direction for testing or modeling;
- **Accessibility to prediction and measurement**, which means that the response of an endpoint can be measured or estimated reliably from field measurements and/or modeling;
- **Susceptibility to the constituent of concern**, which addresses the potential for exposure and responsiveness to the exposure;
- **Biological relevance**, which is a measure of the importance of the endpoint to a higher level of the biological system; and
- **Relevance to program objectives**, which means that the endpoint either must be valued by the decision-maker and the public, or be linked to an effect that is valued.

The assessment endpoints for the environmental characterization focus on the following fundamental indicators of ecological health/viability with respect to chemical stressors.

- Avoid or minimize habitat impairment in order to maintain natural diversity, nutrient cycling and trophic structure of biological communities.
- Avoid or minimize conditions that adversely impact growth, survival and reproductive success.
- Avoid or minimize bioaccumulative concerns whereby constituents in environmental media and food sources could accumulate through the food web and adversely impact "higher order" consumers.

Representative Food Web (Receptors)

The ECORA process acknowledges that it is neither technically feasible nor practical to assess risk to every potential environmental receptor in an exposure pathway. The MCP guidance requires the selection of representative receptor species to represent a trophic level or functional group for assessing local food chain effects. This selection process was used to develop and refine a simple conceptual food web, which incorporates a variety of ecological receptors deemed representative of ecology of the YNPS and the surrounding Site. The conceptual food model considers the following:

- ecological receptors common to or expected to occur on site;
- a simple food web applicable to the habitats observed on site;
- key endpoint receptors in the food web that may have the potential to bioaccumulate/ bioconcentrate contaminants through contact with abiotic media or consumption of contaminated biota;
- selection of species whose life history and ecology are documented in the scientific literature; and
- a basis for empirically determining potential threats to key trophic level receptors based upon the scientific literature, and fate and transport characteristics for contaminants of concern.

The trophic levels included in the assessment endpoints are: producers (plants), benthic and terrestrial invertebrates, primary consumers (fish and amphibians), insectivores (mammal and bird), an omnivore (mammal), piscivores (mammal and birds), carnivore (mammal), and a herbivore (mammal). Figure 3-4 presents the conceptual food web and representative species for each functional group identified for the YNPS Site ECORA. The ECORA will evaluate the selected communities and representative wildlife species listed in Table 3-3.

Ecological receptors to be evaluated in the ECORA include representative terrestrial/aquatic plants, benthic macroinvertebrates, soil invertebrates, birds, mammals, amphibians and fish. Each receptor was chosen based on its diet, suitability of the habitats found on the Site, and the bioaccumulating characteristics of PCBs, a COPC of concern. The following is a list of species and communities selected for evaluation in the ECORA.

Benthic Macroinvertebrates

- Benthic marcroinvertebrates are the principal faunal assemblage present in freshwater aquatic and wetland sediments. They represent a major dietary component for fish populations in the aquatic food chain.

Freshwater Fish

- Freshwater fish represent the most diverse group of vertebrates present in the aquatic food chain. Fish are sensitive to degradation of their habitat (*i.e.*, disappearance of a food source) and may have difficulty adapting to new environmental conditions. Multiple trophic guilds comprising insectivorous, omnivorous and carnivorous species are represented in typical warm water fish communities.

Avian Species

- Belted kingfisher (*Megaceryle alcyon*) – This representative piscivorous species lives and feeds in most freshwater bodies. It primarily feeds on fish, but other aquatic prey such as amphibians, crustaceans, and aquatic animals may also be consumed. This species is selected for its small home range and primary fish diet. This species is expected to breed in moderate numbers at the site (Woodlot, 2004).
- Bald eagle (*Haliaeetus leucocephalus*) – Suitable nesting and roosting habits for this Federally threatened and Massachusetts endangered species are identified along Sherman Reservoir, however none are presently known to be used. Although this migratory species was not observed at the Site, this piscivorous raptor species is selected for its endangered species status, large home range and primary fish diet.
- American robin (*Turdus migratorius*) – This representative insectivorous species lives in upland areas and primarily feeds on terrestrial insects, soil anthropoids and worms. This abundant species is frequently observed at the Site (Woodlot, 2004).

Mammalian Species

- Mink (*Mustela vison*) – This representative piscivorous mammalian species is found in most areas near water. They primarily feed on fish and aquatic and terrestrial vertebrates. The habitats present at the Site indicate the occurrence of mink at the Site is uncommon. Although this resident species is believed to be present in low numbers, this sensitive species was chosen based on its primary fish diet and due to its sensitivity to PCBs.
- Raccoon (*Procyon lotor*) – This representative omnivore exploits a variety of potential dietary components in and around aquatic environments and woodlands. This resident species is observed in moderate numbers at the aquatic and terrestrial habitats of the Site (Woodlot, 2004).
- Short-tailed shrew (*Blarina brevicauda*) – This representative insectivore feeds on insects, worms, snails and other invertebrates. This burrowing mammal inhabits round, underground nests and maintains underground runaways within the top 10 cm of soil. This resident species is observed in moderate numbers at the Site (Woodlot, 2004).

- Red fox (*Vulpes vulpes*) – This representative carnivorous mammal preys extensively on mice and voles, but also feed on small mammals, insects, hares, game birds and occasionally seeds, berries and fruit. The fox usually inhabits an underground den or abandoned burrows. This resident species is observed in moderate numbers at the Site (Woodlot, 2004).
- Eastern cottontail (*Sylvilagus floridanus*) – This representative herbivore is associated with shrub swamps and upland shrub lands. Their diet consists of trees, shrubs and vines, herbs, grasses, sedges, and rushes. This resident species is common within the habitats of YNPS (Woodlot, 2004).

Amphibian Species

- Field personnel observed a northern spring salamander (*Gyrinophilus porphyriticus*), a state species of concern in the northeastern portion of the Site during the wildlife habitat assessment (Woodlot, 2004). Amphibians are most sensitive during the early developmental life stages (*i.e.* embryo and tadpole). Amphibians will be evaluated using surface-water concentration-based benchmarks.

Terrestrial Plants and Soil Invertebrates

- Terrestrial plants form the basis of the terrestrial food chain and represent a major energy introduction into the terrestrial food web. This group of receptors will be evaluated at the community level using community level benchmarks.
- Soil invertebrates such as earthworms are important receptors responsible for nutrient recycling and composition of organic matter within the detrital food web. This group of receptors will be evaluated at the community level using community level benchmarks.

Exposure parameters for each of the avian and mammalian terrestrial and semi-aquatic species are presented in Table 3-4.

Measurement Endpoints

A measurement endpoint is a measurable response to a constituent that is related to the assessment endpoint. Although the measurement endpoints vary, they are selected in general to be indicative of adverse effects on survival, reproduction, or growth of the endpoint species. As outlined in MADEP guidance (MADEP, 1996), three key characteristics define measurement endpoints:

- **Strength of association** refers to the applicability of the measurement endpoint to the assessment endpoint and the correlation between the results of the measurement and the level of risk.
- **Relatedness to assessment endpoint** refers to the degree to which the collected data are relevant to the assessment endpoint.
- **Ease of measurement** refers to the ability of the study, or measurement, to detect effects of concern.

The relationships between measurement endpoints and assessment endpoints enable the risk assessor to use the results of field observations and literature studies to decide whether impacts are associated with site-specific exposures to COPCs.

Three types of measurement endpoints will be used in this ECORA to assess chemical risks: benchmark approach, toxicity quotient method and the tissue residue analysis. The benchmark approach involves comparing water, sediment or tissue concentrations with screening levels identified in the literature. These benchmarks are protective of specific receptors (*i.e.*, terrestrial plants, fish, amphibians, soil invertebrates) exposed to environmental media. The toxicity quotient method characterizes risk by calculating the ratio of the COPC intake from the Site exposure to toxicity reference values obtained from the literature with known endpoints. Tissue residue analysis, which is often the method used to evaluate risk for fish species, involves analyzing fish samples to determine whether the contaminants of concern have accumulated in the organism. Due to the bioaccumulative nature of PCBs, fish were collected and sampled for PCBs. This measure of exposure is then combined with available data on toxic effects, in order to assess the potential for ecological risk associated with that degree of bioaccumulation or exposure (MADEP, 1996). A summary of the types of measurement endpoints that will be used in the ECORA is given below.

Assessment Endpoint (Receptor Group)	**Measurement Endpoint**
Benthic Invertebrates	• Compare COPC concentrations in the sediment of Sherman Reservoir, Deerfield River, and Wheeler Brook to sediment benchmarks in McDonald *et al*. (2000).
Fish	• Compare surface water quality data for COPCs to toxicity reference values for fish survival (Suter and Tsao, 1996; and USEPA, 2002). • Compare PCB body burden concentrations of collected fish tissues to toxicity reference values relating effects to tissue-based concentrations (Jarvinen and Ankley, 1999). • Compare COPC uptake from environmental media to toxicity reference values relating effects to tissue-based concentrations (Jarvinen and Ankley, 1999).
Mammals and Birds	• Estimate COPC uptake from environmental media and food. • Compare COPC uptake to representative toxicity reference values.
Amphibians	• Compare surface water quality data for COPCs to toxicity reference values (where available) for amphibian survival (USEPA, 1996).
Terrestrial Plants and Soil Invertebrates	• Compare COPC concentrations in soil of terrestrial habitats present at the Site to ecological benchmarks present in Efroymson *et al*. (1997a, b).

Radionuclide dose endpoints will be determined according to the USDOE (2002) guidelines, which indicate that the overall absorbed dose from exposure to radiation or radioactive materials for aquatic animals and terrestrial plants should not exceed 1 rad/day, and the absorbed dose for terrestrial and riparian animals should not exceed 0.1 rad/day (see Section 3.3.2).

3.2 Exposure Assessment

In the exposure assessment step, the assessment endpoints will be evaluated using the measurement endpoints. This step will involve the collection and integration of information on constituent concentrations found at the Site (*i.e.*, former industrial area, Sherman Reservoir, Wheeler Brook) and exposure conditions. The exposure assessment will identify:

- exposure pathways defining exposure media where constituent transfers/uptake is possible;
- routes of constituent exposure such as direct contact, ingestion, *etc.;* and
- constituent concentrations in environmental media and estimated constituent intakes as needed.

The conceptual site model outlining the exposure pathways and exposure routes is shown in Figure 3-1. Specific receptors selected for the ECORA are identified in Table 3-1. In general, aquatic organisms may be exposed to COPCs in sediment and surface water *via* direct contact and/or assimilation of sediment-sorbed constituents and dissolved or suspended constituents in the water column. Both invertebrates and vertebrates such as fish or amphibians in direct contact with water or sediment may also serve as contaminant vectors for indirect exposure to higher trophic level consumers.

Semi-aquatic and terrestrial wildlife that forage on either aquatic or terrestrial food sources may be exposed to constituents in sediment/soil and food. Exposure routes to be considered will include dermal contact and ingestion of soil/sediment, water, and ingestion of food and prey items that may have accumulated COPCs. In order to quantify environmental exposures, the COPC concentrations at the point of exposure, or the "exposure point concentrations," must be defined, as described next.

3.2.1 Exposure Point Concentrations

In order to conduct the environmental risk characterization, exposure point concentrations (EPCs) will be estimated in the soil, sediment, surface water, fish, terrestrial and aquatic plants and invertebrates, and small mammals. The following sub-sections present the approach used to quantify EPCs for these media.

3.2.1.1 Soil

Soil sampling efforts have focused on defining the environmental conditions near the former industrial area of the Site. Thus, more samples are available for the industrial area and adjacent locations compared to the non-industrial areas of the Site. Soil samples from the outlying undeveloped/wooded areas (*i.e.*, the majority of the YNPS property) have been collected for radionuclide analysis as reported in the HSA; additional soil samples from these outlying areas will be collected for chemical characterization in support of the Site Closure Plan and will be incorporated into the YNPS database and risk assessment.

Soil data from the environmental site investigations will be used to calculate the average exposure point concentrations of COPCs in soil. Given that any potential impacts from residual chemicals at the Site would likely be greatest in the vicinity of the operational areas, the sampling results from the Site will be used for assessing ecological risks. Shallow soil samples (within the top 1 – 3 feet) will be used to estimate potential exposures for ecological receptors. EPCs will be calculated by averaging concentrations for each constituent, using the detected values and, in cases where the constituent was not detected, using a proxy value equal to one-half the detection limit, per MADEP (1995) guidance. For samples that were collected in a targeted (non-random) manner, a surface weighted average concentration (SWAC) may be adopted. Per discussion with MADEP, the "polygon" SWAC method will be used in such instances.

As noted earlier, the site restoration plan calls for up to 3-feet of grading over the former industrial areas of the Site. With the exception of possible direct radiation exposure from residual radionuclides beneath the overburden (a pathway that will be evaluated), the 3-foot of graded material/overburden will effectively eliminate ecological exposures in this area (*e.g.*, burrowing deeper than 3-feet is unlikely). Thus, the ecological risk assessment will evaluate exposure to COPCs in soil based on shallow (1-3 feet) data collected from those areas of the Site beyond the former industrial area.

3.2.1.2 Sediment

Sediment data from the environmental site investigations will be used to calculate separate average exposure point concentrations of COPCs in sediment for Sherman Reservoir, Deerfield River, Wheeler Brook and the West Storm Drain areas. All sediment samples collected up to one-foot depth will be used to estimate potential exposures to aquatic receptors, excluding sample results remediated for PCBs pursuant to TSCA. As for soils, EPCs will be calculated by averaging concentrations for each constituent, using the detected values and, in cases where the constituent was not detected, using a proxy value equal to one-half the detection limit, per MADEP (1995) guidance.

The sediment samples for PCBs collected in Sherman Reservoir in the vicinity of the East Storm Drain discharge have been collected using a "targeted," or intentionally biased, sampling strategy. That is, a higher density of samples was collected in areas known to have PCBs (as compared to a completely uniform grid). Given this biased sampling approach, the exposure point concentration for sediments will be calculated using a SWAC approach. An area-weighted averaging approach for targeted sampling results is endorsed by MADEP (1995, p. 2-22). A surface weighted averaging approach was adopted in the TSCA RBDAA, which was approved by USEPA.

Based on discussions with MADEP, the SWAC calculation will be performed using a polygon-based approach. In addition, the food web models/equations that will be used to estimate chemical uptake in biological tissues based on the chemical concentration in sediment will use the SWAC values from sediment samples as their inputs.

3.2.1.3 Surface Water

Sherman Reservoir surface water samples collected in 1999 and 2000 show no detectable levels of PCBs. The 2002 YAEC Annual Radiological Environmental Report also shows that radionuclides were not detected in surface water samples from Sherman Reservoir, and "gross-beta" activity, an indicator of hard to detect radionuclides, was consistent with levels upstream in Harriman Reservoir. Thus, the surface water pathway is considered a de minimis (incomplete) pathway for the environmental risk assessment. Results of additional surface water sampling in 2006 are expected to confirm this finding from the earlier sampling. As discussed below, COPC uptake in biota will be estimated based on uptake from sediment and through food.

3.2.1.4 Fish

Fish in Sherman Reservoir have been sampled (in 2002) and analyzed for PCBs in fish filet tissues, and additional samples have been collected in 2006. The EPCs for PCBs in fish will be estimated using these monitoring data, adjusting the filet results (upward) to estimate PCB concentration in "whole body" tissues. The adjustment will simply be based on multiplying the PCB concentration in fish filets by the ratio of the lipid content in whole body tissues, relative to the lipid content in filet tissues.

For PCBs, the estimation of EPCs for fish will be adjusted to account for the removal of PCBs from sediment, which is expected to result in a decline in the PCB concentration in fish. The methods approved by USEPA for the TSCA RBDAA will be adopted in this assessment. The post-remediation PCB concentration in fish tissue will be estimated based on the PCB concentration in fish filets measured prior to sediment remediation, multiplied by the ratio of the post/pre-remediation PCB concentrations in sediment as follows.

$$C_{fish-post} = C_{fish-pre} \times \frac{C_{sed-post}}{C_{sed-pre}} \tag{3-1}$$

where

C_{fish} = concentration of COPC in fish (mg/kg)

C_{sed} = concentration of COPC in sediment (mg/kg)

The notation "pre" and "post" indicate values for pre- and post-remediation conditions, respectively. This approach is equivalent to applying a site-specific biota-sediment accumulation factor (BSAF) as is shown below.

$$BSAF = \frac{C_{fish-pre}}{C_{sed-pre}} \tag{3-2}$$

In order to estimate the post-remediation PCB concentration in fish, the BSAF is multiplied by the post-remediation PCB concentration in sediment:

$$C_{fish\text{-}post} = C_{sed\text{-}post} \times BSAF \tag{3-3}$$

Combining terms from the equations above gives:

$$C_{fish-post} = C_{sed-post} \times \frac{C_{fish-pre}}{C_{sed-pre}}$$

or,

$$C_{fish-post} = C_{fish-pre} \times \frac{C_{sed-post}}{C_{sed-pre}}$$

As noted above, the PCB concentration in whole-body fish tissues will be calculated by multiplying the PCB concentration in fish filet tissues by the ratio of lipid content in whole body tissues and the lipid content of filet tissues:

$$C_{fish-WB} = C_{fish-post} \times \frac{LP_{WB}}{LP_{tissue}} \quad (3\text{-}4)$$

Additional fish sampling performed in 2006 will provide the basis for exposure point concentrations for COPCs in fish other than PCBs, if any. In addition, for any chemical COPCs in sediment for which there are no fish monitoring data, the concentrations of COPCs in fish will be estimated using the equations in Attachment A, which are the methods used for the focused risk assessment supporting the TSCA RBDAA.

As part of the REMP program, fish were collected semiannually by overnight gill netting at two locations. One location (upstream of the plant in Harriman Reservoir) was selected as a "reference," or background, location, and the other location was in the vicinity of the discharge point in Sherman Reservoir to determine the impact, if any, of plant discharges. Edible portions of the collected fish were analyzed for gamma-emitting radionuclides.[9] The only radionuclides detected in fish tissue were naturally-occurring K-40 and Cs-137. The Cs-137, which is a COPC, was detected at concentrations that are consistent with fallout from above-ground nuclear weapons testing (the Cs-137 in Sherman Reservoir fish was similar to the concentration in Harriman fish). Thus, radiological constituents are not present in fish above background concentrations. This conclusion will also be evaluated based on the additional fish sampling that has been performed in 2006.

[9] The radionuclides that are routinely analyzed and reported in a gamma spectroscopy analysis are: Ac/Th-228, Ag-108m, Ag-110m, Ba-140, Be-7, Ce-141, Ce-144, Co-57, Co-58, Co-60, Cr-51, Cs-134, Cs-137, Fe-59, I-131, K-40, La-140, Mn-54, Nb-95, Ru-103, Ru-106, Sb-124, Sb-125, Se-75, Zn-65, and Zr-95.

3.2.1.5 Plants, Invertebrates, and Small Mammals

Constituent concentrations in aquatic or terrestrial forage food items (*i.e.*, plants, macroinvertebrates, small mammals) will be estimated by multiplying the average COPC concentrations in sediment or soil, respectively, by uptake factors published in the scientific literature. Based on the availability of information, one of two types of uptake factors will be used to estimate COPC concentrations in forage food items: (i) linear uptake factors, and (ii) log-linear regression uptake factors.

Because constituent uptake is influenced by characteristics of the organism (*i.e.*, forage food species), separate uptake factors are recommended for each taxonomic group considered (Sample *et al.*, 1997). The linear and log-linear uptake models are summarized in Attachment A (these are the methods used for the focused risk assessment supporting the TSCA RBDAA).

3.2.2 Estimation of Chemical Intake

The environmental characterization will evaluate exposures to COPCs through food and incidental sediment/soil ingestion and direct comparison of media concentrations with published effect levels for ecological receptors. Because many measurement endpoints are based on chemical intake (typically daily intake), it is necessary to estimate the COPC intake based on exposure from environmental media and food sources. Table 3-5 is a list of data sources that will be used for each wildlife assessment endpoint. In general, the daily intake is given by the summation of intakes from all media of potential concern (after Sample *et al*., 1997):

$$\mathbf{DI} = \sum_{\mathbf{i}} \frac{(\mathbf{EPC_i} * \mathbf{IR}_i)}{\mathrm{BW}} \tag{3-5}$$

where:

DI = daily intake of COPC (mg/kg-day)

EPC_i = exposure point concentration in i^{th} media representing soil, sediment, water, food sources, *etc.* (mg/kg)

IR_i = ingestion rate of the i^{th} media, representing soil, sediment, water, food, *etc.* (kg/day)

BW = body weight of organism (kg)

As an example, for receptors that feed on plants, but are also potentially exposed to COPCs in soil/sediment and water, constituent exposures would represent the summation of exposure *via* each pathway:

$$DI = \frac{(EPC_{soil/sed} * IR_{\text{soil/sed}}) + (EPC_{\text{water}} * IR_{\text{water}}) + (EPC_{\text{plant}} * IR_{\text{plant}})}{\text{BW}}$$

where the subscripts "soil/sed", "water", "plant" indicate the respective media concentrations and intake rates. In this same fashion, receptors potentially exposed due to consumption of fish, invertebrates, and terrestrial food sources will be calculated based on combined intakes from each respective route of exposure.

The calculated intake of chemicals (and radiation dose for radionuclides) will take into account the average foraging range for the selected ecological receptors. For species with foraging ranges larger than the area possibly impacted by chemicals (or radionuclides), no chemical or radiological intake would occur when the species forages beyond the YNPS Site. Thus, only a fraction of the dietary intake would contain Site-related constituents. In order to account for this, when calculating exposure (intake), the concentration term will be adjusted based on the area of the Site-related contamination in soil or sediments relative to the typical foraging ranges as follows:

$$EPC_i = \frac{A_{YNPS}}{A_{forage}} C_i \tag{3-6}$$

where

EPC_i	=	Exposure point concentration of constituent in "i^{th}" environmental medium – soil, sediment, diet (mg/kg or pCi/g)
C_i	=	Concentration of constituent in "i^{th}" environmental medium (mg/kg or pCi/g)
A_{YNPS}	=	Area containing residual chemicals or radionuclides (acres)
A_{forage}	=	Foraging range of target species (acres)

The exposure factors defining ingestion rates, animal body weights, and foraging ranges for the identified receptors for the ECORA and summarized in Table 3-4. These exposure factors were obtained primarily from USEPA's Wildlife Exposure Factors Handbook (USEPA, 1993), adopting average or median values when multiple values were reported.

3.2.3 Estimation of Radiological Exposure

As discussed in Section 2.3.2, a Stage II Environmental Risk Characterization is not expected for radiological constituents. This is because the Stage I screening values (BCGs) are well below the DCGLs that YAEC will achieve to support the LTP. However, if a Stage II analysis for radionuclides is required, the methods will adopt the allometric exposure and dose calculation approach described in USDOE (2002), or the simpler calculations described below. The absorbed dose due to internal and external radiation from water and soil/sediment and dietary intake is given by the following (Sample *et al*., 1997; Bechtel/Jacobs, 1998; Blaylock *et al*., 1993):

$$D_{int,i} = 5.11\times10^{-8} \times E_i \times EPC_{diet} \times F_{abs,i} \quad (3\text{-}7a)$$

$$D_{w,i} = 5.11\times10^{-8} \times E_i \times EPC_w \times (1-F_{abs,i}) \quad (3\text{-}7b)$$

$$D_{s,i} = 2.56\times10^{-8} \times E_i \times EPC_s \times (1-\theta) \times (1-F_{abs,i}) \quad (3\text{-}7c)$$

where:

$D_{int,i}$	=	Internal/ingestion dose for alpha, beta, and gamma emissions (rad/day)
$D_{w,i}$	=	External dose from immersion in water (*e.g.*, aquatic species) for alpha, beta, and gamma emissions (rad/day)
$D_{s,i}$	=	External dose from soil/sediment for alpha, beta, and gamma emissions (rad/day)
EPC_{diet}	=	Concentration of constituent in dietary intake (pCi/kg-wet weight)
EPC_w	=	Concentration of constituent in water (pCi/L)
EPC_s	=	Concentration of constituent in soil or sediment (pCi/kg-dry wt)
θ	=	Sediment/soil moisture content (kg-water/kg-solids)
5.11×10^{-8}	=	Unit conversion factor (rad/d per pCi/kg per MeV/nuclear disintegration).[10] The coefficient 5.11 is reduced by 0.5 to 2.56 in Eq. 4-2c for exposure at soil/sediment surface. For subsurface soil/sediment exposure, the 5.11 coefficient is used to account for "immersion" in the medium containing radionuclides.
E_i	=	Average energy of decay -- subscript "i" indicates E_i varies for alpha, beta and/or gamma particles (MeV/disintegration)[11]
$F_{abs,i}$	=	Fraction of absorbed energy based on size of animal -- subscript "i" indicates $F_{abs,i}$ varies for alpha, beta and/or gamma particles. Note that effective dose estimates the energy imparted on the "target" or sensitive organs, which are the internal reproductive organs. For internal dose, F_{abs} is the fraction absorbed by the target organs. For external radiation from water or sediment, F_{abs} is the fraction absorbed by the

[10] Attachment B contains unit conversions needed to derive this conversion factor.

[11] As indicated in the cited references, the average energy of decay represents the combined term in the cited references (E×n) where "n" is the proportion of disintegrations producing an emission of energy "E".

skin/exoskeleton which is therefore not absorbed by the internal target reproductive organs which are considered most sensitive.

The total effective dose equivalent (TEDE), *i.e.*, the absorbed dose, for internal and external radiation sources is simply the sum of the individual dose components, multiplied by a "quality factor" that varies depending on alpha, beta and gamma radiation (indicated by the subscript "i"). Note that alpha particles have very little penetrating energy, and thus they are not included when estimating external dose (USDOE, 2002). As described in USDOE (2002) and Blaylock *et al*. (1993) the quality factor yields an effective dose equivalent that translates dose in rad/day into units of rem/day (similar to the benchmark for human dose comparisons):

$$TEDE = \sum_i \left(D_{\text{int},i} + D_{w,i} + D_{s,i}\right) \times QF_i \qquad (3\text{-}8)$$

where

QF_i = Quality factor to account for relative biological effectiveness of different forms of radiations (default values: 20 for alpha emissions, 1.0 for beta and gamma emissions)[12]

"i" = subscript of summation representing alpha, beta, and gamma emissions

The average concentration of radionuclides in either food, or environmental media (needed for Equation 3-7a,b,c), depends on radionuclide-specific decay rates. Thus, the EPC is not a constant, but rather declines as a function of time according to the following equation:

$$EPC(t) = EPC_o\, e^{-\lambda t} \qquad (3\text{-}9)$$

where

$EPC(t)$ = concentration as a function of time (pCi/kg)

EPC_o = initial concentration at time t=0 (pCi/kg)

λ = $\dfrac{LN(2)}{t_{1/2}}$ is the decay constant (per year)

$t_{1/2}$ = half-life (years)

[12] Quality factors are defaults used for humans in the absence of values for non-human receptors.

The average concentration ($\overline{\text{EPC}}$) over a particular time period (T) is given by integrating the declining concentration over the time period:

$$\begin{aligned}\overline{\text{EPC}} &= \frac{1}{T}\int_0^T \text{EPC}_o e^{-\lambda t}\,dt \\ &= \text{EPC}_0 \frac{(1-e^{-\lambda T})}{T\lambda}\end{aligned} \qquad (3\text{-}10)$$

In addition, as discussed earlier in Section 3.2.2, the exposure to chemicals and radionuclides will depend on the foraging range for aquatic and terrestrial animals. The concentration term in Equation (3-10) will be adjusted for foraging area as described earlier in Equation (3-6).

The decay-adjusted procedures described above will be used to calculate the average exposure point concentrations for radionuclides in environmental media (*e.g.*, water, soil/sediment, and diet) if a Stage II assessment is required. For radionuclides with short half-lives (*e.g.*, shorter than the typical exposure duration of interest), the time-averaged concentration can be appreciably less than the initial concentration. Conversely, for long-lived radionuclides, the adjustment for decay is insignificant.

All of the equations and resulting BCGs contained in the USDOE technical standard have been encoded by USDOE in a series of electronic spreadsheets. The spreadsheets were built using Microsoft Excel and incorporate Visual Basic commands to help guide and automate the progression the biota dose evaluation process. The linked spreadsheets, also known as RAD-BCG Calculator, are described in Module 1 of USDOE's Technical standard (USDOE, 2002). Similarly, the RESRAD model codes also now include a BIOTA module that also uses the USDOE (2002) equations.[13]

If a Stage II ecological assessment is required (*e.g.*, radionuclides exceed Stage I screening values), a site-specific analysis of radionuclide dose will be conducted as described above to calculate site-specific doses for ecological receptors.

[13] Available at: http://homer.ornl.gov/oepa/public/bdac/

3.3 Biological Effects Assessment

3.3.1 Chemical Constituents

The biological effects assessment is the evaluation of adverse effects associated with specific exposure concentrations of COPCs. The toxicological evaluation involves establishing surrogate toxicity benchmarks for each species assessed and for each constituent identified. The toxicity benchmark is a concentration or chemical intake representative of the expected no-observed-adverse-effect-level (NOAEL) or the lowest-observed-adverse-effect-level (LOAEL) for any given receptor and COPC. For the Stage II evaluation, the biological effects assessment will be performed using toxicity criteria derived from data in the scientific literature, including:

- soil benchmark values for plants and soil-dwelling invertebrates (Efroymson *et al.*, 1997a, 1997b);
- sediment benchmark values for benthic invertebrate organisms (MacDonald *et al*., 2000; Jones *et al.*, 1997; Smith et al. 1996; Persaud *et al.*, 1993);
- National Recommended Water Quality Criteria - Ambient Water Quality Criteria (USEPA, 2002);
- Tier II Great Lakes Water Quality Initiative values (Suter and Tsao, 1996);
- Amphibian Toxicity Data for Water Quality Criteria Chemicals (USEPA, 1996); and
- Linkages of effects with tissue residue (Jarvinen and Ankley, 1999).

Values derived from these sources will be used for the benchmark approach as well as the tissue residue analysis.

Toxicity reference values (TRVs) are derived from studies that report either NOAELs or LOAELs. The primarily source of NOAELs and LOAELs for the ECORA is Sample *et al*. (1996). A NOAEL is a concentration or chemical intake that has been determined from laboratory tests not to produce any observable toxicity in the test organism whereas a LOAEL is the lowest chemical intake that has been shown to produce a toxic effect. The MCP recommends evaluating ecological risk using comparisons of chemical exposure to both NOAELs and LOAELs. In cases where multiple NOAEL values are reported for a representative test organism, the highest NOAEL is the recommended benchmark to use, consistent with MCP guidance. In cases where a NOAEL is not available, but a LOAEL is available, a surrogate NOAEL will be estimated from the LOAEL using an uncertainty factor of ten (*e.g.*, the NOAEL is 1/10 the LOAEL) as per MCP guidance. For chemicals which do not have a LOAEL, a surrogate LOAEL will estimated as 3 × NOAEL, per MCP guidance.

Benchmarks will be drawn from studies that considered reproductive and developmental effects or other critical effects indicative of overt impacts to individual organisms that may affect population size. Studies incorporating chronic exposure durations, multiple exposure levels, and statistical evaluation of test results are preferred. As appropriate, NOAEL and LOAEL values will be extrapolated from the published value for the tested organism to the selected receptors using a conversion based on a body size allometric equation discussed below.

In general, smaller sized organisms are more tolerant of constituent exposures because of the higher rate of metabolism and greater detoxification capabilities (smaller size in this case does not refer to life-cycle phases). To account for this source of variation in sensitivity, the published NOAELs and LOAELs will be adjusted to estimate wildlife surrogate toxicity values using the following equation (Sample *et al.,* 1996):

Non-Avian Receptors:

$$TRV = NOAEL_{test} \times (BW_{test}/BW_{wildlife})^{0.25}$$

$$TRV = LOAEL_{test} \times (BW_{test}/BW_{wildlife})^{0.25}$$

where:

$NOAEL_{test}$ = no-observable-adverse-effect level for test species
$LOAEL_{test}$ = lowest-observable-adverse-effect level for test species
Bw_{test} = body weight for test species
$Bw_{wildlife}$ = body weight for wildlife species

Recent research by Mineau *et al.* (1996) suggested that the scaling factors developed for avian receptors for the majority of constituents evaluated (29 of 37 pesticides) were not significantly different from 1. Based on this information, the above equations reduce to:

Avian Receptors:

$$TRV = NOAEL_{test}$$

$$TRV = LOAEL_{test}$$

Thus, an avian wildlife species NOAEL or LOAEL is equivalent to an avian test species NOAEL or LOAEL without any adjustment factor for body weight.

For fish, tissue residue benchmarks from Jarvinen and Ankley (1999) and ERED (2003) will be used as TRVs. TRVs to be used in this ECORA before adjusting for body weight are presented in Tables 3-6 through 3-8.

3.3.2 Radiological Constituents

The USDOE (2002) methods meet the requirements for protection of biota in USDOE Orders 5400.1, "General Environmental Protection Program" 5400.5, and the dose limits for the protection of biota developed or discussed by the NCRP (1991) and the International Atomic Energy Agency (IAEA, 1992). The technical standard uses the biota dose limits specified below within a graded approach to demonstrate that populations of plants and animals are adequately protected from the effects of ionizing radiation (USDOE, 2002):[14]

- Aquatic animals: The absorbed dose should not exceed 1 rad/day (10 mGy/day) from exposure to radiation or radioactive material released into the aquatic environment.
- Terrestrial Plants: The absorbed dose should not exceed 1 rad/day (10 mGy/day) from exposure to radiation or radioactive material released into the terrestrial environment.
- Terrestrial Animals: The absorbed dose should not exceed 0.1 rad/day (1 mGy/day) from exposure to radiation or radioactive material released into the terrestrial environment.

These dose limits represent expected safe levels of exposure and are analogous to No-Adverse-Effects-Levels (NOAELs) for effects on population-relevant attributes in natural populations of biota. Avoiding measurable impairment of reproductive capability is deemed the crucial biological endpoint of concern in establishing the dose limits for aquatic and terrestrial biota. The dose limits should not be interpreted as a bright line that, if exceeded, would trigger a mandatory regulatory or remedial action. Rather they should be interpreted as applied as dose rate guidelines that provide an indication that populations of plants and animals could be impacted from exposure to ionizing radiation and that further investigation and action may be necessary.

[14] See Attachment B for the relationship between an absorbed dose in rad/day and an effective dose in rem/day. Note that on an annual basis (which is the basis for human health dose limits in the license termination plan), these ecological dose targets represent 36.5 to 365 rad/year (1.8 to 18 rem/yr).

3.4 Risk Characterization

In this step, current and potential future risks associated with exposure to chemical constituents to ecological receptors are estimated. Constituent concentrations in environmental media and chemical intake (and radiation dose) will be compared to available toxicity information or benchmark values for biological effects through a hazard quotient method. The ecological risk characterization will identify constituents in environmental media that may pose a potential hazard to ecological receptors.

3.4.1 Chemical Constituents

Risk estimation is the process of comparing exposure concentrations and chemical effects data (USEPA, 1998). A Hazard Quotient (HQ) will be calculated as the measure of possible ecological hazard (MADEP, 1996). A hazard quotient is the ratio of the estimated chemical intake (or exposure concentration) to the toxicity benchmarks (TRVs) discussed above:

$$\mathrm{HQ} = \frac{\text{Chemical Intake (or Concentration)}}{\mathrm{TRV}}$$

Hazard quotients for multiple chemicals will be summed to calculate cumulative hazards for multiple constituents.

The MCP (MADEP, 1996) recognizes the following general considerations for using hazard quotients to characterize risk.

- When the site COPC intake exceeds the LOAEL and the LOAEL-based hazard quotient is greater than one, it is reasonable to conclude that the quotient evaluation method provides evidence of harm.
- When the site COPC intake is lower than the NOAEL and the NOAEL-based hazard quotient is less than one, it is reasonable to conclude that the quotient method does not provide evidence of harm.
- When the site COPC intake is greater than the NOAEL, but less than the LOAEL, no conclusion may be reached based on the predictive method alone, and additional assessment efforts are necessary to determine whether the oil or hazardous material has harmed or may harm the environment.

The risk characterization will address the relative magnitudes of uncertainty from sources, that may over- or under-estimate the risk to ecological receptors based on the type of data used in the hazard quotient method.

3.4.2 Radiological Constituents

In the event radionuclides exceed BCG screening values, a site-specific radiological dose will be calculated, as described in Section 3.2.3. The possible risk or hazard from radiological exposure will be expressed in the form of a Hazard Quotient, analogous to the HQ for chemicals:

$$HQ_{rad} = \frac{TEDE}{Dose_{Limit}}$$

where:

$Dose_{Limit}$ = Target effective dose equivalent (rad/d) – equivalently expressed as a target in rem/day when the TEDE is presented as an effective dose equivalent

TEDE = Total effective dose equivalent (absorbed dose) from internal and external radiation (rad/d)[15]

The absorbed target dose rate limit is 1 rad/d for aquatic organisms and terrestrial plants, and 0.1 rad/d for riparian and terrestrial animals. Internal doses originate from radionuclides inside the organism's body. The internal dose is calculated as the product of the internal radionuclide concentration and internal dose conversion factor. External doses originate from radionuclides external to the organism and are calculated as the product of the radionuclide concentration in the environmental medium in which the organism resides and the corresponding dose conversion factor.

An analogous hazard quotient for radiological constituents when a media BCG is available is simply the ratio of the measured radionuclide concentration in soil to the corresponding BCG:

$$HQ_{rad} = \frac{C_{soil}}{BCG_{soil}}$$

[15] The TEDE dose units are actually in rem/day when the calculated dose rates are multiplied by the "quality factor"

The sum of HQs across all radionuclides is termed the "sum of fractions" and this sum is analogous to the Hazard Index for chemical constituents.

4 Ecological Significance and Uncertainty

The interpretation of the ecological significance in the ecological risk assessment places chemical and radiological hazards in the context of the types and extent of the anticipated effects. It is a link between the estimation of hazards and the communication of the assessment results. Some aspects to be considered in the discussion of the ecological significance include the nature and magnitude of effects, the spatial and temporal pattern of effects, and the potential for recovery once stressor is removed. The degree of confidence in the risk assessment, the rational for any risk management decision, and the options for reducing risks are also considered when interpreting the ecological significance of the risk characterization results.

There are many uncertainties inherent in current risk assessment methodology that may serve to under- or over-estimate potential ecological hazards. The predominant uncertainties in the risk characterization will be discussed when characterizing the potential ecological hazards. Some typical areas of uncertainty encountered in the risk assessment may include:

- adequacy of site characterization;
- quality of analytical data;
- selection of ecological receptors;
- accuracy of modeling and exposure estimates;
- accuracy of the assumption concerning frequency, duration and magnitude of exposures;
- availability and accuracy of toxicity data; and
- large uncertainties pertaining to whether the exceedance of a benchmark concentration or dose at a species level will have possible impacts at the community/ecosystem level.

The environmental risk assessment results, combined with the parallel assessment of human health risks, will be used to identify whether site conditions upon site restoration are protective of human health and the environment. Should the cumulative risk assessment results identify potential risks above background risks and above risk guidelines established by MADEP and USEPA, this will serve as the basis for identifying additional remedial measures or environmental controls to reduce these potential risks.

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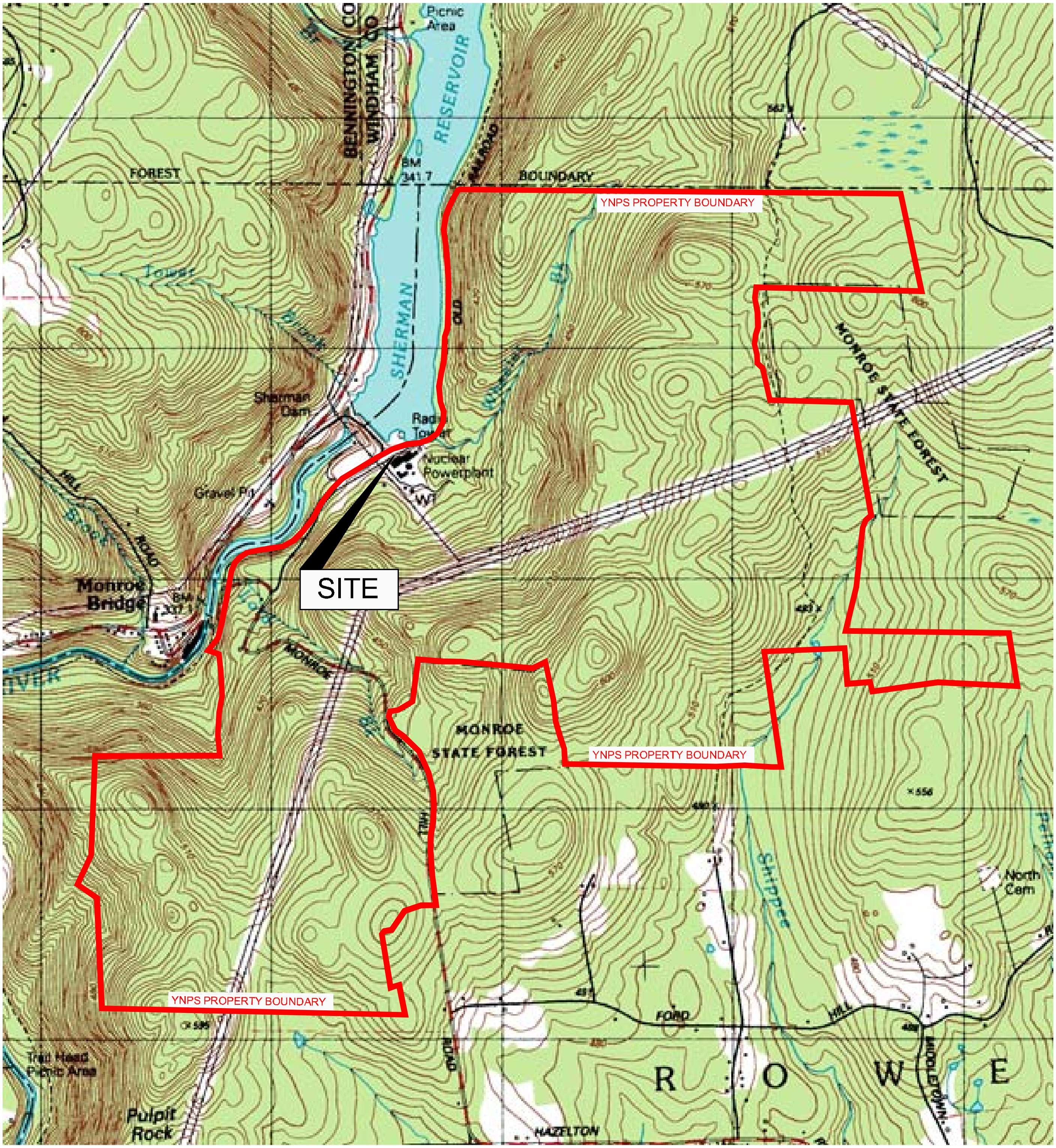
Figures



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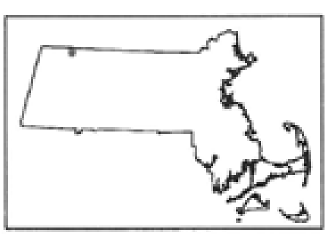

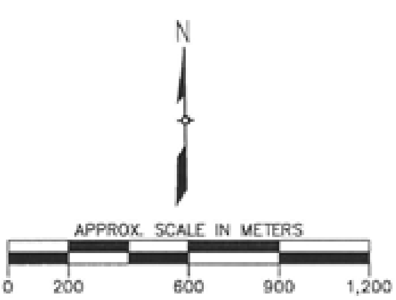

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FIGURE 1-1

YNPS Site Location

Yankee Nuclear Power Station
Rowe, MA

Drawing By: JMP	Checked By: DEM	Project No.: 204017
Date: 07/31/06	Date: 07/31/06	File: 204017–100_03

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Figure 1-2
YNPS Environmental Assessment Approach

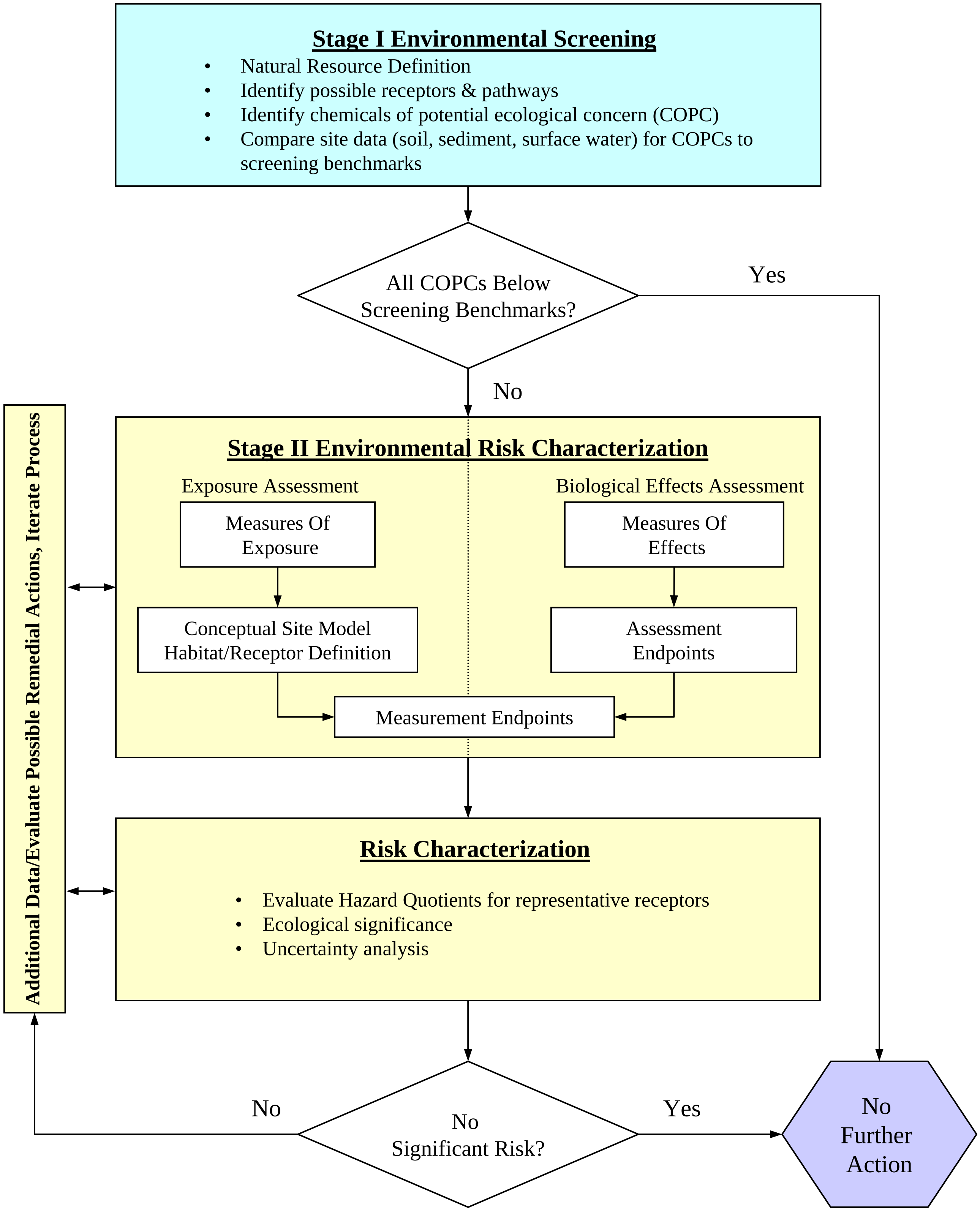

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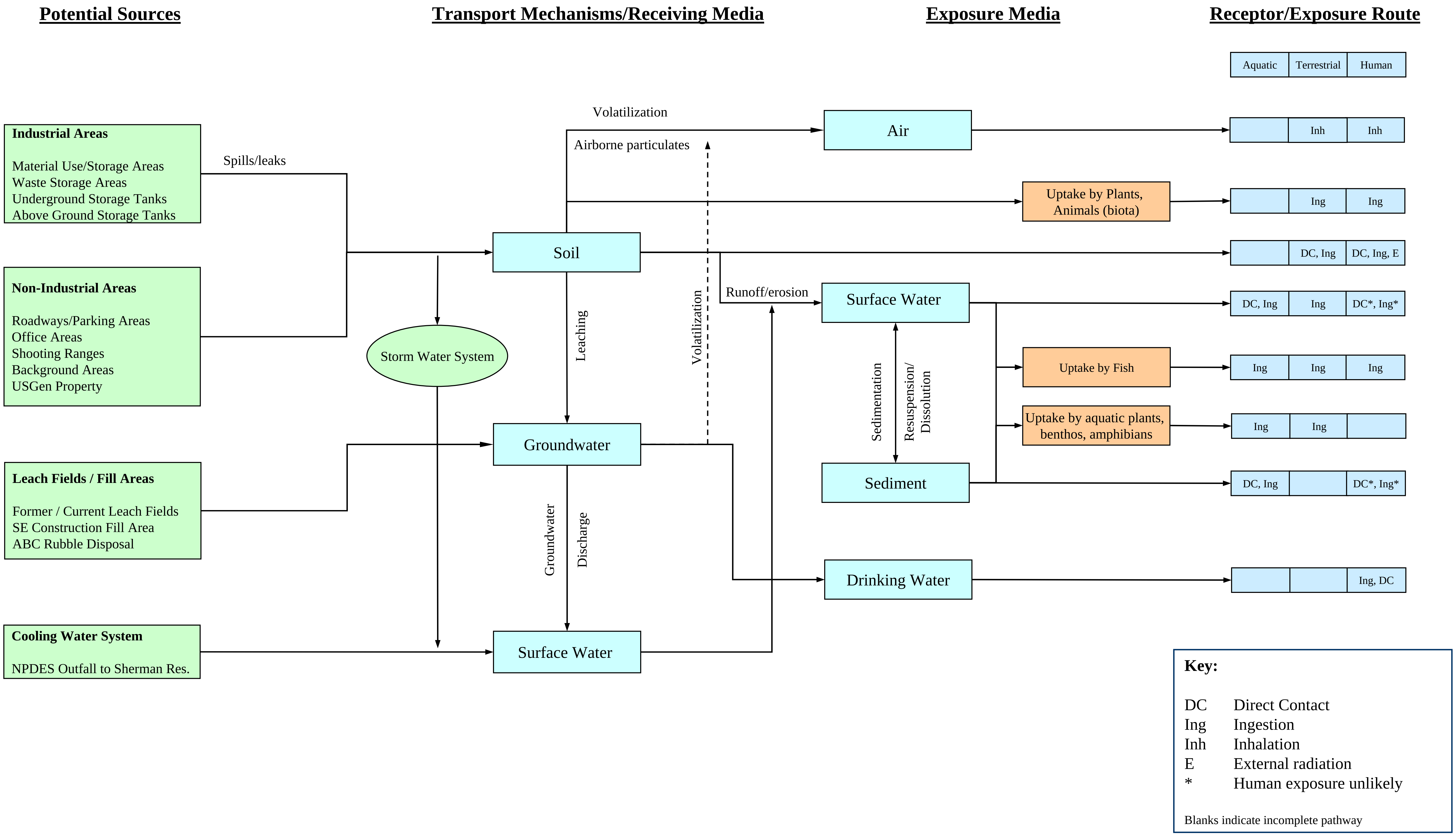
Figure 3-1
YNPS Human and Environmental Risk Assessment Conceptual Site Model

Chemical Release Sources, Pathways of Exposure, and Potentially Exposed Receptors



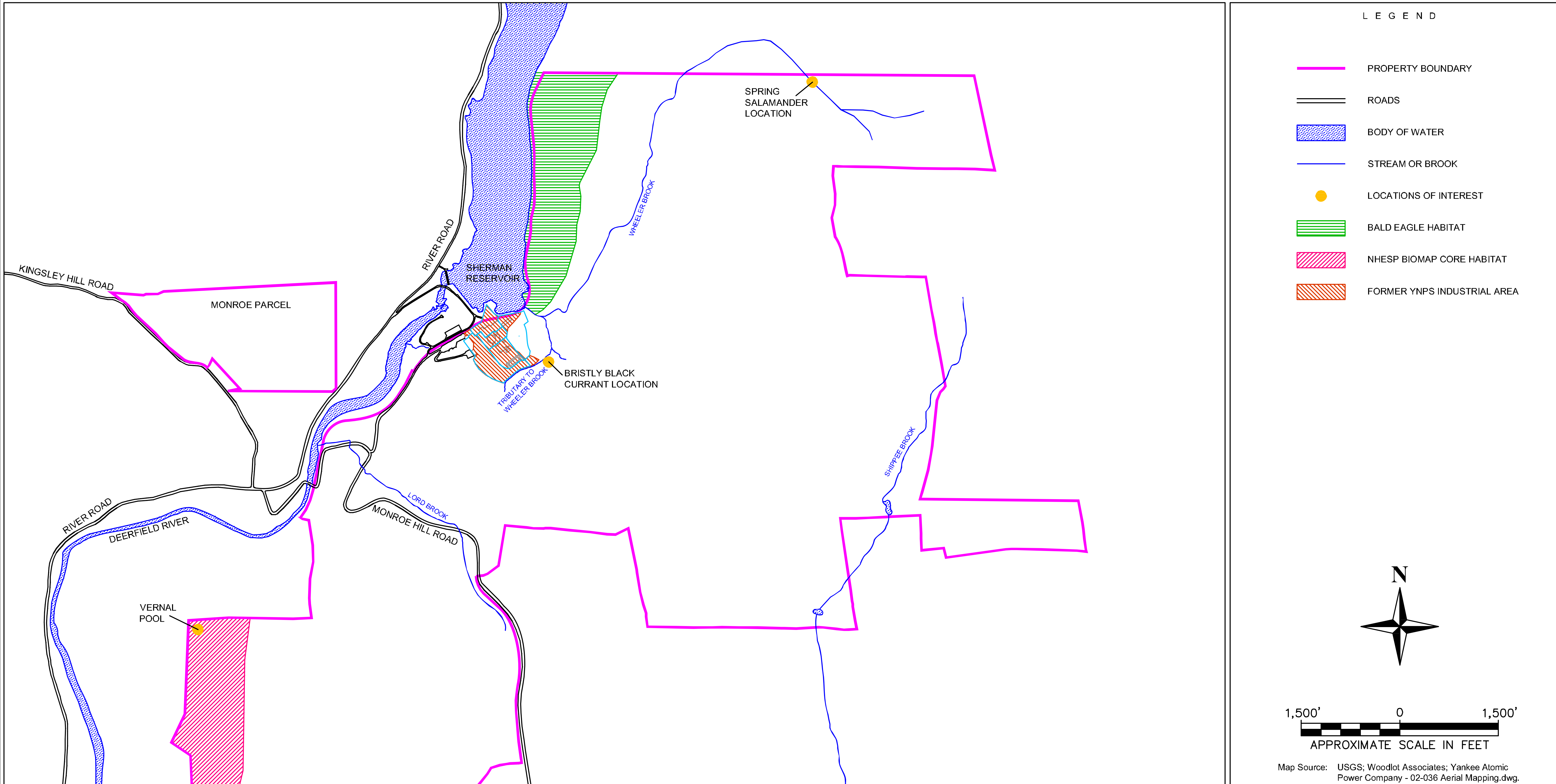


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FIGURE 3-2

Yankee Property Boundaries
and Site Features

Yankee Nuclear Power Station
Rowe, MA

Drawing By: JMP	Checked By: DEM	Project No.: 204017
Date: 07/31/06	Date: 07/31/06	File: 204017–100_01

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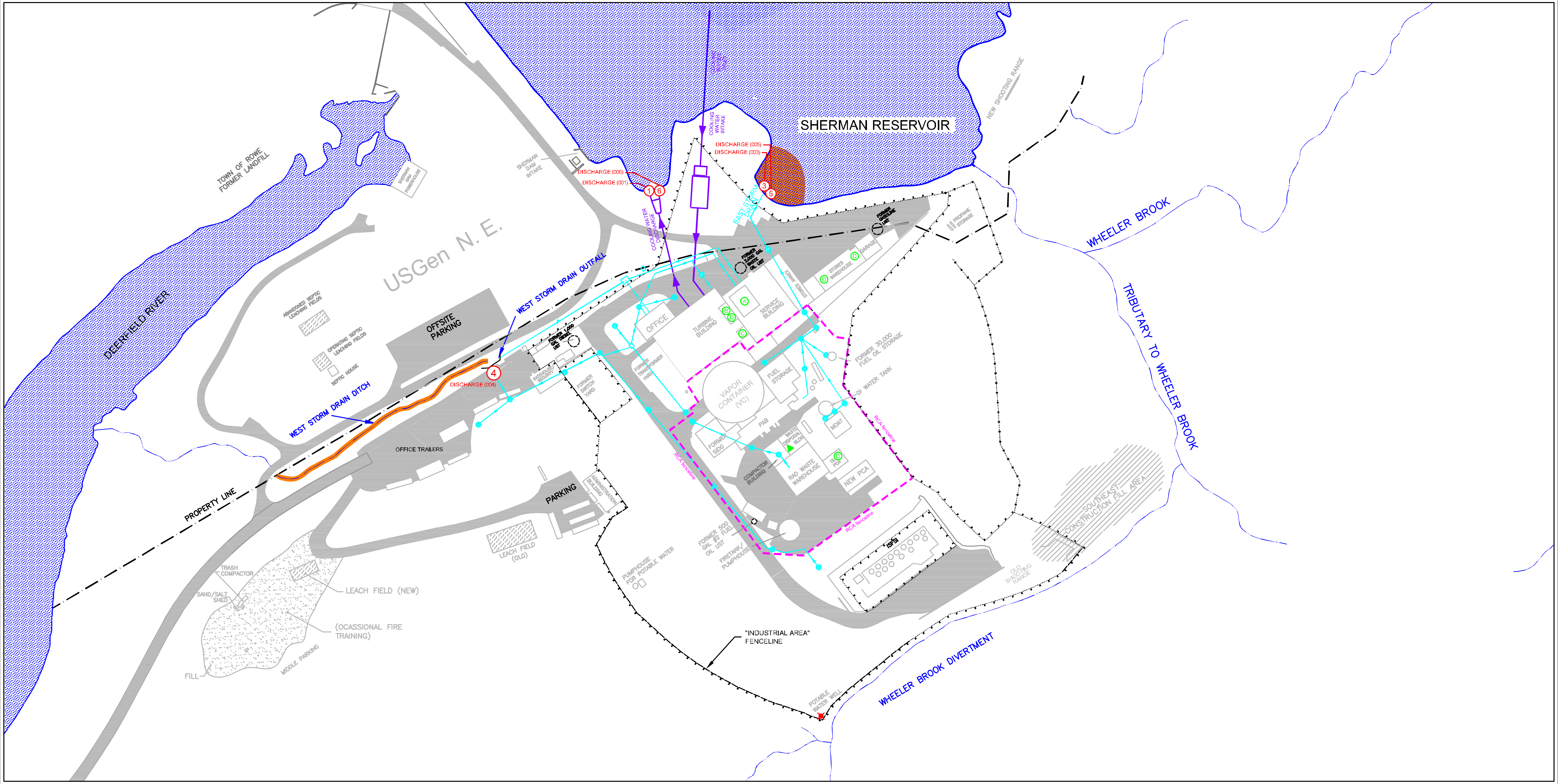

LEGEND

- Paved areas
- Sediment PCB Remediation Completed
- Stormwater drain/catch basin
- Fence line
- (1) NPDES discharge outfall

TARGET LOCATIONS

- (A) Former water treatment
- (B) Lube oil room
- (C) Auxilary boiler room
- (D) Hazardous waste storage
- ▲ Former Incinerator

N

200' 0 200'

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FIGURE 3-3

YNPS Former Industrial Area

Yankee Nuclear Power Station
Rowe, MA

Drawing By:	JMP	Checked By:	DEM	Project No.:	204017
Date:	07/31/06	Date:	07/31/06	File:	204017–100_02

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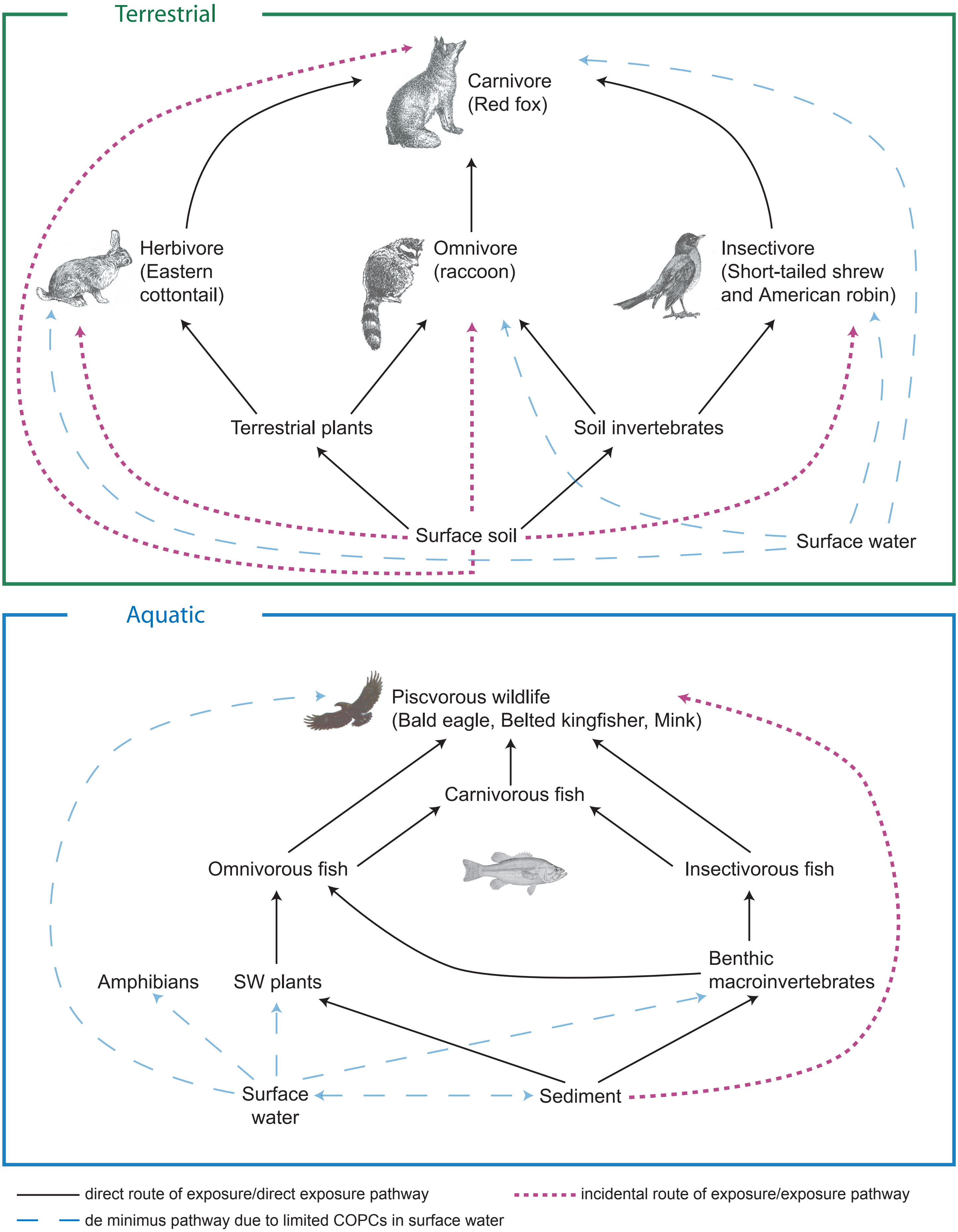
Figure 3-4
Food Web and Exposure Pathways



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Tables

Table 2-1

Constituents of Potential Concern (COPCs) by Media
YNPS, Rowe, Massachusetts

Constituents of Potential Concern (COPCs)	Soils	Sediment: Deerfield River	Sediment: Sherman Pond	Sediment: Wheeler Brook	Sediment: West Storm Drain	Surface Water	Groundwater
Total Petroleum Hydrocarbon							
TPH	X				X		X
TPH-DRO	X						X
TPH-GRO							X
VPH							
C5-C8 Aliphatics							X
C9-C10 Aromatics							X
EPH							
C11-C22 Aromatics	X						X
C19-C36 Aliphatics	X						X
Total EPH (ug/g DW)	X						
Volatile Organic Compounds							
1,1-Dichloroethane							X
1,1-Dichloroethene			X	X	X		
1,2,4-Trimethylbenzene			X				
2-Butanone	X	X	X	X			
4-Isopropyltoluene		X					
4-Methyl-2-pentanone			X				
Acetone	X	X	X	X		X	X
Carbon disulfide			X			X	X
Chloromethane		X				X	
Diethyl Ether	X						
Methylene chloride	X				X	X	
Methyl-t-butyl ether							X
Toluene	X		X			X	X
Alcohols							
iso-Propyl Alcohol							X
Semi-Volatile Organic Compounds							
2-Methylnaphthalene					X		
Acenaphthene	X		X		X		
Acenaphthylene	X						
Anthracene	X		X		X		
Benzo(a)anthracene	X	X	X		X		
Benzo(a)pyrene	X	X	X		X		
Benzo(b)fluoranthene	X	X	X		X		
Benzo(g,h,i)perylene	X	X	X		X		
Benzo(k)fluoranthene	X	X	X		X		
Benzoic acid					X		
bis(2-Ethylhexyl)phthalate	X	X	X		X		X
Carbazole	X				X		
Chrysene	X	X	X		X		
Dibenzo(a,h)anthracene	X				X		
Dibenzofuran					X		
Fluoranthene	X	X	X		X		X
Fluorene	X		X		X		
Indeno(1,2,3-cd)pyrene	X	X	X		X		
Naphthalene	X		X		X		X
Phenanthrene	X	X	X		X		X
Pyrene	X	X	X		X		X
Polychlorinated Biphenyls							
Aroclor-1254	X	X	X		X		X
Aroclor-1260	X	X					
Dioxin/Furan	X						

Table 2-1

Constituents of Potential Concern (COPCs) by Media
YNPS, Rowe, Massachusetts

Constituents of Potential Concern (COPCs)	Soils	Sediment				Surface Water	Groundwater
		Deerfield River	Sherman Pond	Wheeler Brook	West Storm Drain		
Inorganics							
Aluminum	X						
Antimony			X		X		
Arsenic	X		X		X		
Barium	X		X	X	X	X	X
Beryllium			X		X		
Boron	X						X
Cadmium			X		X		
Chromium	X		X		X		X
Copper	X	X	X		X	X	X
Iron						X	X
Lead	X	X	X	X	X		X
Lithium	X		X				
Manganese	X					X	X
Mercury	X		X	X	X		
Molybdenum	X						
Nickel	X		X		X		X
Selenium	X		X		X	X	
Silver					X	X	
Thallium					X		
Zinc	X		X		X		X
Uranium	X	X	X		X	X	

Notes:
X = COPC for specified media (see ERM, 2005b)
These COPCs are not final. Final COPCs will be identified based on procedures in this Work Plan.

Table 2-2
Radionuclide Constituents of Potential Concern (COPCs) and
Biota Concentration Guideline (BCG) Screening Levels by Media
YNPS, Rowe, Massachusetts

Radionuclide COPC	Soil DCGL[1] (pCi/g)	Sediment BCG				Soil BCG			
		Aquatic Animals (pCi/g)	Source	Riparian Animals (pCi/g)	Source	Terrestrial Plants (pCi/g)	Source	Terrestrial Animals (pCi/g)	Source
Ag-108m	2.5	24,000	b	2,300	b	9,900	b	1,100	b
Am-241	10	704,000	a	5,150	a	21,500	a	3,890	a
C-14	1.9	789,000	a	59,000	a	60,700	a	4,760	a
Cm-243	11	150,000	b	3,800	b	35,000	b	2,600	b
Cm-244	11	4,010,000	a	5,190	a	153,000	a	4,060	a
Co-60	1.4	14,900	a	1,460	a	6,130	a	695	a
Cs-134	1.7	22,800	a	1,480	a	1,090	a	11	a
Cs-137	3	49,300	a	3,120	a	2,210	a	21	a
Eu-152	3.5	25,900	a	3,040	a	14,700	a	1,520	a
Eu-154	3.3	318,000	a	2,570	a	12,500	a	1,290	a
Eu-155	140	300,000	a	31,600	a	153,000	a	15,800	a
Fe-55	10,000	6,600,000	b	660,000	b	3,000,000	b	331,000	b
H-3	130	7,040,000	a	374,000	a	1,680,000	a	174,000	a
Nb-94	2.5	23,000	b	2,200	b	11,000	b	1,100	b
Ni-63	280	2,300,000	b	220,000	b	1,000,000	b	162,000	b
Pu-238	11	3,950,000	a	5,730	a	17,500	a	5,270	a
Pu-239	10	7,040,000	a	5,860	a	12,700	a	6,110	a
Pu-240	340	3,900,000	b	5,800	b	18,000	b	5,900	b
Pu-241	340	7,500,000	b	740,000	b	22,500	b	370,000	b
Sb-125	11	70,400	a	7,030	a	34,900	a	3,520	a
Sr-90	0.6	35,200	a	582	a	3,580	a	23	a
Tc-99	5	469,000	a	42,200	a	21,900	a	4,490	a

[1] DCGL = Derived Concentration Guideline Level (based on achieving dose limit of 10 mrem/yr).

Sources

[a] Calculated using USDOE (2004) RESRAD-Biota Software.

[b] Calculated using BCG equations in USDOE (2002), with parameters in Table 2-3 (BCGs not available in RESRAD-Biota software)

Table 2-3
Radionuclide Average Emission Energies, Dose Conversion Factors (DCF), and Uptake Factors for BCG Calculations

Radionuclide (pCi/g)	Half-life (years)	Average Emission Energies (MeV/disintegration) [a]						Internal DCF			External DCF		Uptake Factors (UF) -- (pCi/g-biota)/(pCi/g-media)					
		Alpha	Beta	Gamma	Internal Energies [c]	Beta+Gamma Energies [d]	Beta+Gamma DOE [b]	Calculated [j] w/ progeny (rad/day) / (pCi/g)	Calculated [j] w/o progeny (rad/day) / (pCi/g)	DOE	Calculated [j] (rad/day) / (pCi/g)	DOE	Sediment to Riparian Animal	source	Soil to Terrestrial Animal	source	Soil to Terrestrial Plants	source
Quality Factors (QF)=>		20	1	1														
Ag-108m	127		1.59E-02	1.62E+00	1.64E+00	1.64E+00	1.63E+00	1.16E-04	8.38E-05		8.38E-05	8.38E-05 [b]	0.003	f	0.003	f	0.15	h
Am-241	432.2	5.57E+00	5.19E-02	3.24E-02	1.11E+02	8.43E-02	5.75E-02	5.70E-03	5.71E-03	5.70E-03 [e]	4.32E-06	2.94E-06 [e]	0.003	e	0.004	e	0.008	i
C-14	5730		4.95E-02		4.95E-02	4.95E-02	4.95E-02	2.53E-06	2.54E-06	2.53E-06 [e]	2.54E-06	2.53E-06 [e]	0.169	e	7.28	e	5.5	i
Cm-243	28.5	5.88E+00	1.37E-01	1.34E-01	1.18E+02	2.71E-01	2.75E-01	6.81E-02	6.04E-03		1.39E-05	1.31E-05 [b]	0.0032	e	0.004	e	0.003	h
Cm-244	18.11	5.89E+00	8.59E-03	1.70E-03	1.18E+02	1.03E-02	7.90E-03	5.70E-02	6.03E-03	6.03E-03 [e]	5.27E-07	5.00E-07 [e]	0.0032	e	0.004	e	0.001	i
Co-60	5.271		9.62E-02	2.50E+00	2.60E+00	2.60E+00	2.60E+00	1.33E-04	1.33E-04	1.33E-04 [e]	1.33E-04	1.32E-04 [e]	0.0099	e	0.08	e	0.22	i
Cs-134	2.062		1.63E-02	1.55E+00	1.57E+00	1.57E+00	1.72E+00	8.77E-05	8.02E-05	8.76E-05 [e]	8.02E-05	8.78E-05 [e]	0.27	g	110	g	9.5	i
Cs-137	30		1.87E-01		1.87E-01	1.87E-01	1.71E-01	4.34E-05	9.58E-06	4.34E-05 [e]	9.58E-06	4.05E-05 [e]	0.27	e	110	e	9.5	i
Eu-152	13.3		1.36E-01	1.14E+00	1.28E+00	1.28E+00	1.28E+00	2.33E-03	6.54E-05	6.53E-05 [e]	6.54E-05	6.54E-05 [e]	0.00386	e	0.005	e	0.04	i
Eu-154	8.8		2.88E-01	1.22E+00	1.51E+00	1.51E+00	1.53E+00	7.72E-05	7.72E-05	7.71E-05 [e]	7.72E-05	7.82E-05 [e]	0.00386	e	0.005	e	0.04	i
Eu-155	4.96		6.26E-02	6.05E-02	1.23E-01	1.23E-01	1.22E-01	6.30E-06	6.31E-06	6.30E-06 [e]	6.31E-06	6.30E-06 [e]	0.00337	e	0.004	e	0.04	i
Fe-55	2.7		4.20E-03	1.69E-03	5.89E-03	5.89E-03	5.70E-03	3.01E-07	3.02E-07		3.02E-07	2.92E-07 [b]	0.0003	f	0.0003	f	0.001	h
H-3	12.35		5.68E-03		5.68E-03	5.68E-03	5.70E-03	2.91E-07	2.91E-07	2.91E-07 [e]	2.91E-07	2.94E-07 [e]	0.43	e	1	e	1.067	i
Nb-94	20300		1.68E-01	1.57E+00	1.74E+00	1.74E+00	1.72E+00	8.89E-05	8.90E-05		8.90E-05	8.73E-05 [b]	0.0000003	f	0.0000003	f	0.01	h
Ni-63	96.1		1.17E-02		1.17E-02	1.17E-02	1.71E-02	8.75E-07	5.99E-07		5.99E-07	8.77E-07 [b]	0.01	f	0.01	f	0.05	h
Pu-238	87.74	5.58E+00	1.06E-02	1.81E-03	1.12E+02	1.24E-02	9.90E-03	5.31E-02	5.72E-03	5.68E-03 [e]	6.36E-07	5.07E-07 [e]	0.00303	e	0.003	e	0.01	i
Pu-239	6569	5.23E+00	6.66E-03	7.96E-04	1.05E+02	7.45E-03	5.60E-03	5.35E-03	5.36E-03	5.35E-03 [e]	3.82E-07	2.84E-07 [e]	0.00316	e	0.003	e	0.01	i
Pu-240	6569	5.24E+00	1.06E-02	1.73E-03	1.05E+02	1.23E-02	9.80E-03	5.11E-02	5.37E-03		6.32E-07	5.02E-07 [b]	0.00316	g	0.003	g	0.01	i
Pu-241	14.4	1.22E-04	5.24E-03	2.54E-06	7.68E-03	5.24E-03	5.20E-03	4.41E-02	3.93E-07		2.69E-07	2.67E-07 [b]	0.00316	g	0.003	g	0.001	h
Sb-125	2.77		9.93E-02	4.30E-01	5.29E-01	5.29E-01	5.30E-01	2.71E-05	2.71E-05	2.93E-05 [e]	2.71E-05	2.94E-05 [e]	0.000409	e	0.0004	e	0.01	i
Sr-90	29.12		5.46E-01	1.96E-01	7.42E-01	7.42E-01	1.96E-01	5.79E-05	3.80E-05	5.79E-05 [e]	3.80E-05	5.79E-05 [e]	2.48	e	75.8	e	3.844	i
Tc-99	213000		1.01E-01		1.01E-01	1.01E-01	8.46E-02	5.17E-06	5.17E-06	5.17E-06 [e]	5.17E-06	4.36E-06 [e]	0.0457	e	3.48	e	8.0	i

Notes

[a] ICRP, 1983. Radionuclide Transformations Energy and Intensity of Emissions. Publications 38
[b] NTIS, 1980 - A Radionuclide Decay data base - Index and Summary Table
[c] Internal energies are the sum of alpha, beta and gamma energies multiplied by their respective "Quality Factors".
[d] External energies for beta and gamma radiation. Alpha radiation lacks penetrating power and is only included in internal radiation calculations.
[e] USDOE, 2004 - RESRAD-Biota Software
[f] Beef/feed transfer values used from NTIS, 1993 - Compilation of Radionuclide transfer factors for the plant, meat, milk and aquatic food pathways and the suggested default values for the RESRAD code
[g] Values from similar compound were used for analytes with no specified value
[h] Soil/plant transfer used from NTIS, 1993 - Compilation of Radionuclide transfer factors for the plant, meat, milk and aquatic food pathways and the suggested default values for the RESRAD code
[i] DOE, 2002 - A graded Approach for Evaluating Radiation Doses to Aquatic and Terrestrial Biota
[j] Calculated from emission energies using following unit conversion:
5.122E-05 (rad/day)/(pCi/g) per MeV/disintegration.

Table 3-1

Ecological Receptors
YNPS, Rowe, Massachusetts

Common Name	Scientific Name	Functional Group	Terrestrial Habitats			Aquatic Habitats		
			Former Industrial Area (FIA)	Non-Impacted Area (NIA)[2]	West Storm Drain	Deerfield River	Sherman Reservior	Wheeler Brook
Communities								
Terrestrial Plants		Producers	DC	DC	DC	--	--	--
Terrestrial Invertebrates		Primary Consumers	DC	DC	DC	--	--	--
Benthic Macroinvertebrates		Primary Consumers	--	--	DC	DC	DC	DC
Fish		Primary Consumers	--	--	--	DC	DC	--
Amphibians		Primary Consumers	--	--	--	DC	DC	DC
Representative Species - Birds								
American Robin	*Turdus migratorius*	Insectivore	[1]	DI, II	DI, II, WI	WI	WI	WI
Belted Kingfisher	*Megaceryle alcyon*	Piscivore	--	--	--	DI, II, WI	DI, II, WI	DI, II, WI
Bald Eagle	*Haliaeetus leucocephalus*	Piscivore	--	--	--	DI, II, WI	DI, II, WI	DI, II, WI
Representative Species - Mammals								
Short-tailed Shrew	*Blarina brevicauda*	Insectivore	[1]	DM, DI, II	DI, II, WI	WI	WI	WI
Raccoon	*Procyon lotor*	Omnivore	[1]	DM, DI, II	DI, II, WI	WI	WI	WI
Mink	*Mustela vison*	Piscivore	--			DI, II, WI	DI, II, WI	DI, II, WI
Red Fox	*Vulpes vulpes*	Carnivore	[1]	DM, DI, II	DI, II, WI	WI	WI	WI
Eastern Cottontail	*Sylvilagus floridanus*	Herbivore	[1]	DM, DI, II	DI, II, WI	WI	WI	WI

Notes
DC - Direct Contact
DM - Dermal Contact
DI - Dietary Ingestion of prey items inhabiting these habitats
WI - Water Ingestion
II - Incidental Ingestion

"--" Not aplicable pathway for this receptor/exposure unit.
[1] A 3-foot overburden will be in place after final site restoration and grading, limiting contact in this area.
[2] Non-impacted area is expected to yield de minimis exposures.

Table 3-2
Exposure Parameters for Ecological Receptors
YNPS, Rowe, Massachusetts

Exposure Parameter	Insectivorous Mammal and Bird		Herbivorous Mammal	Omnivorous Mammal	Carnivorous Mammal	Piscivorous Mammal and Birds		
	Short-tailed Shrew (*Blarina brevicauda*)	American Robin (*Turdus migratorius*)	Eastern Cottontail (*Sylvilagus floridanus*)	Raccoon (*Procyon lotor*)	Red Fox (*Vulpes vulpes*)	Mink (*Mustela vison*)	Belted Kingfisher (*Megaceryle alcyon*)	Bald Eagle (*Haliaeetus leucocephalus*)
Sex, Age, Breeding Status	Adult Breeding Female	Adult Breeding Female	Adult Breeding Female	Adult Breeding Female	Adult Breeding Female	Adult Breeding Female	Adult Breeding Female	Adult Breeding Female
Body Weight (Kg)	0.017	0.081	1.22	5.6	4.5	1.0	0.15	4.2
Body Surface Area (cm^2)	69	--	--	--	2990	--	--	--
Water Ingestion Rate (L/day)	0.0038	0.011	0.12	0.46	0.380	0.079	0.11	0.15
Food Ingestion Rate (Kg/day - wet wt.)	0.01	0.10	0.273	1.107	0.51	0.158	0.32	0.48
Invertebrate	0.008	0.053	--	0.50	0.020	0.032	0.022	--
Plant	0.001	0.044	0.27	0.50	0.051	--	--	--
Fish	--	--	--	--	--	0.040	0.30	0.254
Herbivore	0.0005	--	--	0.055	0.180	0.041	--	0.051
Bird	--	--	--	--	0.081	0.032	--	0.139
Omnivore	--	--	--	0.055	0.177	0.014	--	0.018
Food Ingestion Rate (Kg/day - dry wt.)	0.0029	0.032	0.101	0.283	0.164	0.044	0.17	0.13
Dietary Composition (% wet wt.)	85% invertebrates, 5% herbivores, 15% plants	55% terrestrial invertebrates, 45% plants	100% plants	45% invertebrates, 45% plants, 5% herbivores, 5% omnivores	16% birds, 35% herbivores, 4% invertebrates, 35% omnivores, 10% plants	100% fish	80% fish, 20% aquatic invertebrates	100% fish
Percent Composition of Soil or Sediment in Diet[1] (%)	5.9%	10%	2%	9.4%	3%	5%	2%	5%
Foraging Radius or Home Range (acres)	1	39	8.0	1550	2560	700	351	5800

Notes:
All data are average values derived from EPA (1993) and Sample et al. (1997) unless otherwise noted.
[1] Beyer (1994)
"--" Not applicable

Table 3-3
Measured and Modeled Data Sources for Ecological Receptors
YNPS, Rowe, Massachusetts

Data Source	Communities					Representative Birds			Representative Mammals				
	Terrestrial Plants	Terrestrial Invertebrates	Benthic Macro-invertebrates	Fish	Amphibians	American Robin	Belted Kingfisher	Bald Eagle	Short-tailed Shrew	Raccoon	Mink	Red Fox	Eastern Cottontail
Measured Concentrations													
Soil	X	X				X			X			X	X
Sediment			X				X	X		X	X		
Surface Water				X	X	X	X	X	X	X	X	X	X
Fish Tissue				X[a]			X	X			X		
Modeled Concentrations [b]													
Plants						X			X	X		X	X
Invertebrates						X			X	X	X	X	
Fish Tissue				X			X	X			X		
Small birds								X		X	X	X	
Small mammals								X	X	X	X	X	

Notes:

[a] Fish tissue data are available for PCBs and radionuclides.

[b] Modeled concentrations are calculated using equations from Attachment A and collected media concentrations.

Table 3-4

Toxicity Reference Values (TRVs) for Avian and Mammalian Receptors
YNPS, Rowe, Massachusetts

Constituent of Potential Concern (COPC)	Birds					Mammals				
	$NOAEL_{Test}$ (mg/kg-d)		$LOAEL_{Test}$ (mg/kg-d)		Endpoints	$NOAEL_{Test}$ (mg/kg-d)		$LOAEL_{Test}$ (mg/kg-d)		Endpoints
Total Petroleum Hydrocarbon										
TPH	--		--		No avian data available	1.95	5j	5.85	2	Based on an LD50 of laboratory rats
TPH-DRO	--		--		No avian data available	1.95	5j	5.85	2	Based on an LD50 of laboratory rats
TPH-GRO	--		--		No avian data available	1.95	5j	5.85	2	Based on an LD50 of laboratory rats
VPH - C5-C8 Aliphatics	--		--		No avian data available	1.95	6	5.85	2	Based on an LD50 of laboratory rats
VPH - C9-C10 Aromatics	--		--		No avian data available	1.95	6	5.85	2	Based on an LD50 of laboratory rats
EPH - C11-C22 Aromatics	--		--		No avian data available	13.25	5j	39.75	2	Based on an LD50 of laboratory mice
EPH - C19-C36 Aliphatics	--		--		No avian data available	13.25	5j	39.75	2	Based on an LD50 of laboratory mice
Total EPH	--		--		No avian data available	13.25	5j	39.75	2	Based on an LD50 of laboratory mice
Volatile Organic Compounds										
1,1-Dichloroethane	17.2	a	51.6	2	Fewer Eggs	50	a	150	2	Reproductive Impairment
1,1-Dichloroethene	--		--		No avian data available	30	a	90	2	Mortality
1,2,4-Trimethylbenzene	--		--		No avian data available	177.5	5j	532.5	2	Based on an LD50 of laboratory rats
2-Butanone	200	5m	600	2	Based on an LD50 of mallards	145	5j	435	2	Based on an LD50 of laboratory rats
4-Isopropyltoluene	--		--		No avian data available	237.5	5j	712.5	2	Based on an LD50 of laboratory rats
4-Methyl-2-pentanone	--		--		No avian data available	104	5j	312	2	Based on an LD50 of laboratory rats
Acetone	52000	n	156000	2	No avian data available	10	a	50	a	Offspring mortality
Carbon disulfide	--		--		No avian data available	11	k	33	2	Fetal toxicity of rabbits
Chloromethane	112.5	5m	337.5	2	Based on an LD50 of mallards	90	5j	270	2	Based on an LD50 of laboratory rats
Diethyl Ether	--		--		No avian data available	500	k	1500	2	Mortality, decreased food intake, and body weight loss
Methylene chloride	--		--		No avian data available	5.85	a	17.55	2	Liver histology
Methyl-t-butyl ether	--		--		No avian data available	--		--		No mammalian data available
Toluene	--		--		No avian data available	26	a	78	2	Reduced fetal weights
Alcohols										
iso-Propyl Alcohol	--		--		No avian data available	316	k	948	2	Liver and kidney toxicity in rats
Semi-Volatile Organic Compounds										
2-Methylnaphthalene	143	3	1430	3	Infertility	1000	3	10000	3	Reduce pregnancy rate of viable litters
Acenaphthene	143	3	1430	3	Infertility	1000	3	10000	3	Reduce pregnancy rate of viable litters
Acenaphthylene	143	3	1430	3	Infertility	1000	3	10000	3	Reduce pregnancy rate of viable litters
Anthracene	14.3	3	143	3	Infertility	100	3	1000	3	Reduce pregnancy rate of viable litters
Benzo(a)anthracene	1.43	3	14.3	3	Infertility	10	3	100	3	Reduce pregnancy rate of viable litters
Benzo(a)pyrene	0.143	b	1.43	b	Infertility	1	a	10	a	Reduce pregnancy rate of viable litters
Benzo(b)fluoranthene	1.43	3	14.3	3	Infertility	10	3	100	3	Reduce pregnancy rate of viable litters
Benzo(g,h,i)perylene	14.3	3	143	3	Infertility	100	3	1000	3	Reduce pregnancy rate of viable litters
Benzo(k)fluoranthene	14.3	3	143	3	Infertility	100	3	1000	3	Reduce pregnancy rate of viable litters
Benzoic acid	--		--		No avian data available	175	k	525	2	Maternal toxicity, fetal toxicity and teratogenicity in mice
bis(2-Ethylhexyl)phthalate	1.1	a	3.3	2	Reproductive Impairment	18.3	a	183	a	Reproductive Impairment
Carbazole	--		--		No avian data available	250	5j	750	2	Based on LD50 of laboratory rats
Chrysene	14.3	3	143	3	Infertility	100	3	1000	3	Reduce pregnancy rate of viable litters
Dibenzo(a,h)anthracene	0.143	3	1.43	3	Infertility	1	3	10	3	Reduce pregnancy rate of viable litters

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Table 3-4

Toxicity Reference Values (TRVs) for Avian and Mammalian Receptors
YNPS, Rowe, Massachusetts

Constituent of Potential Concern (COPC)	Birds					Mammals				
	$NOAEL_{Test}$ (mg/kg-d)		$LOAEL_{Test}$ (mg/kg-d)		Endpoints	$NOAEL_{Test}$ (mg/kg-d)		$LOAEL_{Test}$ (mg/kg-d)		Endpoints
Dibenzofuran	--		--		No avian data available	--		--		no mammalian data
Fluoranthene	143	3	1430	3	Infertility	1000	3	10000	3	Reduce pregnancy rate of viable litters
Fluorene	143	3	1430	3	Infertility	1000	3	10000	3	Reduce pregnancy rate of viable litters
Indeno(1,2,3-cd)pyrene	1.43	3	14.3	3	Infertility	10	3	100	3	Reduce pregnancy rate of viable litters
Naphthalene	143	3	1430	3	Infertility	1000	3	10000	3	Reduce pregnancy rate of viable litters
Phenanthrene	143	3	1430	3	Infertility	1000	3	10000	3	Reduce pregnancy rate of viable litters
Pyrene	143	3	1430	3	Infertility	10000	3	100000	3	Reduce pregnancy rate of viable litters
Polychlorinated Biphenyls										
Aroclor-1254	0.6	c	1.2	c	Reduced egg productivity, egg fertility, hatchability, chick body weight and chick survival	0.09	4	0.21	4	Estimated from Aroclor 1260 values based on ratio of dioxin-like TEFs.
Aroclor-1260	1.18	4	2.35	4	Estimated from Aroclor 1254 values based on ratio of dioxin-like TEFs	0.17	h	0.41	h	Mink study (mating success, offspring survival and number, adult survival).
Dioxin/Furan										
2,3,7,8-TCDD	0.000014	a	0.00014	a	Reduced egg production and hatchability	0.000001	a	0.00001	a	Fertility and neonatal survival
2,3,7,8-TCDF	0.000001	a	0.00001	a	Mortality	0.0000016	a	0.00016	a	Reduced body weight of young
Inorganics										
Aluminum	109.7	a	329.1	2	Reproductive Impairment	1.93	a	19.3	a	Reproductive Impairment
Antimony	840	i	2520	2	Female growth	0.125	a	1.25	a	Longevity
Arsenic	5.14	a	12.84	a	Mortality	0.126	a	1.26	a	Declining litter size
Barium	20.8	a	41.7	a	Mortality	1.98	1a	19.8	a	Mortality
Beryllium	--		--		No avian data available	0.66	a	1.98	2	Longevity, weight loss
Boron	28.8	a	100	a	Reduced egg fertility and duckling growth, increased embryo and duckling mortality	28	a	93.6	a	Sterility
Cadmium	1.45	a	20	a	Fewer Eggs	1	a	10	a	Reduced Fetal Survival
Chromium	1	a	5	a	Duckling survival	2737	a	8211	2	Reproductive Impairment
Copper	47	a	61.7	a	Mortality and Growth	11.7	a	15.14	a	Mortality of kits
Iron	--		--		No avian data available	--		--		Toxicity value not available
Lead	1.13	a	11.3	a	Reduced egg hatchability	8	a	80	a	Reduced offspring weights and kidney damage in the young
Lithium	28.35	5m	85.05	2	Based on an LD50 of mallards	9.4	a	28.2	2	Reduced offspring and offspring weights
Manganese	977	a	2931	2	Aggressive behavior (indirectly affecting reproduction)	88	a	284	a	Reduced pregnancy percentage and fertility
Mercury	0.45	a	0.9	a	Reduced fertility and hatchability	0.032	a	0.16	a	Morality, weight loss, behavioral problems
Molybdenum	3.5	a	35.3	a	Reduced embryonic viability	0.26	a	2.6	a	Reduced reproductive success
Nickel	77.4	a	107	a	Mortality	40	a	80	a	Reduced offspring weights
Selenium	0.5	a	1	a	Duckling survival	0.2	a	0.33	a	Fertility, juvenile growth and survival
Silver	6.22	d	62.2	d	Significantly reduced growth	32.86	f	328.6	f	Reduced growth and eventually mortality
Thallium	0.06	e	0.6	e	Based on an LD50 of golden eagles	0.074	g	0.74	g	Reproductive Impairment
Zinc	14.5	a	131	a	Reproductive Impairment	160	a	320	a	Increased rates of fetal resportion and reduce fetal growth rates

Table 3-4

Toxicity Reference Values (TRVs) for Avian and Mammalian Receptors
YNPS, Rowe, Massachusetts

Constituent of Potential Concern (COPC)	Birds			Mammals		
	$NOAEL_{Test}$ (mg/kg-d)	$LOAEL_{Test}$ (mg/kg-d)	Endpoints	$NOAEL_{Test}$ (mg/kg-d)	$LOAEL_{Test}$ (mg/kg-d)	Endpoints

Table 3-6 Notes:

a - Sample et al, 1996
b - Hough et al, 1993
c - USEPA, 2003
d - Peterson and Jensen, 1975
e - Bean and Hudson, 1976
f - Matuk et al, 1981
g - Formigli et al, 1986
h - Bursian et al, 2003
i - Damron and Wilson, 1975
j - HSDB, 2004
k - IRIS, 2005
m - EPA ECOTOX, 2002
n - Hill and Camardese, 1986

1 - No published NOAEL. NOAEL estimted as LOAEL/10.
2 - No published LOAEL. LOAEL estimated as NOAEL x 3.
3 - Values for PAHs are based on the benzo(a)pyrene benchmark and applying toxicity equivalency factors (TEF) ranging from 10 to 10,000.
4 - Aroclor values are adjusted from reported values based on relative dioxin-like TEF ratio for Aroclor 1254/Aroclor 1260 = 0.51.
5 - NOAEL is the LD_{50} divided by an uncertainty factor of 20.
6 - The NOAEL for TPH is used in the absence of a specific benchmark.

Table 3-5

Toxicity Reference Values (TRVs) for Terrestrial Plants and Invertebrates, Benthic Macroinvertebrates, and Fish
YNPS, Rowe, Massachusetts

Constituent of Potential Concern (COPC)	Terrestrial Plants (mg/Kg)		Terrestrial Invertebrates (mg/Kg)		Benthic Macroinvertebrates (mg/Kg)		Water Quality Criteria					
							Acute (ug/L)		Chronic (ug/L)		Lowest Chronic Value for Fish (ug/L)	
Total Petroleum Hydrocarbon												
TPH	--		--		--		--		--		--	
TPH-DRO	--		--		--		--		--		--	
TPH-GRO	--		--		--		--		--		--	
VPH - C5-C8 Aliphatics	--		--		--		250	l	--		--	
VPH - C9-C10 Aromatics	--		--		--		540	l	--		--	
EPH - C11-C22 Aromatics	--		--		--		--		--		--	
EPH - C19-C36 Aliphatics	--		--		--		2100	l	--		--	
Total EPH	--		--		--		--		--		--	
Volatile Organic Compounds												
1,1-Dichloroethane	--		--		4.2	j	--		--		14680	f
1,1-Dichloroethene	--		--		5.9	j	3030	f	303	f	2800	f
1,2,4-Trimethylbenzene	--		--		--		--		--		--	
2-Butanone	--		--		27	j	--		--		282170	f
4-Isopropyltoluene	--		--		--		--		--		--	
4-Methyl-2-pentanone	--		--		--		--		--		77400	f
Acetone	--		--		0.0571	c	--		1500	f	507640	f
Carbon disulfide	--		--		0.23	j	--		--		9538	f
Chloromethane	--		--		--		--		--		--	
Diethyl Ether	--		--		--		--		--		--	
Methylene chloride	--		--		7.2	j	19300	f	1930	f	108000	f
Methyl-t-butyl ether	--		--		--		--		--		--	
Toluene	200	a	--		130	j	1750	f	175	f	1269	f
Alcohols												
iso-Propyl Alcohol	--		--		--		--		--		--	
Semi-Volatile Organic Compounds												
2-Methylnaphthalene	20	2a	30	4b	0.15 (TEC)	6d	170	2f	17	2f	74	2
Acenaphthene	20	a	30	4b	0.15 (TEC)	6d	170	f	17	f	74	f
Acenaphthylene	20	2a	30	4b	0.15 (TEC)	6d	170	2f	17	2f	74	2
Anthracene	20	2a	30	4b	0.0572 (TEC)	d	170	2f	17	2f	0.09	f
Benzo(a)anthracene	20	2a	30	4b	0.110 (TEC)	d	170	2f	17	2f	74	2
Benzo(a)pyrene	20	2a	30	4b	0.15 (TEC)	d	170	2f	17	2f	74	2
Benzo(b)fluoranthene	20	2a	30	4b	0.037 (ERL)	c	170	2f	17	2f	74	2
Benzo(g,h,i)perylene	20	2a	30	4b	0.15 (TEC)	6d	170	2f	17	2f	74	2
Benzo(k)fluoranthene	20	2a	30	4b	0.037 (ERL)	c	170	2f	17	2f	74	2
Benzoic acid	--		--		--		--		42	f	12976	f
bis(2-Ethylhexyl)phthalate	--		--		13.3	c	1110	f	0.3	f	--	
Carbazole	--		--		--		--		--		--	
Chrysene	20	2a	30	4b	0.170 (TEC)	d	170	2f	17	2f	74	2

Table 3-5

Toxicity Reference Values (TRVs) for Terrestrial Plants and Invertebrates, Benthic Macroinvertebrates, and Fish
YNPS, Rowe, Massachusetts

Constituent of Potential Concern (COPC)	Terrestrial Plants (mg/Kg)		Terrestrial Invertebrates (mg/Kg)		Benthic Macroinvertebrates (mg/Kg)		Water Quality Criteria					
							Acute (ug/L)		Chronic (ug/L)		Lowest Chronic Value for Fish (ug/L)	
Dibenzo(a,h)anthracene	20	2a	30	4b	0.033 (TEC)	d	170	2f	17	2f	74	2
Dibenzofuran	--		--		5.1	g	--		--		--	
Fluoranthene	20	2a	30	4b	0.423 (TEC)	d	398	f	39.8	f	30	f
Fluorene	20	2a	30	b	0.0774 (TEC)	d	170	2f	17	2f	74	2
Indeno(1,2,3-cd)pyrene	20	2a	30	4b	0.03 (ERL)	c	170	2f	17	2f	74	2
Naphthalene	20	2a	30	4b	0.176 (TEC)	d	230	f	62	f	620	f
Phenanthrene	20	2a	30	4b	0.204 (TEC)	d	170	2f	17	2f	74	2
Pyrene	20	2a	30	4b	0.2 (TEC)	d	170	2f	17	2f	74	2
Polychlorinated Biphenyls												
Aroclor-1254	40	a	2.51	b	0.06 (TEC)	d	0.2	f	0.014	e	1.3	7
Aroclor-1260	40	a	2.51	b	0.06 (TEC)	d	0.2	f	0.014	e	1.3	f
Dioxin/Furan												
2,3,7,8-TCDD	--		500	c	0.00041	c	0.01	g	0.00001	g	--	
2,3,7,8-TCDF	--		--		--		--		--		--	
Inorganics												
Aluminum	50	a	600	3b	14,000 (ERL)	c	750	5e	87	5e	3288	f
Antimony	5	a	--		64 (AET)	c	1300	f	300	m	1600	f
Arsenic	10	a	60	b	9.79 (LEL)	d	340	5e	150	5e	2962	f
Barium	500	a	3000	3b	20	c	--		41,000	m	--	
Beryllium	10	a	40	i	--		16	f	7.3	m	57	f
Boron	0.5	a	20	3b	--		--		750	f	--	
Cadmium	4	a	20	b	5 (PEC)	d	2	5e	0.25	5e	1.7	f
Chromium	1	a	0.4	b	110 (PEC)	d	570	5e	74	5e	68.63	f
Copper	100	a	50	b	150 (PEC)	d	13	5e	9	5e	3.8	f
Iron	--		200	3b	2,000,000	h	--		1000	e	1300	f
Lead	50	a	500	b	130 (PEC)	d	65	5e	2.5	5e	18.88	f
Lithium	2	a	10	3b	--		--		--		--	
Manganese	500	a	100	3b	630	g	--		--		1780	f
Mercury	0.3	a	0.1	b	0.18 (TEC)	d	1.4	e	0.77	e	0.23	f
Molybdenum	2	a	200	3b	--		--		--		--	
Nickel	30	a	200	b	49 (PEC)	d	470	5e	52	5e	35	f
Selenium	1	a	70	b	0.1 (AET)	c	20	f	5	e	0.12	f
Silver	2	a	50	3b	4.5 (AET)	c	3.2	5e	0.12	5n	--	
Thallium	1	a	--		--		140	f	110	m	57	f
Zinc	50	a	200	b	460 (PEC)	d	120	5e	120	5e	36.41	f

Table 3-5

Toxicity Reference Values (TRVs) for Terrestrial Plants and Invertebrates, Benthic Macroinvertebrates, and Fish
YNPS, Rowe, Massachusetts

Constituent of Potential Concern (COPC)	Terrestrial Plants (mg/Kg)	Terrestrial Invertebrates (mg/Kg)	Benthic Macroinvertebrates (mg/Kg)	Water Quality Criteria		
				Acute (ug/L)	Chronic (ug/L)	Lowest Chronic Value for Fish (ug/L)

Table 3-7 Notes:

a - Sample et al, 1997a
b - Sample et al. 1997b
c - EPA, 1999
d - McDonald et al. (2000); MADEP (2006)

e - EPA, 2006
f - Suter and Tsao, 1996
g - NOAA, 1999
h - Persaud et al, 1993

i - EPA, 2000 Eco SSLs
j - Jones et al., 1997
k - Rhett et al., 1989
l - MADEP, 2002
m- MADEP, 2006 (MCP GW.xls; Sheet SW Target)
n - McDonald et al. (1999)

1 - No published NOAEL. NOAEL estimted as LOAEL/10.
2 - Values for Acenaphthene are used in the absence of specific PAH TRVs.
3 - Values protective of microbial processes are used in the absence of terrestrial invertebrate TRVs.
4 - Values for Fluorene are used in the absence of specific PAH TRVs.
5 - Values may be subject to change depending on available hardness/pH data.
6 - Values for Benzo(a)pyrene are used in the absence of specific PAH TRVs.
7 - Values for Aroclor-1260 are used for Aroclor-1254 in the absence of specific TRVs.
8- No chronic AWQC value available; value is for human health consumption of water and organisms.
-- = No Toxicity Reference Value is available.

TEC = Threshold Effects Concentration
PEC = Probable Effects Concentration

AET = Apparent Effects Threshold
ERL = Effects Range Low
LEL = Lowest Effects Level

Table 3-6
Toxicity Reference Values (TRVs) for Fish and Amphibians

Constituent of Potential Concern (COPC)	Fish									Amphibians				
	Rainbow Trout (mg/Kg)	Brown Trout (mg/Kg)	Bullhead (mg/Kg)	Bluegill (mg/Kg)	Perch (mg/Kg)	Carp (mg/Kg)	Endpoints		Test Species	Life Stage	Acute LC_{50} (ug/L)	$NOAEL_{Test}$ (ug/L)	$LOAEL_{Test}$ (ug/L)	
Total Petroleum Hydrocarbon														
TPH	--	--	--	--	--	--	No fish data available		--	--	--	--	--	
TPH-DRO	--	--	--	--	--	--	No fish data available		--	--	--	--	--	
TPH-GRO	--	--	--	--	--	--	No fish data available		--	--	--	--	--	
VPH - C5-C8 Aliphatics	--	--	--	--	--	--	No fish data available		--	--	--	--	--	
VPH - C9-C10 Aromatics	--	--	--	--	--	--	No fish data available		--	--	--	--	--	
EPH - C11-C22 Aromatics	--	--	--	--	--	--	No fish data available		--	--	--	--	--	
EPH - C19-C36 Aliphatics	--	--	--	--	--	--	No fish data available		--	--	--	--	--	
Total EPH	--	--	--	--	--	--	No fish data available		--	--	--	--	--	
Volatile Organic Compounds														
1,1-Dichloroethane	--	--	--	--	--	--	No fish data available		--	--	--	--	--	
1,1-Dichloroethene	--	--	--	--	--	--	No fish data available		--	--	--	--	--	
1,2,4-Trimethylbenzene	--	--	--	--	--	--	No fish data available		--	--	--	--	--	
2-Butanone	--	--	--	--	--	--	No fish data available		--	--	--	--	--	
4-Isopropyltoluene	--	--	--	--	--	--	No fish data available		--	--	--	--	--	
4-Methyl-2-pentanone	--	--	--	--	--	--	No fish data available		--	--	--	--	--	
Acetone	2660	--	--	--	--	--	Mortality	d	*Ambystoma mexicanum*	larvae	20000	1000	500	6
Carbon disulfide	--	--	--	--	--	--	No fish data available		--	--	--	--	--	
Chloromethane	--	--	--	--	--	--	No fish data available		--	--	--	--	--	
Diethyl Ether	--	--	--	--	--	--	No fish data available		--	--	--	--	--	
Methylene chloride	--	--	--	--	--	--	No fish data available		*Rana palustris*	embryo	32000	1600	800	6
Methyl-t-butyl ether	--	--	--	--	--	--	No fish data available		*Rana palustris*	embryo	32000	1600	800	6
Toluene	1010	--	--	--	--	--	Mortality	d	*Ambystoma gracile*	embryo	850	43	21	2b
Alcohols														
iso-Propyl Alcohol									--	--	--	--	--	
Semi-Volatile Organic Compounds														
2-Methylnaphthalene	10.2	--	--	--	--	--	Survival - no effect	4	*Xenopus laevis*	embryo	10,000	500	250	4
Acenaphthene	10.2	--	--	3.5	--	--	Survival - no effect; Mortality	4, d	*Rana pipiens*	tadpole	110	6	3	2b
Acenaphthylene	10.2	--	--	--	--	--	Survival - no effect	4	*Xenopus laevis*	embryo	10,000	500	250	4
Anthracene	10.2	--	--	--	--	--	Survival - no effect	4	*Xenopus laevis*	embryo	10,000	500	250	4
Benzo(a)anthracene	10.2	--	--	--	--	--	Survival - no effect	4	*Xenopus laevis*	embryo	10,000	500	250	4
Benzo(a)pyrene	10.2	--	4.9	--	--	25	Survival - no effect; liver toxicity - no effect	a, d	*Xenopus laevis*	embryo	10,000	500	250	2b
Benzo(b)fluoranthene	10.2	--	--	--	--	--	Survival - no effect	4	*Xenopus laevis*	embryo	10,000	500	250	4
Benzo(g,h,i)perylene	10.2	--	--	--	--	27.5	Survival - no effect; liver toxicity - no effect	4, d	*Xenopus laevis*	embryo	10,000	500	250	4
Benzo(k)fluoranthene	10.2	--	--	--	--	--	Survival - no effect	4	*Xenopus laevis*	embryo	10,000	500	250	4
Benzoic acid	--	--	--	--	--	--	No fish data available		*Xenopus laevis*	embryo	10839500	541,975	270,988	6
bis(2-Ethylhexyl)phthalate	--	--	--	0.66	--	--	Survival - no effect	d	--	--	--	--	--	
Carbazole	1.3	--	--	--	--	--	Survival - no effect	d	--	--	--	--	--	
Chrysene	10.2	--	13.2	--	--	22.7	Survival - no effect; liver toxicity - no effect	4, d	*Xenopus laevis*	embryo	10000	500	250	4
Dibenzo(a,h)anthracene	10.2	--	--	--	--	--	Survival - no effect	4	*Xenopus laevis*	embryo	10,000	500	250	4
Dibenzofuran	8.1	--	--	--	--	--	Survival - no effect		--	--	--	--	--	

Table 3-6
Toxicity Reference Values (TRVs) for Fish and Amphibians

Constituent of Potential Concern (COPC)	Fish									Amphibians				
	Rainbow Trout (mg/Kg)	Brown Trout (mg/Kg)	Bullhead (mg/Kg)	Bluegill (mg/Kg)	Perch (mg/Kg)	Carp (mg/Kg)	Endpoints		Test Species	Life Stage	Acute LC_{50} (ug/L)	$NOAEL_{Test}$ (ug/L)	$LOAEL_{Test}$ (ug/L)	
Fluoranthene	10.2	--	129	--	--	20	Survival - no effect; liver toxicity - no effect	4, d	*Rana pipiens*	tadpole	90	5	2	2b
Fluorene	8	--	--	--	--	--	Survival - no effect	d	*Xenopus laevis*	embryo	10,000	500	250	4
Indeno(1,2,3-cd)pyrene	10.2	--	--	--	--	--	Survival - no effect	4	*Xenopus laevis*	embryo	10,000	500	250	4
Naphthalene	10.2	--	--	--	--	--	Survival - no effect	4	*Xenopus laevis*	tadpole	2,100	105	53	2b
Phenanthrene	10.2	--	161	--	--	--	Survival - no effect; liver toxicity - no effect	4, d	*Xenopus laevis*	embryo	10,000	500	250	4
Pyrene	10.2	--	83.9	83.9	--	20	Survival - no effect; tumors; liver toxicity - no effect	4, d	*Rana pipiens*	tadpole	140	7	4	2b
Polychlorinated Biphenyls														
Aroclor-1254	81	26.3	--	--	--	--	Survival, growth - no effect	a	*Bufo americanus*	embryo	2.02	0.10	0.05	2b
Aroclor-1260	81	26.3	--	--	--	--	Survival, growth - no effect	5	*Bufo americanus*	embryo	2.02	0.10	0.05	5
Dioxin/Furan														
2,3,7,8-TCDD	1.38	0.0012	--	--	--	--	Survival, growth - no effect	a, d	--	--	--	--	--	
2,3,7,8-TCDF	0.0025	--	--	--	--	--	Survival - no effect	a	--	--	--	--	--	
Inorganics														
Aluminum	8.53	12.5	--	--	--	--	Survival - no effect; gro	a, d	*Rana pipiens*	embryo	471	24	12	2b
Antimony	9.0	--	--	--	--	--	Survival - reduced 50%	a	*Gastrophyrne carrolinensis*	embryo	3.0E-07	1.5E-08	7.5E-09	2b
Arsenic	6.1	--	--	1.8	--	--	Survival, growth - no effect	a	*Rana hexadactyla*	tadpole	249	12	6	2b
Barium	--	--	--	--	--	--	No fish data available		*Rana clamitans*	larva	--	7	21	6d
Beryllium	--	--	--	5	--	--	Survival - no effects	d	*Ambystoma opacum*	larva	3150	158	79	2b
Boron	--	--	--	--	--	--	No fish data available		*Rana pipiens*	embryo	--	6000	3000	3b
Cadmium	9.7	55.4	26	26	0.075		Reduced survival - death	a	*Ambystoma gracile*	larva	--	48.9	193.1	3b
Chromium	3.48	--	--	--	--	--	Survival - no effect	a	*Rana hexdactyla*	tadpole	42,950	2,148	1,073.8	2b
Copper	100	329	6.6	11.4		7.4	Survival - no effect	a	*Xenopus laevis*	embryo	--	50	100.0	3b
Iron	--	54	--	--	--	--	Hatching success - no effects	d	*Xenopus laevis*	embryo	1800	90	45	2b
Lead	0.64	2.4	--	--	--	--	Survival, growth - no effect	a	*Rana hexadactyla*	tadpole	3.3E-05	1.7E-06	8.3E-07	2b
Lithium	--	--	--	--	--	--	No fish data available		--	--	--	--	--	
Manganese	--	--	--	--	--	--	No fish data available		*Microhyla ornata*	tadpole	14330	720	360	2b
Mercury	12			10.7			Reduced survival	a	*Rana hecksheri*	tadpole	502	25	13	2b
Molybdenum	--	--	--	--	--	--	No fish data available		--	--	--	--	--	
Nickel	0.82	--	--	--	--	46.7	Survival - no effect	a	*Xenopus laevis*	embryo	1700	85	43	2b
Selenium	2.5	--	--	4.6	--	--	Survival - no effect	a	*Xenopus laevis*	embryo	1500	75	38	2b
Silver	0.24	--	--	0.06	--	--	Survival, growth - no effect	a, d	*Rana hexadactyla*	tadpole	25,700	1,285	643	2b
Thallium	--	--	--	2.72	--	--	Survival - no effect	d	*Gastrophyrne carrolinensis*	embryo	110	5.5	2.8	2b

Table 3-6
Toxicity Reference Values (TRVs) for Fish and Amphibians

Constituent of Potential Concern (COPC)	Fish									Amphibians				
	Rainbow Trout (mg/Kg)	Brown Trout (mg/Kg)	Bullhead (mg/Kg)	Bluegill (mg/Kg)	Perch (mg/Kg)	Carp (mg/Kg)	Endpoints		Test Species	Life Stage	Acute LC_{50} (ug/L)	$NOAEL_{Test}$ (ug/L)	$LOAEL_{Test}$ (ug/L)	
Zinc	60	60	28.6	--	21.78	--	Survival - no effect, Liver toxicity - no effect	a, d	*Xenopus laevis*	embryo	899	45	22	2b

Table 3-8 Notes:

a - Jarvinen and Ankley, 1999
b - USEPA, 1996
c - Pauli, Perrault and Money, 1986
d - USACE ERED, 2003

1 - TRVs are from survival studies analyzing whole body tissue.
2 - $NOAEL_{Test}$ are based on the acute LC_{50} divided by an uncertainty factor of 20 and/or $LOAEL_{Test\ are}$ based on the acute LC50 divided by an uncertainty factor of 40.
3 - LC_{50} was not used to calculate NOAEL and LOAEL values.
4 - TRV for Benzo(a)pyrene was used in the absence of specific PAH TRVs.
5 - Aroclor-1254 was used in the absence of specific PCB TRVs.
6 - No published LOAEL. LOAEL estimated as NOAEL x 3.

$NOAEL_{Test}$ - No Observed Adverse Effects Level in Test Species
$LOAEL_{Test}$ - Lowest Observed Adverse Effects Level in Test Species
-- = No Toxicity Reference Value Available

Attachments

Attachment A

Exposure Estimation Methods For Biota

Determination of Exposure Point Concentrations in Biota

In order to conduct the environmental risk characterization, it is necessary to estimate exposure point concentrations (EPCs) in biota such as aquatic and terrestrial plants, aquatic and terrestrial invertebrates, fish, small mammals, and birds. With the exception of PCB and radionuclide monitoring data for fish, these EPCs in biota will be estimated using the published approaches described below. Note that a variety of empirical approaches are described below. The particular approach will be selected depending on the availability of published uptake factors for particular compounds and receptors.

Linear biouptake factors represent the ratio of the chemical concentration in biological tissue to that in soil or sediment. These models (based on regression equations) assume that accumulation is linear and across all soil/sediment concentrations. A linear uptake factors of this form are often termed bioconcentration factors (BCFs), biota-sediment accumulation factors (BSAF), *etc.*.

Log-linear regression uptake models have also been developed. These non-linear models predict decreasing bioaccumulation as chemical concentration in soil/sediment increases. Various soil/sediment properties, such as pH, clay content, calcium, and organic matter, can strongly affect the retention of contaminants in soil/sediment and the bioavailability of these contaminants for uptake by receptors, thus producing the observed non-linear relationships. These empirical regression models are "linearized" by performing the regressions in log-space. Because contaminant uptake is influenced by characteristics of the organism and by the properties of the chemical, separate uptake factors are recommended for each chemical and taxonomic group considered (Sample *et al.*, 1997).

Biota-sediment accumulation factors are commonly used to estimate the uptake of organic chemicals in fish. The primary exposure pathway for fish is the consumption of contaminated food. Sediments often act as a local sink for contaminants, which may increase the contaminant exposure for sediment-associated biota that ingest sediment particles while foraging. BSAFs are transfer coefficients that relate concentrations in biota to concentrations in sediment. They are calculated as the ratio of the concentration of organic chemical in fish tissue (normalized by lipid content) to the concentration of organic chemical in sediment (normalized by organic carbon content).

A.1 Plants

A.1.1 EPCs for COPCs in Plants

Chemical uptake in plants *via* the roots can be estimated as (USEPA, 1999):

$$C_p \quad = \quad C_s \times BCF_p \times (1 - F_{wc}) \qquad \text{(A.1-1)}$$

where:

C_p = concentration in plant (mg/kg-wet weight)
C_s = concentration in soil or sediment (mg/kg - dry weight)
BCF_p = soil/sediment-plant uptake factor (mg/kg plant dry wt./ mg/kg soil dry wt.)
F_{wc} = water content (g-water/g-fresh wt.)
F_{wc} : 0.63 terrestrial plants (USEPA, 1993)

For organic compounds without sufficient data to develop empirical BCF_p values, estimated uptake factors can be estimated from the octanol-water partition coefficient using the following regression (Travis and Arms, 1988; USEPA, 1999):

$$\log_{10}(BCF_p) \quad = \quad 1.58 - 0.58 \log_{10}(K_{ow}) \qquad \text{(A.1-2)}$$

For inorganic compounds, empirically determined values for BCF_p have been reported by Baes *et al*. (1984) or chemical uptake in plants can be estimated using log-linear models (Bechtel Jacobs, 1998a).

A.1.2 EPCs for COPCs in Plants – Log-linear Regression Equation for Inorganics

Bechtel Jacobs (1998a) developed a non-linear regression equation relating chemical uptake in plants. The power model is of the form:

$$C_p \quad = \quad m\left(C_s\right)^b$$

The natural log-transformed linear regression model is then:

$$LN(C_p) = \quad m' + b\,LN(C_s)$$

or

$$C_p = \exp[m' + b\ LN(C_s)] \qquad (A.1\text{-}3)$$

$$C_{p\text{-}ww} = C_p \times (1 - F_{wc})$$

where:

C_p	=	concentration in plant (mg/kg – dry wet)
$C_{p\text{-}WW}$	=	concentration in plant (mg/kg – wet weight)
m'	=	y-intercept of the regression line for log-transformed data
b	=	slope of the regression line for log-transformed data
C_s	=	concentration in soil or sediment (mg/kg – dry weight)
F_{wc}	=	water content (terrestrial = 0.63; aquatic = 0.78; USEPA, 1993)
exp()	=	exponential function (e^x)
LN()	=	natural logarithm

Note that Bechtel Jacobs developed similar non-linear power models for chemical uptake in invertebrates (discussed below), but used base-10 logarithms for the regression models.

A.2 Invertebrates

Empirical relationships using linear and log-linear regression equations have been developed for chemical uptake in invertebrates relating the chemical concentration in the invertebrate to the chemical concentration in soil or sediment.

A.2.1 Linear Bio-Uptake Model:

Sample *et al*. (1997) published a model relating chemical concentrations in pore-water to the chemical concentration in earthworms, a representative soil invertebrate. The linear model is:

$$C_v = K_{bw} \times C_{pw} \qquad (A.2\text{-}1)$$

For non-ionic chemicals, the chemical concentration in pore-water is related to the chemical concentration adsorbed to soil/sediment according to:

$$C_{pw} = C_s/K_d \qquad (A.2\text{-}2)$$

Combining (A-3) and (A-4) gives:

$$C_v = BCF_v \times C_s \quad \text{(A.2-3)}$$

where

$$BCF_v = \frac{K_{bw}}{K_d} \quad \text{(A.2-4)}$$

The conversion from dry-weight concentration to wet weight is simply:

$$C_{v\text{-}WW} = C_v \times (1\text{- } F_{wc}) \quad \text{(A.2-5}$$

where:

C_v	=	concentration in invertebrate (mg/kg-dry weight)
$C_{v\text{-}WW}$	=	concentration in invertebrate (mg/kg-wet weight)
C_{pw}	=	concentration in pore-water (mg/L)
C_s	=	concentration in soil/sediment (mg/kg – dry weight)
K_{bw}	=	biota-water partition coefficient (L/kg)
K_d	=	soil-water partition coefficient (L/kg)
BCF_v	=	soil-biota uptake factor (mg/kg-invert. dry wt.)/(mg/kg-dry soil)
F_{wc}	=	water content (mg-water/mg-fresh wt.)
		F_{wc}: 0.79 aquatic; 0.71 terrestrial (USEPA, 1993)

The biota-water partition coefficient can be estimated from the octanol-water partition coefficient (K_{ow}) from the following (Sample *et al*., 1997):

$$\log_{10} K_{bw} = \log_{10} K_{ow} - 0.6$$

or $\quad$ (A.2-6)

$$K_{bw} = 10^{(\log Kow - 0.6)}$$

The soil-water partition coefficient is given by:

$$K_d = f_{oc} \times K_{oc} \quad \text{(A.2-7)}$$

where

f_{oc}	=	fraction of organic carbon (kg-OC/kg-soil)
K_{oc}	=	organic carbon-soil partition coefficient (L/kg)

If a value of K_{oc} is not available, it can be estimated from K_{ow} (Sample *et al*., 1997):

$$\log_{10} K_{oc} = 0.983 \log_{10} K_{ow} + 0.00028 \quad \text{(A.2-8)}$$

The value of BCF_v can be estimated as K_{bw}/K_d using the above relationships, or alternatively USEPA (1999) provides the following empirical relationship (note this empirical equation is based on a wet weight basis for chemical concentration in invertebrate tissue):

$$\log BCF_{v\text{-}ww} = 0.819 \log K_{ow} - 1.146$$

where

$BCF_{v\text{-}ww}$ = soil-biota uptake factor (mg/kg-invert wet wt.)/(mg/kg-dry soil)

For inorganic chemicals, uptake factors (BCF_v) are available from Sample *et al*. (1997), Sample *et al*. (1998), or Bechtel Jacobs (1998).

A.2.2 Log-Linear Regression Models

Power models have also been used to develop regression equations relating chemical uptake in invertebrates for metals and PCBs. The power model is of the form:

$$C_v = m\left(C_s\right)^b$$

Several authors have developed log-linear regression relationships from this model, using field data to develop the regression parameters. Bechtel Jacobs (1998) developed log-regression parameters based on dry-weight sediment chemical concentration data for metals and organic-carbon normalized data for PCBs. The Bechtel Jacobs (1998) regression equations predict the dry-weight metal concentration in invertebrates, whereas for PCBs the regressions were based on lipid-normalized data. Sample *et al*. (1998) developed similar regression models, but used natural logarithm transformations, and did not use lipid or organic carbon adjusted values for PCBs.

Thus, the general form of the equations above translates into the following specific log-regression models:

Bechtel Jacobs (1998) -- Regression Model for Metals:

$$\log_{10}(C_v) = m' + b \log_{10}(C_s)$$

$$C_{v-DW} = 10^{(m'+b\log(C_s))}$$

$$C_{v-WW} = C_{v-DW} \times (1 - F_{WC}) \qquad \text{(A.2-9)}$$

Bechtel Jacobs (1998) – Log Regression for PCBs:

$$C_{v-LP} = 10^{(m'+b\log(C_{s-OC}))}$$

$$C_{s-OC} = C_s / OC \qquad \text{(A.2-10)}$$

$$C_{v-WW} = C_{v-LP} \times LP_v$$

Sample et al. (1998) – Natural Log Regression for Metals and PCBs :

$$LN(C_{v\text{-}DW}) = m' + b\, LN(C_s)$$

or

$$C_{v\text{-}DW} = \exp[m' + b\, LN(C_s)] \qquad \text{(A.2-11)}$$

$$C_{v\text{-}WW} = C_{v\text{-}DW} \times (1\text{-}F_{wc})$$

where:

C_v	=	chemical concentration in invertebrates (mg/kg)
$C_{v\text{-}ww}$	=	chemical concentration in invertebrates (mg/kg – wet wt.)
$C_{v\text{-}DW}$	=	chemical concentration in invertebrates (mg/kg – dry wt.)
$C_{v\text{-}LP}$	=	lipid-normalized PCB concentration in invertebrates (mg/kg-lipid)
m'	=	y-intercept of the log-transformed regression model (mg/kg_{biota})
b	=	slope of the log-transformed regression model (mg/kg_{biota} per mg/kg_{sed})
C_s	=	chemical concentration in sediment (mg/kg – dry wt.)
$C_{s\text{-}OC}$	=	chemical concentration in sediment - carbon normalized (mg/kg-OC dry wt.)
LP_v	=	lipid content in invertebrates (kg-lipid/kg-tissue)
OC	=	organic carbon content in sediment (kg-OC/kg-sediment)
F_{wc}	=	water content (mg-water/mg-tissue)
		F_{wc}: 0.79 aquatic; 0.71 terrestrial (USEPA, 1993)
log()	=	base 10 logarithm
LN()	=	natural logarithm
exp()	=	exponential function (e^x)

Sample *et al*. (1997) report that 0.02 kg-lipid/kg-tissue is a typical lipid content of invertebrates (*e.g.*, LP_v = 0.02).

A.3 Fish

Chemical concentrations for organic COPCs in fish can be estimated using one of two methods. One method involves a two-step process that combines (1) estimates of chemical concentrations in invertebrates (as discussed in previous Section), coupled with (2) the use of an assimilation of the invertebrate diet into fish tissue. Alternatively, empirically derived biota sediment accumulation factors (BSAF) relating the chemical concentration in fish to the chemical concentration in sediment, can be used. The selection of the particular approach will be based on the availability of data or published values.

A.3.1 Assimilation Approach – Inorganics

In the absence of BSAF or BCF values for inorganics, the chemical concentration in fish tissue can be estimated as a function of the inorganic COPC concentration in food (invertebrates) and based on the food assimilation efficiency:

$$C_f = C_v \times \alpha \qquad \text{(A.3-1)}$$

where

C_f = chemical concentration in fish (mg/kg-wet weight)
C_v = chemical concentration in invertebrate food source (mg/kg-wet weight)
α = food assimilation efficiency (unitless fraction)

The assimilation efficiency of food is the fraction of food ingested that does not appear in the feces, *i.e.*, conservatively assumed to be incorporated into fish tissue. A food assimilation efficiency for lake trout of 0.8 is reported by Thomann and Connolly (1984). This approach assumes that 80% of food is assimilated by the fish, and 100% of the chemical in the assimilated food source is retained in fish with no further metabolism or depuration.

A.3.2 BSAF Approach – Organics

For the uptake of organic COPCs into fish for which measured data are unavailable, a biota–sediment accumulation factor (BSAF) can be used to estimate fish tissue concentrations (USEPA, 1997):

$$C_f = BSAF \times C_s \times \frac{LP}{OC} \qquad (A.3\text{-}2)$$

where:

C_f	=	chemical concentration in fish tissue (mg/kg)
BSAF	=	biota sediment accumulation factor (mg-chem/kg-lipid per mg-chem/kg-OC)
C_s	=	chemical concentration in sediment (mg/kg)
LP	=	lipid content in fish whole body or filet (kg-lipid/kg-tissue)
OC	=	organic carbon fraction in sediment (kg-OC/kg-sed)

A.4 COPCs in Herbivores, Omnivores, Carnivores

The measurement endpoints for herbivores, omnivores, and carnivores are based on chemical intake, so it is necessary to estimate the COPC concentration in food and environmental matrices ingested by these receptors. The concentration of COPCs in animal tissue (herbivores, omnivores, carnivores) can be estimated as a function of consumption of dietary items and incidental sediment/soil/water ingestion using the following model including bioconcentration factors and food chain multipliers for trophic transfer (USEPA, 1999):

$$C_a = (C_s \times BCF_{s\text{-}a} \times P_s) + (C_w \times BCF_{w\text{-}a} \times P_w) + (C_p \times BCF_{p\text{-}a} \times F_p \times P_p)$$

$$+ \sum_i \left(C_{FI,i} \times BMF_{FI,i} \times F_{FI,i} \times P_{FI,i} \right) \qquad (A.4\text{-}1)$$

where:

C_a	=	COPC concentration in animal tissue (mg/kg)
C_s	=	COPC concentration in soil or sediment (mg/kg)
$BCF_{s\text{-}a}$	=	soil/sediment-animal biouptake factor (mg/kg-animal)/(mg/kg-soil/sed.)
P_s	=	proportion of soil/sediment containing COPC (unitless fraction)
C_w	=	COPC concentration in water (mg/L)
$BCF_{w\text{-}a}$	=	water-animal biouptake factor (mg/kg-animal)/(mg/L-water)
P_w	=	proportion of water containing COPC (unitless fraction)
C_p	=	COPC concentration in plants (mg/kg)
$BCF_{p\text{-}a}$	=	plant to animal biouptake factor (mg/kg-animal)/(mg/kg-plant)
F_p	=	fraction of diet consisting of plants (unitless fraction) (herbivore F_p = 1.0; carnivore F_p = 0)
P_p	=	proportion of plants containing COPC (unitless fraction)
$C_{FI,i}$	=	COPC concentration in i^{th} non-plant food item (mg/kg)
$F_{FI,i}$	=	fraction of i^{th} non-plant food item in diet (unitless decimal)
$P_{FI,i}$	=	proportion of non-plant food item containing COPC (unitless fraction)
$BMF_{FI,i}$	=	biomagnification multiplier (unitless)

In the absence of specific target receptors, representative dietary fractions for herbivore, omnivore, carnivore prey items (*e.g.*, food items) are given below.

Animal Type	**Dietary Fraction**
Herbivore (*e.g.*, rabbit)	F_p = 1.0 $F_{FI,i}$ = 0 (*e.g.*, diet 100% plant)
Omnivore (mammal) (*e.g.*, raccoon)	F_p = 0.45 $F_{FI,1}$ = 0.45 (invertebrates) $F_{FI,2}$ = 0.1 (other omnivore/carnivore)
Omnivore (bird) (*e.g.*, robin)	F_p = 0.5 $F_{FI,1}$ = 0.5 (invertebrates)
Carnivore (mammal) (*e.g.* fox)	F_p = 0 $F_{FI,1}$ = 0.5 (herbivore) $F_{FI,2}$ = 0.5 (other omnivore/carnivore)

The BCF parameter (by medium) represents the ratio of chemical concentration in animal tissue to the chemical concentration in water, soil/sediment, or plant materials:

$$\text{BCF} = \frac{C_{animal}(\text{mg} - \text{COPC}/\text{kg} - \text{animal})}{C_{media}(\text{mg} - \text{COPC}/\text{kg} - \text{media})}$$

While this ratio is frequently viewed as a "unitless" proportion, the units must be carefully defined. The BCF factors can be defined in terms of either fresh-weight or dry-weight of biological tissues (*e.g.*, mg/kg-wet wt. or mg/kg-dry wt.). The chemical concentration in soil or sediment is typically reported on a dry-weight basis, but also can sometimes be reported on an organic-carbon normalized basis. Thus, it is important to determine the underlying units of measure when applying a reported BCF or when using a regression-derived BCF.

Estimates of the $BCF_{s\text{-}a}$ and $BCF_{w\text{-}a}$ are provided in USEPA (1999, Appendix D). Estimates of $BCF_{p\text{-}a}$ for ingestion of food items is derived according to the following formula using biotransfer factors (Travis and Arms, 1988)

$$BCF_{p\text{-}a} = B_a \times IR \qquad \text{(A.4-2)}$$

where:

$BCF_{p\text{-}a}$	=	plant-animal biouptake factor (mg-COPC/kg-animal)/(mg-COPC/kg-plant)
B_a	=	biotransfer factor (day/kg-tissue ingested – wet weight)
IR	=	average ingestion rate (kg/day – wet weight)

For organics (other than dioxins/furans) the following regression equation can be used to estimate B_a (USEPA, 1999)

$$\begin{aligned} &\text{Mammals:} \quad \log_{10} B_{a,mammal} = \log_{10} K_{ow} - 7.6 \\ &\text{Birds:} \quad B_{a,bird} = B_{a,mammal} \times 0.8 \end{aligned} \qquad \text{(A.4-3)}$$

The biotransfer factor for birds is estimated from the biotransfer factor for mammals, adjusting for lipid content in birds of approximately 80% the lipid content in mammals (USEPA, 1999).

The biomagnification parameter (BMF) depends on the trophic level of the food item, relative to the trophic level of the animal and can be estimated as follows (USEPA, 1999).

$$BMF = \frac{FCM_{TL-an}}{FCM_{TLi-prey}} \qquad \text{(A.4-4)}$$

where

$FCM_{Tl\text{-}an}$	=	food chain multiplier for the trophic level of the animal (unitless)
$FCM_{TLi\text{-}prey}$	=	food chain multiplier for the trophic level of the prey (unitless)

Estimates of FCM by trophic level, which varies depending on the chemical K_{ow}, are provided by USEPA (1999).

The proportion of the media or food intake that is contaminated with the COPC will depend on the environmental extent of contamination and the home range or foraging area for a particular receptor (USEPA, 1999). Thus, P_i can be estimated as (Sample *et al.*, 1997):

$$P_i = \frac{A_c}{A_f} \qquad \text{(A.4-5)}$$

where

P_i	=	proportion of i^{th} media or food item containing COPC (unitless fraction)

A_c = area containing COPC (acres)
A_f = total foraging area of receptor (acres)

Dietary composition estimates (*e.g.*, to estimate F_{FI}) for various bird and mammal species are published in Baes *et al*.(1984), Sample *et al*., (1997), USEPA (1993), and USEPA (1999).

A.5 Estimation of Total Exposure to COPCs

Because many measurement endpoints are based on chemical intake (typically daily intake), rather than body burden, it is necessary to estimate the total COPC intake based on exposure from environmental media and food. Daily intake, ingestion rates, and species foraging ranges are published in USEPA (1993). The daily intake is given by the summation of intakes from all media of potential concern (USEPA,1999):

$$DI = \sum_i \frac{(C_i \times IR_i \times P_i)}{BW} \qquad (A.5\text{-}1)$$

where:

DI = daily intake of COPC (mg/kg/day)
C_i = COPC concentration in i^{th} media or food item (mg/kg)
IR_i = ingestion rate of i^{th} media (kg/day)
P_i = proportion of i^{th} media or food item that is contaminated (unitless fraction)
BW = body weight of receptor (kg)

Note that the proportion of the contaminated media or food occurs in Equation (A.5-1) as it does in Equation (A.4-1). This is not "double-counting" as each equation is based on different receptors. That is, the chemical intake of say a carnivore calculated using Equation (A.5-1) would include the chemical concentration in food items calculated using Equation (A.4-1). The COPC concentration in these food items would depend in turn on the habitat/foraging range of these prey items, which is separate from the foraging range of the carnivore consuming them in this example. The "P_i" value for the carnivore chemical intake estimate would thus be different from the "P_i" value corresponding to the calculation of chemical body burden in the food items consumed by the carnivore. For prey with small foraging ranges, the value of "P_i" would tend toward a value of one (1.0).

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Attachment B

Radiation Activity and Dose Units and Unit Conversions

Measure	International Units	Convential Units	Unit Conversion
Activity	Becquerel (Bq) 1 nuclear disintegration /sec	Curie (Ci) 3.7×10^{10} disintegrations/sec	1 Bq = 2.7×10^{-11} Ci 1 Ci = 3.7×10^{10} Bq
Absorbed Dose	Gray (Gy) = 1 Joule/kg	1 rad = 0.01 Joule/kg 1 rad = 100 erg/g tissue	1 Gy = 100 rad 1 rad = 0.01 Gy
Effective Dose Equivalent	Sievert (Sv) = Gy × QF (QF = quality factors)	Radiation Equivalent Man (rem)	1 rem = 0.01 Gy × QF 1 rem = 1 rad × QF

The energy of radioactive decay is sometimes given in units of million electron volts (MeV) per disintegration. Conversions for energy units are:

1 erg = 10^{-7} Joule
1 erg = 6.24145×10^{5} MeV

Absorbed Dose (rad) *vs*. Effective Dose Equivalent (rem)

The conversion from rad (radiation absorbed dose) to rem ("radiation equivalent man" dose) is given by:

rem = rad × QF (× organ-specific absorption -- sometimes)

where QF represents a "quality factor" that increases for high energy radiation. Generally, for high energy (>10 MeV) emissions such as alpha emissions, QF = 20. For lower energy emissions, such as gamma, beta, and x-rays, the QF value is typically 1, although radionuclide-specific QF values can vary somewhat and are tabulated in reference documents. In addition to adjusting for radiation quality factors, the conversion from rad to rem is sometimes adjusted based on organ or tissue-specific absorption.

Conversion of Mass Units to Activity Units

$$\frac{\text{pCi}}{\text{g}} = \frac{\text{mg}}{\text{kg}} \times 10^{-6}\,\frac{\text{kg}}{\text{mg}} \times \left[\text{AvNo}\left(\frac{6.02\times 10^{23}\,\text{atoms}}{\text{mole}}\right)\Big/\text{MW}\left(\frac{\text{g}}{\text{mole}}\right)\right]$$

$$\times\left(\frac{\text{LN}(2)}{t_{1/2}}\right)\times\frac{1\,\text{yr}}{31{,}536{,}000\,\text{sec}}\times\frac{1\,\text{pCi}}{0.037\,\text{atom disint/sec}}$$

$$\frac{\text{pCi}}{\text{g}} = \frac{\text{mg}}{\text{kg}} \times \left[3.576\times 10^{11}\Big/\left(\text{MW}\times t_{1/2}\right)\right]$$

$$\frac{\text{mg}}{\text{kg}} = \frac{\text{pCi}}{\text{g}} \times 2.796\times 10^{-12}\times \text{MW}\times t_{1/2}$$

For Aqueous conversion from pCi/L to mg/L, a similar conversion applies:

$$\frac{\text{mg}}{\text{L}} = \frac{\text{pCi}}{\text{L}} \times 2.796\times 10^{-15}\times \text{MW}\times t_{1/2}$$

where

AvNo	=	Avogadro's Number (6.02×10^{23} atoms/mole)
MW	=	Atomic Weight (g/mole)
$t_{1/2}$	=	half-life (yrs)