5.0 OVERALL ERC APPROACH

5.1 Purpose

The purpose of this section is to briefly describe the scope and sequence of the Environmental risk Characterization (ERC). ERC is a process that evaluates the potential that adverse ecological effects may occur or are occurring as a result of exposure to one or more biological, chemical, or physical stressors (USEPA, 1992). Specifically, the objective of an MCP ERC is to "characterize the risk of harm to habitats and biota to oil and hazardous material at, or from, a disposal site". The "risk of harm" standard relies upon available evidence to determine the likelihood of actual, or potential impacts. "Habitats and biota exposed" refers to ecological subpopulations and communities that, under current and foreseeable future conditions, may or could experience, potentially adverse levels of exposure. As such, an ERC is a two-staged process. Stage I identifies actual or potential impacts. Stage II is a site-specific evaluation of the potential for adverse exposure to ecological receptors at the site. An ERC is used to methodically evaluate and organize information, data, assumptions, and uncertainties for the purpose of understanding and predicting the relationships between stressors and ecological effects in a way that is useful for environmental decision making. Risk managers can then use the information from an ERC to determine the acceptability of adverse effects and, if necessary, make recommendations for a remedial investigation/feasibility study (RI/FS).

5.2 Stage I – Screening-Level ERC

As specified by the MCP (310 CMR 40.0995), there is a two–tiered process for conducting a Method 3 ERC. The first step is a Stage I screening-level environmental risk characterization (Stage I ERC) in which the objective is to identify and document conditions that do *not* warrant a Stage II ERC, either because of the absence of a potentially significant exposure pathway or because environmental harm is readily apparent and, therefore, additional assessment would be redundant. Additional details on the Stage I ERC process are discussed in more detail in later sections. If any potentially significant exposure pathways are indicated from the Stage I ERC, then these pathways are further evaluated in a more refined assessment termed a Stage II ERC or baseline ERA (BLERA).

5.3 Stage II ERC

A Stage II ERC is a quantitative, site-specific characterization of risk of harm to ecological receptors. The three major components of a Stage II ERC are described below and will be discussed in more detail in later sections (MADEP, 1999 ; USEPA, 1998):

- **Problem Formulation** – In the problem formulation phase, goals are evaluated, assessment and measurement endpoints are selected, and the conceptual model is prepared. Assessment endpoints are clear, specific expressions of the actual value that is to be protected, are the ultimate focus in risk characterization, and act as a link to the risk management process (such as the policy goals). Effects measures or measurement endpoints are responses that may be more easily measured than assessment endpoints but are, however, related quantitatively or qualitatively to the assessment endpoints.

- **Analysis Phase** – During the analysis phase, exposure to stressors and the relationship between stressor concentrations and ecological effects are evaluated. The analysis phase involves collection and integration of information on toxicity of the chemical(s) of potential ecological concern (COPECs), COPEC concentrations and spatial distribution, and exposure conditions (temporal and spatial patterns), as well as observations or predictions of adverse effects.

- **Risk Characterization** – In the risk characterization step, risk is estimated through integration of exposure and stressor-response profiles, risk is described by discussing lines of evidence and determining ecological adversity. The measurement results are evaluated to determine whether they support a conclusion of no significant risk for each assessment endpoint. In some cases, more than a single measurement has been conducted to evaluate an assessment endpoint. If the results of those measurements do not agree, those results are considered in combination, and a conclusion is based on a "weight-of-evidence" as described in the MCP guidance.

The overall risk characterization approach to be applied is a hazard quotient (HQ) approach (section 10.0). In this approach, measures of exposure (section 8.0) will be compared to measures of effect (section 9.0).

5.3.1 Hazard Quotients

Potential ecological risks were determined based upon a series of calculated hazard quotients (HQs). In short, a HQ is calculated by dividing the estimated or measured exposure concentration by a toxicity benchmark for each receptor (Eq. 5-1):

$$HQ = \frac{ADD_{pot}\ (mg / kg\ BW / d)}{\text{Toxicity Reference Value}\ (mg / kg\ BW / d)} \qquad \text{Eq. 5-1}$$

where: ADD_{pot} is the average potential daily dose (see section on Exposure Assessment for details);

Toxicity Reference Value is either based on a no observable adverse effect level (NOAEL) or a lowest observable effect level (LOAEL) (see section on Effects Assessment for details).

While useful and appropriate as an ERC approach, this method does not indicate the actual probability or exact magnitude of risk, but rather the possibility that risk may exist. Because the procedures used to calculate HQs in this ERC do not include entirely site-specific information on certain exposure pathways, conservative default assumptions were utilized to maintain an appropriate degree of conservatism. For regulatory purposes, the ERC is required to err on the side of protection (minimizing type I errors) so the assessor must employ compensatory conservative bias and safety factors greater than or equal to each of the above uncertainties. The contribution of key parameters towards the overall uncertainty of this analysis will be discussed as a sensitivity analysis later in this ERC.

5.3.2 Non-Chemical Stressors

This ERC did not fully consider the potential impact of non-chemical stressors, including habitat suitability, siltation, and urbanization. Since these natural and anthropogenic stressors can have potential impact on certain receptor populations and productivity, the effects of these stressors are likely confounding factors in this ERC.

5.4 Weight-of-Evidence Approach

The Massachusetts Weight-of-Evidence Workgroup defines weight-of-evidence as "*the process by which multiple measurement endpoints are related to an assessment endpoint to evaluate whether significant risk of harm is posed to the environment*" (Massachusetts Weigh-of-Evidence Workgroup, 1995). A weight-of-evidence approach may either be quantitative or qualitative. While the qualitative approach is clearly simpler to apply than the quantitative approach, it potentially introduces greater subjectivity. Despite this, MADEP recognizes that the qualitative approach is useful in situations in which multiple measurement endpoints do not contradict each other or when a contradiction exists but there is a clear difference in the scientific defensibility of the endpoints.

In the qualitative approach, the first step is that each measurement endpoint is assigned a qualitative score of high, medium, or low for each of the following three attributes:

1. Strength of association between assessment and measurement endpoints;
2. Data quality; and
3. Study design and execution.

Next, the numbers of high, medium, and low scores for each measurement endpoint are counted and the measurement endpoint is assigned an overall score based on the majority of attribute-specific scores. The second step is to evaluate the outcome of each measurement endpoint with respect to indication of risk of harm (e.g., positive, negative, and undetermined) and magnitude of the outcome (e.g., high or low). The third step is to integrate the measurement endpoint weight and magnitude of response on a matrix, in to determine whether the overall evidence indicates a risk of harm.

Assessment and measurement endpoints are presented in the section on Problem Formulation. The weight-of-evidence approach will be applied only in situations for which multiple measurement endpoints are utilized for a single assessment endpoint. The weighting of each measurement endpoint will be presented in the section on Problem Formulation. The evaluation of the outcome of each measurement endpoint with respect to indication of risk of harm will be presented in the section on Risk Characterization.

6.0 STAGE I SCREENING-LEVEL ERC

Initially, a Stage I screening-level ERC was conducted, as specified in the MCP (310 CMR 40.0000), in order to:

- Identify potential exposure pathways and determine whether each exposure pathway is complete. Incomplete exposure pathways are eliminated from further consideration.
- Determine whether risk of harm is "readily apparent" for each complete exposure pathway. If harm is "readily apparent", a full quantitative risk characterization may not be necessary.
- Determine which complete exposure pathways need to be further evaluated in a Stage II ERC.

The Stage I ERC was conducted by comparing measured concentrations of chemicals in each exposure media from the site to conservative benchmarks. The list of potentially applicable or suitably analogous standards that were evaluated included:

- Massachusetts Surface Water Standards promulgated in 314 CMR 4.00;
- USEPA National Recommended Water Quality Criteria (USEPA, 1999);
- USEPA Region IV Ecological Screening Values (USEPA Region IV, 2000);
- Toxicological Benchmarks for Screening Potential Contaminants of Concern for Effects on Aquatic Biota (Suter and Tsao, 1996)
- Draft Ecological Soil Screening Levels (Eco-SSLs; USEPA, 2000a);
- Concentrations reported in the scientific literature to be associated, or potentially associated, with toxic effects; and
- Site size, location, and/or landscape characteristics specifically adopted by the MADEP as screening criteria.

The benchmarks that were selected were primarily those published by USEPA Region IV because this compilation of ecological screening values are conservative and very comprehensive in the coverage of chemicals of concern, and the values are media-specific (*e.g.*, surface water, sediment, or wetland soil; Appendix D). Screening-level values for COPECs in surface water are primarily USEPA ambient water quality criteria for the protection of aquatic organisms except when not available. Note that for several of the metals, the benchmarks were adjusted site-specifically based on hardness for each sampling time (*e.g.*, inundation versus non-inundation). Screening-level values for chemicals in sediments and wetland soils are presented in the sections below. There are some chemicals for which no screening-level values are available. For these chemicals, either they were considered relatively non-toxic or naturally occurring for a particular medium (*e.g.*, aluminum in soil) or other chemicals were used as surrogates (*e.g.*, certain PAHs do not have individual screening values whereas others do and therefore, PAHs were quantified as total PAHs and compared to benchmark values for total PAHs).

6.1 Evaluation of the Condition for "Readily Apparent Harm"

The condition for "readily apparent harm" was evaluated at this site based on MCP guidance (310 CMR 40.0995(3)(b). The following conditions were found to represent "readily apparent harm":

- Visual observation of stunted vegetation;
- Exceedances of Massachusetts Surface Water Standards promulgated in 314 CMR 4.00, which include USEPA Ambient Water Quality Criteria;
- Concentrations of COPECs (e.g., copper and chromium) in wetland soil that are associated with the stunted vegetation zone (i.e., the 95% lower confidence limit of the arithmetic mean of COPECs in wetland soil from the known area of stressed vegetation); and
- Concentrations of PCBs that are equal to or greater than 50 mg/kg, dry weight, a concentration that is consistent with regulatory thresholds stipulated under the federal Toxic Substances Control Act (TSCA; specifically 40 CFR Part 761; USEPA, 2000b) that would require removal to meet federal regulations for the management of PCB remediation waste. The only exception to this condition is location T-10-3. The PCB concentration at T-10-3 is questionable since the Aroclor analysis resulted in a PCB concentration of 61 mg/kg and the congener-specific analysis resulted in a PCB concentration of 1.9 mg/kg. Also, since the location of T-10-3 is isolated and not contiguous to the remaining ARAH, the T-10-3 location is not included in the ARAH, but is included in the Stage II ERC and Phase III evaluation.

It was determined that there is an area of approximately 27,580 sq. ft. in which there is visible evidence of stressed or stunted vegetation. This same area, which is proximal to the outfall (OF-1) corresponds well with significantly elevated COPEC concentrations (i.e., hot spot), including copper and chromium which are both present in this area at median and mean concentrations that are greater than 5000 mg/kg, dry weight in wetland soil (Figure 1-1). It is also in this same area that surface water concentrations exceed national ambient water quality criteria. Both of these conditions, the visible evidence of stressed vegetation and the exceedances of water quality criteria, indicate that significant environmental harm is "readily apparent" for a limited portion of the site as defined by the MCP. Thus, these areas in which a condition of "readily apparent harm" was determined were not included in the Stage II ERC, in accordance with the MCP. However, for completeness, a separate Stage II ERC in the Appendix section of this report contains an evaluation of potentially current site-wide exposures for avian and mammalian wildlife receptors which includes the area of "readily apparent harm".

Samples that are located within the "Area of Readily Apparent Harm" (Table 6-1 and Figure 1-1) were not included in the exposure concentrations where noted in this ERC since a full quantitative assessment of this area is not necessary, in accordance with MCP guidance (310 CMR 40.0995 (3) (b)).

Table 6-1. Samples that are located within the "Area of Readily Apparent Harm" as shown in Figure 1-1:

FP-1	FP-2								
T-1-1	T-1-2	T-1-3	T-1-4						
T-2-A	T-2-1	T-2-2	T-2-3	T-2-4	T-2-6	T-2-7	T-2-8		
T-3-3	T-3-4	T-3-4	T-3-5	T-3-6	T-3-7	T-3-8			
T-4-2	T-4-3	T-4-4	T-4-5						
T-5-1	T-5-2	T-5-3	T-5-4	T-5-5	T-5-6	T-5-7	T-5-9	T-5-9	T-5-10
T-6-1	T-6-2	T-6-3	T-6-4	T-6-5	T-6-6				
T-7-1	T-7-6	T-7-7	T-7-9	T-7-11					
T-8-8	T-8-9	T-8-10							

6.2 Selection of Chemicals of Potential Ecological Concern (COPECs) and Potentially Significant Exposure Pathways That Require Further Evaluation

To focus the efforts of the ERC for the site, chemicals of potential ecological concern (COPEC) were identified by evaluation of background and local conditions and comparison of conservative benchmarks to chemical concentrations found at the site. These evaluations were performed as a tiered, screening evaluation in which site data were first compared to background (if available), and then the COPECs that were not consistent with background were compared to local conditions (if available), and then the COPECs that were not consistent with local conditions were compared to an ecological screening level benchmark. COPECs that exceeded the ecological screening benchmark were carried forward into the Stage II ERC for further evaluation. To maintain conservatism, the 95% UCL of the arithmetic mean concentrations of COPECs were utilized for sediment and wetland soil matrices, in accordance with MCP guidance [310 CMR 40.0926(3)(a)3]. However, due to sample size limitations with surface water and vegetation sampling, the maximum concentrations of COPECs in surface water and vegetation at the site were utilized in this initial screen, in accordance with MCP guidance [310 CMR 40.0926(3)(b)]. It should be emphasized that the risk estimates that are derived later in the Stage II ERC are based on exposure point concentrations that reflect exposures without the "Area of Readily Apparent Harm". For comparative purposes, risk estimates have also been calculated based on exposure point concentrations that reflect sitewide exposures including the "Area of Readily Apparent Harm" (refer to Appendix E for this assessment).

6.2.1 Evaluation of Background and Local Conditions

MADEP (1995) provides generic background concentrations of inorganic chemicals in soil for comparison to site-specific values. In addition, guidance is provided for defining media-specific local conditions for comparison to site-specific values. Technically, the comparison of site conditions to local conditions is parallel to comparisons of site contaminants to background levels. However, local conditions are more site-specific than the generic MADEP background levels and can be developed for different media. Local conditions consider concentrations of COPECs that are influenced by regional or local factors such as difference in parent rock material, disposal sites, permitted discharges and many non-point sources that do not conform to the MCP definition of background. These considerations are relevant to risk characterization at the former Raytheon facility because there are Superfund sites in the watershed including the Nyanza site in Ashland, and the Natick Laborotory Army Research, Development, and Engineering Center in Natick. Additionally, there is the Wayland landfill located near Wash Brook that enters the Sudbury River just south of Route 20. The former Raytheon facility is located downstream (north) of Route 20 adjacent to the Sudbury River. The values for local conditions used in this ERC represent concentrations of COPECs present in a larger area surrounding the former Raytheon facility (refer to Section 7.2 and Table 7-1 for details).

Media specific concentrations of chemicals at the site were compared to background and local conditions. The median and maximum values of each data set were compared to evaluate if the site concentrations were consistent with the background levels and local conditions. In such cases where comparison of the median values yielded the opposite result of a comparison of the maximum values, a tolerance limit of 50% was employed as recommended by the MADEP (1995). For example, if the maximum value of the site data was less than or equal to the maximum value of the local conditions, and the median value of the site data was no more than 50% greater than the median value for the local conditions, then it was concluded that the site data was consistent with background.

Media-specific background and local condition values were compared to site-specific values calculated with and without inclusion of the "Area of Readily Apparent Harm". Tables showing comparisons and which chemicals are consistent with background and local conditions are presented in Appendix F.

6.2.2 Surface Water Exposure Pathways

Ambient water quality criteria for the protection of aquatic organisms were utilized, whenever they were available, for many of the COPECs. If ambient water quality criteria for the protection of aquatic organisms were not available, then other screening benchmarks were utilized. COPECs for which other screening benchmarks for the protection of aquatic organisms were utilized and the sources of these benchmarks are discussed below. For antimony, beryllium, and thallium, water quality benchmarks were from USEPA Region IV screening benchmarks (Appendix D). For PCBs, although a chronic ambient water quality criteria is available, the criteria is not based on protection of aquatic organisms, but rather higher trophic level piscivorous wildlife. However, this site has a limited capacity (both spatially and temporally) to contain a substantial portion of the prey base for piscivorous species due to the periodic non-inundation and relative dryness of the wetland during substantial amounts of time each year (for more details, refer to Sections 3.5 and 7.7). Thus, to be protective of aquatic organisms, the chronic water quality benchmark for PCBs is from Suter and Tsao (1996) and represents a Tier II secondary chronic value for the protection of aquatic organisms as calculated under the Water Quality Guidance for the Great Lakes System (USEPA, 1995). If the maximum concentration of a chemical measured in surface water at the site exceeded its respective ambient water quality criteria (chronic) or other relevant screening benchmarks (Tables 6-2, 6-3, 6-4, and 6-5), then it was retained as a COPEC that was further evaluated in the Stage II ERC. The COPECs for surface water are listed in Table 6-6.

6.2.2.1 Rationale for Exclusion of Certain COPECs from Surface Water Exposure Pathways

All COPECs for which the maximum concentration detected on site exceeded a water quality criteria or screening benchmark were retained as COPECs for further analysis in the Stage II ERC. However, it is recognized that additional site-specific parameters that can affect toxicity (*e.g.*, speciation, complexation, and bioavailability) were not assessed. All other chemicals were screened out as COPECs for surface water because they either did not exceed a water quality criteria or screening benchmark.

Table 6-2. Concentrations of organic and inorganic residues in surface water samples from the entire site (including the Area of Readily Apparent Harm) collected in November 1999 and October 2000 during conditions of low flow.

	Water quality criteria or screening benchmark[1]		Chemical concentration (µg/L;)	
Chemical	**Acute**	**Chronic**	**95% UCL**	**Max**
Metals				
Aluminum	750	87	114	210
Antimony	1300	160	2.52	2.50
Arsenic	340	150	8.81	20.5
Barium			58.5	76.0
Beryllium	16	0.53	0.25	0.25
Cadmium	5.31[*]	2.60[*]	2.57	4.00
Chromium (Cr3+)	672.34[*]	87.46[*]	7.76	15.0
Chromium (Cr6+)	16	11	2.50[A]	2.50[A]
Cobalt			4.12	5.90
Copper	16.26[*]	10.64[*]	157	310
Iron		1000	750	1410
Lead	80.42[*]	3.13[*]	2.15	3.10
Manganese			865	1100
Mercury	1.4	0.77	0.10[A]	0.10[A]
Nickel	555.56[*]	61.71[*]	15.8	19.6
Selenium	20	5	1.24	1.25
Silver	4.88[*]		0.48	0.75
Thallium	140	4	0.25[A]	0.25[A]
Tin			10.2	10.0
Vanadium			1.57	2.10
Zinc	278.14*	140.21*	362	447
PAHs				
Acenaphthene	170	17	0.120	0.100
Acenaphthylene			0.025	0.024
Anthracene			0.070	0.064
Benz[a]anthracene			0.233	0.220
Benzo[b]fluoranthene			0.488	0.460
Benzo[k]fluoranthene			0.181	0.170
Benzo[a]pyrene			0.304	0.290
Benzo[g,h,i]perylene			0.287	0.270
Chrysene			0.375	0.350
Dibenzo[a,h]anthracene			0.056	0.046
Fluoranthene	398	39.8	0.795	0.740
Fluorene			0.053	0.050
Naphthalene	230	62	0.019	0.019
Phenanthrene			0.379	0.320
Pyrene			0.513	0.480
Total PCBs	0.2	0. 19	0.043	0.043

[1]Source of water quality criteria and screening values are discussed in the text.

[*]Hardness-dependent criteria calculated from site-specific hardness data collected synoptically with the chemistry data (average hardness during low flow condition in November 1999 and October 2000 sampling = 122.4 mg/L). Equations to calculate hardness-dependent criteria are in Appendix G.

[A]The chemical was not detected and one-half the detection limit is reported.

Measured values that exceeded the water quality criteria or benchmark value are outlined with double-lines.

Table 6-3. Concentrations of organic and inorganic residues in surface water samples from the area outside of the "Area of Readily Apparent Harm" collected in November 1999 and October 2000 during conditions of low flow (non-inundation).

Chemical	Water quality criteria or screening benchmark[1] Acute	Chronic	Chemical concentration (µg/L;) 95% UCL	Max
Metals				
Aluminum	750	87	85.7	66.0
Antimony	1300	160	2.50	2.50
Arsenic	340	150	2.19	2.00
Barium			52.9	50.0
Beryllium	16	0.53	0.25	0.25
Cadmium	5.31*	2.60*	2.03	1.60
Chromium (Cr3+)	672.34*	87.46*	5.74	5.40
Chromium (Cr6+)	16	11	2.50[A]	2.50[A]
Cobalt			5.90	4.70
Copper	16.26*	10.64*	47.6	39.0
Iron		1000	681	580
Lead	80.42*	3.13*	1.37	1.10
Manganese			1221	1000
Mercury	1.4	0.77	0.10[A]	0.10[A]
Nickel	555.56*	61.71*	8.89	8.60
Selenium	20	5	1.25[A]	1.25[A]
Silver	4.88*		0.25[A]	0.25[A]
Thallium	140	4	0.25[A]	0.25[A]
Tin			10.0[A]	10.0[A]
Vanadium			1.25[A]	1.25[A]
Zinc	278.14*	140.21*	229	210
PAHs				
Acenaphthene	170	17	NA	NA
Acenaphthylene			NA	NA
Anthracene			NA	NA
Benz[a]anthracene			NA	NA
Benzo[b]fluoranthene			NA	NA
Benzo[k]fluoranthene			NA	NA
Benzo[a]pyrene			NA	NA
Benzo[g,h,i]perylene			NA	NA
Chrysene			NA	NA
Dibenzo[a,h]anthracene			NA	NA
Fluoranthene	398	39.8	NA	NA
Fluorene			NA	NA
Naphthalene	230	62	NA	NA
Phenanthrene			NA	NA
Pyrene			NA	NA
Total PCBs	0.2	0. 19	NA	NA

[1]Source of water quality criteria and screening values are discussed in the text.

*Hardness-dependent criteria calculated from site-specific hardness data collected synoptically with the chemistry data (average hardness during low flow condition in November 1999 sampling = 122.4 mg/L). Equations to calculate hardness-dependent criteria are in Appendix G.

[A]The chemical was not detected and one-half the detection limit is reported.

Measured values that exceeded the water quality criteria or benchmark value are outlined with double-lines.

Table 6-4. Concentrations of organic and inorganic residues in surface water samples from the entire site (including the Area of Readily Apparent Harm) collected in May 2000 during conditions of inundation by the Sudbury River.

Chemical	Water quality criteria or screening benchmark[1] Acute	Chronic	Chemical concentration (μg/L;) 95% UCL	Max
Metals				
Aluminum	750	87	18.2	22.9
Antimony	750	87	0.57	0.64
Arsenic	340	150	1.38	1.70
Barium			27.3	30.0
Beryllium	16	0.53	0.47	0.50
Cadmium	1.99*	1.33*	0.17	0.19
Chromium (Cr3+)	319.89*	41.61*	3.72	4.80
Chromium (Cr6+)	16	11	2.50[A]	2.50[A]
Cobalt			0.39	0.52
Copper	6.92*	4.90*	55.4	68.2
Iron		1000	325	385
Lead	29.75*	1.16*	0.94	1.00
Manganese			162	207
Mercury	1.4	0.77	0.010[A]	0.010[A]
Nickel	257.93*	28.65*	2.48	2.80
Selenium	20	5	0.70[A]	0.70[A]
Silver	1.03*		0.23	0.28
Thallium	140	4	0.15[A]	0.15[A]
Tin			8.90[A]	8.90[A]
Vanadium			0.99	1.00
Zinc	128.98*	62.68*	21.8	23.4
PAHs				
Acenaphthene	170	17	0.020	0.027
Acenaphthylene			0.011	0.011
Anthracene			0.024	0.034
Benz[a]anthracene			0.141	0.230
Benzo[b]fluoranthene			0.339	0.560
Benzo[k]fluoranthene			0.237	0.390
Benzo[a]pyrene			0.225	0.370
Benzo[g,h,i]perylene			0.219	0.360
Chrysene			0.297	0.490
Dibenzo[a,h]anthracene			0.029	0.042
Fluoranthene	398	39.8	0.724	1.200
Fluorene			0.021	0.029
Naphthalene	230	62	0.061	0.071
Phenanthrene			0.399	0.660
Pyrene			0.507	0.840
Total PCBs	0.2	0. 19	0.012	0.011

[1]Source of water quality criteria and screening values are discussed in the text.
*Hardness-dependent criteria calculated from site-specific hardness data collected synoptically with the chemistry data (average hardness during low flow condition in November 1999 sampling = 49.42 mg/L). Equations to calculate hardness-dependent criteria are in Appendix G.
[A]The chemical was not detected and one-half the detection limit is reported.
Measured values that exceeded the water quality criteria or benchmark value are outlined with double-lines.

Table 6-5. Concentrations of organic and inorganic residues in surface water samples from the area outside of the "Area of Readily Apparent Harm" collected in May 2000 during conditions of inundation by the Sudbury River.

	Water quality criteria or screening benchmark[1]		Chemical concentration (μg/L;)	
Chemical	**Acute**	**Chronic**	**95% UCL**	**Max**
Metals				
Aluminum	750	87	28.5	22.9
Antimony	750	87	0.41	0.38
Arsenic	340	150	0.76	0.75
Barium			22.9	22.6
Beryllium	16	0.53	0.50	0.50
Cadmium	1.99*	1.33*	0.107	0.093
Chromium (Cr3+)	319.89*	41.61*	0.87	0.86
Chromium (Cr6+)	16	11	2.50[A]	2.50[A]
Cobalt			0.18	0.16
Copper	6.92*	4.90*	5.12	4.50
Iron		1000	172	170
Lead	29.75*	1.16*	0.86	0.72
Manganese			88.7	83.8
Mercury	1.4	0.77	0.01[A]	0.01[A]
Nickel	257.93*	28.65*	2.34	2.10
Selenium	20	5	0.70[A]	0.70[A]
Silver	1.03*		0.38	0.28
Thallium	140	4	0.15[A]	0.15[A]
Tin			8.90[A]	8.90[A]
Vanadium			0.88	0.83
Zinc	128.98*	62.68*	28.6	23.4
PAHs				
Acenaphthene	170	17	0.011	0.011
Acenaphthylene			0.011	0.011
Anthracene			0.011	0.011
Benz[a]anthracene			0.011	0.011
Benzo[b]fluoranthene			0.011	0.011
Benzo[k]fluoranthene			0.011	0.011
Benzo[a]pyrene			0.011	0.011
Benzo[g,h,i]perylene			0.011	0.011
Chrysene			0.011	0.011
Dibenzo[a,h]anthracene			0.011	0.011
Fluoranthene	398	39.8	0.010	0.010
Fluorene			0.011	0.011
Naphthalene	230	62	0.084	0.071
Phenanthrene			0.008	0.008
Pyrene			0.006	0.006
Total PCBs	0.2	0. 19	NA	NA

[1]Source of water quality criteria and screening values are discussed in the text.
*Hardness-dependent criteria calculated from site-specific hardness data collected synoptically with the chemistry data (average hardness during low flow condition in November 1999 sampling = 49.42 mg/L). Equations to calculate hardness-dependent criteria are in Appendix G.
[A]The chemical was not detected and one-half the detection limit is reported.
Measured values that exceeded the water quality criteria or benchmark value are outlined with double-lines.

Table 6-6. Chemicals of potential ecological concern that exceeded water quality criteria or screening benchmarks.

	Exceedance of Water Quality Criteria or Screening Benchmark			
	Acute		Chronic	
Chemical	Low Flow	High Flow[1]	Low Flow	High Flow[1]
Aluminum			√	
Cadmium			√	
Copper	√	√	√	√
Iron			√	
Zinc	√		√	

[1]High flow refers to periods of inundation of the site by the Sudbury River.

6.2.3 Sediment Exposure Pathways

The portion of the site that is defined as sediment was defined previously in this ERC (refer to sections 3.5 and 4.3.2). Site specific sediment values were compared to local conditions as described in section 6.2. For COPECs that were not consistent with local conditions, sediment screening benchmarks were compared to the 95% UCL of the arithmetic mean for chemicals at the site for each of the remaining COPECs. These analyses are presented in Appendix F.

6.2.3.1 Rationale for Exclusion of Certain COPECs from Sediment Exposure Pathways

Chemicals were screened out as COPECs for sediment exposure pathways first based on local condition comparisons as described in section 6.2. Finally, if the 95% UCL of the arithmetic mean concentration of a COPEC measured in sediments at the site was less than its respective screening benchmark, then it was not retained as a COPEC for further analysis in the Stage II ERC. Also, if the chemical is naturally abundant and no background values were available (e.g., calcium, potassium, sodium), then it was not carried forward as a COPEC. If there was no information on local conditions and screening benchmarks, then it was retained as a COPEC that will be further evaluated in the ERC. The COPECs for sediment are listed in Table 6-7.

6.2.4 Wetland Soil Exposure Pathways

The portion of the site that is defined as wetland soil was defined previously in this ERC (refer to sections 3.5 and 4.3.3). Site-specific soil values were compared to MADEP soil background values and local conditions as described in section 6.2. During times of inundation of the site by the Sudbury River, it is likely that sediments from the Sudbury River are deposited in the wetland. Thus, the local condition evaluation for wetland soils was based on a comparison to Sudbury River sediments that were collected upstream of the confluence of the drainage swale with the Sudbury River. Finally, for COPECs that were not consistent with background or local conditions, soil screening benchmarks were compared to the 95% UCL of the arithmetic mean for chemicals at the site for each of the remaining COPECs. These analyses are presented in Appendix F.

6.2.4.1 Rationale for Exclusion of Certain COPECs from Soil Exposure Pathways

Chemicals were screened out as COPECs for soil exposure pathways if the concentration for that chemical was less than the screening value or if the chemical is naturally abundant and the site value is less than background (Table 6-5). An additional reason for excluding some chemicals occurred when the arithmetic mean concentration was below the screening value or less than background even though the 95% UCL of the arithmetic mean exceeded the screening value or background slightly. The rationale for this comparison is that the exposure point concentrations in the Stage II ERC are based on the arithmetic mean instead of the 95% UCL of the arithmetic mean in accordance with MCP guidance [310 CMR 40.0926(3)]. Also, if the chemical is naturally abundant and no background values were available (e.g., calcium, potassium, sodium), then it was not carried forward as a COPEC. If there was no information on background, local conditions, and screening benchmarks, then it was retained as a COPEC that will be further evaluated in the ERC.

6.3 Stage I Screening-Level ERC Conclusions

After conducting a Stage I screening-level ERC, the primary COPECs in wetland sediment and soil at this site were determined to be metals (including antimony, arsenic, cadmium, chromium (Cr3+), chromium (Cr6+), copper, lead, manganese, mercury, silver, tin, vanadium, and zinc), polycyclic aromatic hydrocarbons, and polychlorinated biphenyls (PCBs). The primary COPECs in surface water from the wetland were determined to be aluminum, cadmium, copper, iron, and zinc. Potentially significant exposure pathways were determined to be surface water, sediment, wetland soil, and biota. For these potentially significant exposure pathways and list of potential COPECs (Table 6-9), a quantitative Stage II ERC was subsequently conducted (see following sections).

As part of the Stage I screening level assessment and as specified in MCP guidance, an evaluation was made to determine if a condition of "readily apparent harm" was present at the site. It was determined that there is an area of approximately 27,580 sq. ft. in which there is visible evidence of stressed or stunted vegetation. This same area, which is proximal to the outfall (OF-1) corresponds well with the hot spot of COPEC concentrations, including copper and chromium which are both present in this area at median and mean concentrations that are greater than 5000 mg/kg, dry weight in wetland soil (Figure 1-1). It is also in this same area that surface water concentrations exceed national ambient water quality criteria. Both of these conditions, the visible evidence of stressed vegetation and the exceedances of water quality criteria, indicate that significant environmental harm is "readily apparent" for a limited portion of the site as defined by the MCP. Thus, the area of "readily apparent harm" was not included in the Stage II ERC, in accordance with the MCP. However, for completeness, a separate Stage II ERC in the Appendix section of this report contains an evaluation of potentially current site-wide exposures for avian and mammalian wildlife receptors which includes the "Area of Readily Apparent Harm".

This report presents the Stage II ERC results for the site without the "Area of Readily Apparent Harm" as the primary assessment. The Stage II ERC results for the entire site including the "Area of Readily Apparent Harm" is considered an ancillary assessment. The results of both scenarios, with and without the "Area of Readily Apparent Harm", are presented to provide decision makers with all pertinent information regarding potential risk at the site.

Table 6-7. Inorganic and organic residues of potential ecological concern (COPECs) for sediment.

Chemical	COPEC	Rationale for Inclusion or Exclusion as a Sediment COPEC
Metals		
Aluminum	NO	Naturally abundant[1], site value < local conditions
Antimony[2]	YES	Sitewide value > sediment screening level
Arsenic	NO	Site value < local conditions
Barium	NO	Site value < local conditions
Beryllium	NO	Site value < local conditions
Cadmium[2]	YES	Sitewide value > local conditions and sediment screening level
Calcium	NO	Naturally abundant[1], non-toxic
Chromium (Cr3+)	YES	Site value > local conditions and sediment screening level
Chromium (Cr6+)[2]	YES	No screening value available
Cobalt	NO	Site value < sediment screening level
Copper	YES	Site value > local conditions and sediment screening level
Iron	NO	Naturally abundant[1], site value < local conditions
Lead	NO	Site value < local conditions
Magnesium	NO	Site value < local conditions
Manganese	NO	Site value < local conditions
Mercury[2]	YES	Sitewide value > local conditions and sediment screening level
Nickel	NO	Site value < local conditions
Potassium	NO	Naturally abundant[1], non-toxic
Selenium[2]	NO	Sitewide value < local conditions
Silver[2]	YES	Sitewide value > local conditions and sediment screening level
Sodium	NO	Naturally abundant[1], non-toxic
Thallium[2]	NO	Sitewide value < local conditions
Tin	YES	No screening value available
Vanadium	NO	Site value < local conditions
Zinc	NO	Site value < local conditions
Total PAHs[2]	YES	Sitewide value > local conditions and sediment screening level
Total PCBs	YES	Site value > local conditions and sediment screening level

[1]Reference for natural abundance is Foth, (1990).

[2]Insufficient data were available due to removal of data from locations within the "Area of Readily Apparent Harm". Therefore, the rationale for inclusion or exclusion as a sediment COPEC was based on the sitewide values which include the "Area of Readily Apparent Harm".

Table 6-8. Inorganic and organic residues of potential ecological concern (COPECs) for soil.

Chemical	COPEC	Rationale for Inclusion or Exclusion as a Soil COPEC
Metals		
Aluminum	NO	Naturally abundant[1], site value < MADEP background
Antimony	YES	Site value > MADEP background and soil screening level
Arsenic	YES	Site value > MADEP background, local conditions and soil screening level
Barium	NO	Site value < local conditions
Beryllium	NO	Site value < soil screening level
Cadmium	NO	Site value < local conditions
Calcium	NO	Naturally abundant[1], non-toxic
Chromium (Cr3+)	YES	Site value > MADEP background, local conditions and soil screening level
Chromium (Cr6+)	NO	Very low frequency and concentration
Cobalt	NO	Site value < soil screening level
Copper	YES	Site value > MADEP background, local conditions and soil screening level
Iron	NO	Naturally abundant[1], site value < MADEP background
Lead	YES	Site value > MADEP background, local conditions and soil screening level
Magnesium	NO	Site value < MADEP background
Manganese	YES	Site value > MADEP background, local conditions and soil screening level
Mercury	NO	Site value < local conditions
Nickel	NO	Site value < local conditions
Potassium	NO	Naturally abundant[1], non-toxic
Selenium	NO	Site value < local conditions
Silver	YES	Site value > MADEP background, local conditions and soil screening level
Sodium	NO	Naturally abundant[1], non-toxic
Thallium	NO	Site value < local conditions
Tin	NO	Site value < USEPA soil screening level
Vanadium	YES	Site value > MADEP background, local conditions and soil screening level
Zinc	NO	Site value < local conditions
Total PAHs	YES	Site value > local conditions and soil screening level
Total PCBs	YES	Site value > local conditions and soil screening level

[1]Reference for natural abundance is Foth, (1990).

Table 6-9. Summary of inorganic residues of potential concern that exceeded media-specific ecological screening-level values for surface water, sediment, and soils.

Chemical	Exceedance of media-specific ecological screening-levels: Surface water	Sediment	Soil
Metals			
Aluminum	√		
Antimony		√	√
Arsenic			√
Barium			
Beryllium			
Cadmium	√	√	
Calcium			
Chromium (Cr3+)		√	√
Chromium (Cr6+)		√	
Cobalt			
Copper	√	√	√
Iron	√		
Lead			√
Magnesium			
Manganese			√
Mercury		√	
Nickel			
Potassium			
Selenium			
Silver		√	√
Sodium			
Thallium			
Tin		√	
Vanadium			√
Zinc	√		
PAHs		√	√
Total PCBs		√	√

7.0 STAGE II ERC - PROBLEM FORMULATION

7.1 Purpose

The problem formulation provides the framework for risk assessment (USEPA, 1992, 1997, 1998; MADEP, 1999) in which ecological endpoints are identified and relevant features of the environment and sources of contamination are described. This process includes a description of fate and transport characteristics of the chemicals of potential ecological concern (COPECs), an identification of exposure pathways and receptors, a brief evaluation of the potential toxicological effects of the COPECs, the development of a conceptual site model, and the development of a weight-of-evidence approach.

7.2 Fate and Transport Characteristics of COPECs

The MCP requires consideration of current and foreseeable future conditions with respect to the potential for migration of COPECs (MADEP, 1999).

7.2.1 Metals

The general fate and transport characteristics of the metal COPECs (*e.g.*, chromium, copper, lead, *etc.*) are that they can be soluble in water but are typically present in complexes or insoluble precipitates, bound to particulates, or bound to dissolved organic matter. Factors that affect bioavailability of metals in soils include pH, amount of clay, organic carbon content, and/or cation exchange capacity, *etc* (USEPA, 2000a). Bioavailability of metals is relatively low in soils that have relatively great amounts of clay, fraction organic carbon, and cation exchange capacity. At this site, the relatively great amount of organic carbon and cation exchange capacity in wetland soil and sediment samples (refer to section 4.3.3) indicates that bioavailability of metals should be reduced compared to soils with lower organic carbon and cation exchange capacity. Historical information suggests that migration of metals has been minimal based on USFWS data (Eaton and Carr, 1991) and current data on sediments and soils. The USFWS data contains information on the Sudbury River sediments collected from depositional areas upstream and downstream of the confluence with the swale that drains the wetland site near the former Raytheon facility (Table 7-1). These data show that concentrations of these metals are not different between the two locations. Thus, the data do not support the conclusion that appreciable amounts of metals have been transported into the Sudbury River from this site. Future exposures are not likely to differ substantially from current exposures because the wetland is protected from development.

7.2.2 Polycyclic Aromatic Hydrocarbons (PAHs) and Polychlorinated Biphenyls (PCBs)

The general fate and transport characteristics of polycyclic aromatic hydrocarbons (PAHs) and polychlorinated biphenyls (PCBs) are that they tend to bind to particulate matter, are not very water soluble, and their association with particulates is in part related to the organic carbon content. In other words, as organic carbon content increases, the amount of PAHs and PCBs that partition into the water column and become biologically available to biota decreases. The data presented in Table 7-1 (see text above) demonstrate that concentrations of PAHs and PCBs are not different between the two locations. Thus, the data do not support the conclusion that appreciable amounts of PAHs and PCBs have been transported into the Sudbury River from this site.

Table 7-1. Inorganic residues in sediments (ppm dry weight) collected by USFWS in 1987 and 1989 from upstream of the Raytheon site in the Sudbury River near Wayland, Massachusetts.

Chemical	Average concentration in Sudbury River sediments (mg/kg, dry weight)	
	Upstream	**Downstream**
Metals		
Aluminum	10,033	10,504
Arsenic	13.0	10.8
Barium	174	139
Beryllium	1.0	0.8
Cadmium	6.2	4.6
Chromium	97.8	54.7
Copper	134	90.2
Iron	15,533	15,159
Lead	342	180
Magnesium	3,237	2,302
Manganese	739	997
Mercury	3.7	1.3
Nickel	30.3	23.2
Selenium	9.0	9.0
Silver	2.0	2.3
Thallium	5.3	5.2
Vanadium	34.8	27.1
Zinc	294	198
PAHs	5.8	4.4
PCBs	1.1	1.0

Data transcribed from USFWS (1990).

Upstream sample locations are SU3 and SU4 from 1987 and GMS7 from 1989.

Downstream sample locations are SU6, SU7, SU8, SU9, SU10, and SU11 from 1987 and GMS10, GMS11, and GMS12 from 1989.

7.3 Identification of Potential Receptors and Exposure Pathways

The previously described parameters, including fate and transport characteristics of COPECs, have been combined into a conceptual model that represents potential exposure pathways of COPECs from a source to relevant biological receptors (Figure 7-1). These pathways include a number of ingestion and direct contact pathways.

The exposure pathways for aquatic receptors identified in this evaluation include:

- Direct exposure with COPECs in surface water by aquatic invertebrates, amphibians, and fish.

The exposure pathways for wetland receptors identified in this evaluation include:

- Direct contact of plant root systems with COPECs in wetland soils by wetland plants, and
- Ingestion of COPECs in surface water, sediment, soil, terrestrial plants, and other food by mammalian and avian wildlife.

It is not feasible to evaluate exposures and risks for each avian and mammalian species potentially present within the study area. For this reason, specific, representative wildlife species are identified as sentinel receptors of concern (ROCs) for the purpose of estimation of quantitative exposures (doses) in the ERC. Thus, the selection of receptors for consideration in this ERC was based on consideration of life history parameters, likelihood of exposure, presence or likely presence at the site, and representativeness of receptor class (*e.g.*, muskrats as a representative species for herbivorous small mammals). Receptors that are the focus of this ERC are summarized in Table 7-2. Both aquatic and terrestrial ecological receptors have been selected. Aquatic receptors include aquatic invertebrates, amphibians, and fish. Terrestrial/semi-aquatic receptors include wetland plants, mammals, and birds. The presence of all of the specific target species (e.g., mallard, red-tailed hawk, muskrat, meadow vole, and white-tailed deer) have been confirmed at the site.

MCP guidance recommends selecting receptors that have a great likelihood of exposure and sensitivity to COPECs, ideally with home ranges that are of similar magnitude to the size of the site. Of the receptors that were selected, it was expected that muskrats and mallards would have relatively great potential exposure due to their foraging behavior and life history parameters. Furthermore, the available toxicological data indicate that rodents and waterfowl are sufficiently sensitive to the toxic effects of the site-related COPECs.

Table 7-2. Receptors considered in this ERC.

Receptor Group	Representative Species
Aquatic invertebrates	No specific target species
Fish	No specific target species
Amphibians	No specific target species
Wetland plants	No specific target species
Waterfowl	Mallard (*Anas platyrhynchos*)
Herbivorous semi-aquatic mammals	Muskrat (*Ondatra zibethicus*)
Small herbivorous mammals	Meadow vole (*Microtus pennsylvanicus*)
Large herbivorous mammals	White-tailed deer (*Odocoileus virginianus*)
Carnivorous birds	Red-Tailed Hawk (*Buteo jamaicenisis*))

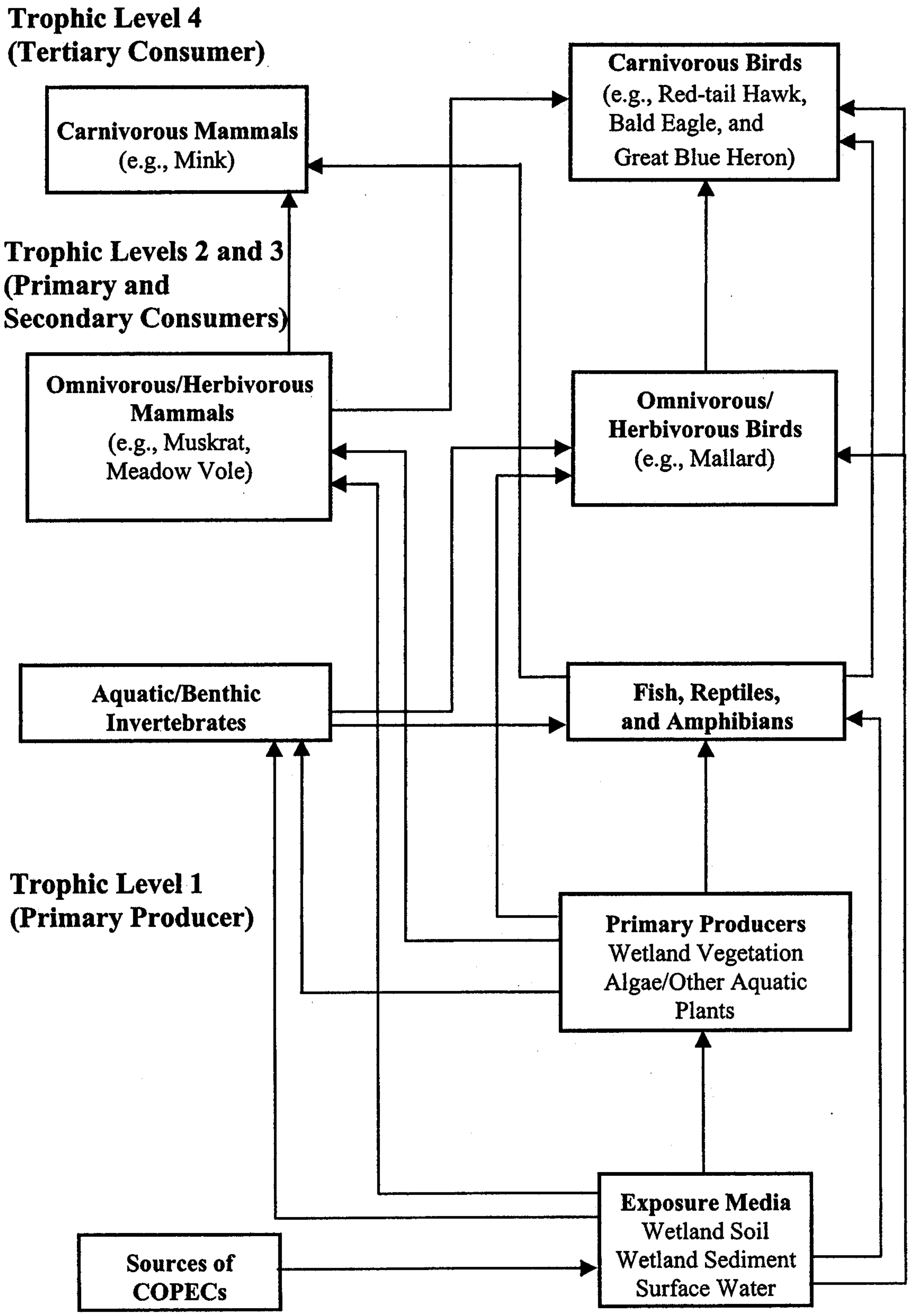

Figure 7-1. Conceptual model schematic of potential exposure pathways.

7.4 Assessment Endpoints

Endpoint selection is a critical component of the problem formulation process. Assessment endpoints are explicit expressions of the environmental values that are to be protected. In a complex ecosystem, many potential assessment endpoints can be identified. Assessment endpoints are selected for the study area based on known processes of the wetlands including its communities, and trophic structure relationships. The EPA guidance for Superfund (USEPA 1997) states that the selection of assessment endpoint depends upon:

1. chemicals present and their concentrations;
2. mechanisms of toxicity of the chemicals to different groups of organisms;
3. potential sensitivity of highly exposed receptor groups present and their natural history; and
4. potential complete exposure pathways.

Protection of subpopulations, populations, and communities for aquatic organisms and wetland plants, and the reproductive success and population sustainability of avian and mammalian wildlife from COPECs were selected as assessment endpoints (Table 7-3). Specifically, the assessment endpoint for protection of aquatic organisms includes consideration of sensitive life stages of aquatic organisms and maintenance of aquatic invertebrates as a prey base for insectivorous biota. Other receptors that were considered but were not included in the Stage II ERC are discussed later in section 7.7.

7.5 Measurement endpoints

One basic type of effects data is available for this assessment as a measurement endpoint (*i.e.*, literature-derived single-chemical toxicity test data). Single chemical toxicity data consist of estimated NOAELs and LOAELs as determined primarily from literature review (measurement endpoints are discussed in more detail in the section on "Effects Assessment").

A more detailed description of information to be utilized in this Stage II ERC is provided in Table 7-3. This table presents the relationship between the assessment and measurement endpoints. Assessment endpoints are explicit expressions of the environmental values that are to be protected. Assessment endpoints are general, large-scale expressions of environmental components or characteristics that may be at risk and, therefore, require protection. Although related and highly interdependent, measurement and assessment endpoints are not equivalent. In general, measurement endpoints are used to derive a quantitative expression of potential effects, which then forms the basis for extrapolation to higher levels of biological organization or complexity. The assessment endpoints were evaluated specifically with information obtained from measurement endpoints to determine if reduced survival or impaired reproduction of key receptors would be likely as a result of exposure to chemical stressors present in the wetlands.

Table 7-3. Relationships between assessment and measurement endpoints.

Assessment Endpoint	Measurement Endpoints
1. Protection of fish, amphibians, and aquatic invertebrate communities from adverse effects related to exposure to COPECs in surface water.	A. Comparison of concentrations of COPECs in surface water from the wetland to surface water quality criteria that are designed to be protective of aquatic organisms. B. Comparison of concentrations of COPECs in surface water from the wetland to surface water benchmarks from literature-derived studies that were conducted under conditions of similar bioavailability to those at the site
2. Protection of wetland vegetation from adverse effects related to exposure to COPECs in wetland soils.	A. Comparison of concentrations of COPECs in wetland soils to literature-based phytotoxicity benchmarks that are reported to be protective of vegetation. B. Comparison of concentrations of COPECs in plant tissues from the wetland to literature-based plant tissue residue effect levels that are reported to be protective of vegetation. C. Comparison to site-specific, field-measured effect concentrations of COPECs in soil that are found in the area of stunted vegetation.
3. Protection of wetland avian and mammalian wildlife from adverse effects on reproductive success and population sustainability related to exposure to COPECs in surface water, sediment, wetland soil, and food.	A. Comparison of the average predicted daily doses of COPECs from surface water, sediment, wetland soil, and food to toxicity reference values that are designed to be protective of avian and mammalian wildlife.

7.6 Weight-of-Evidence Approach

For two of the assessment endpoints, there was more than a single measurement endpoint. If the results of those measurements do not agree, those results were considered in combination, and a conclusion was based on a "weight-of-evidence" approach as described in the MCP guidance (refer to Section 5.4 for more details). In order to perform a weight-of-evidence analysis, the measurement endpoints must first be scored or weighed by determining the relative weighting factors for ten different attributes (Massachusetts Weight-Of-Evidence Working Group, 1995). For each of the ten attributes, a score of 1 to 5 and a reasoning for the score was recorded based on the quantitative weight-of-evidence approach (Figures 7-4 through 7-8; refer to Massachusetts Weight-of-Evidence Working Group, (1995) for more details). The quantitative approach was used to score the attributes, the overall weight was converted to a qualitative term (low, medium, or high) as described in the footnotes to Tables 7-9 and 7-10). These ten attributes generally fall into three categories:

- Attributes related to strength of association between assessment and measurement endpoints
- Attributes related to data quality
- Attributes related to study design and execution

For example, the assessment endpoint relating to protection of aquatic organisms will be assessed by surface water benchmarks, some of these benchmarks are water quality criteria for the protection of aquatic organisms and some of these benchmarks are from the scientific literature. For surface water concentrations of copper, for example, the measurement endpoints will be a comparison to both water quality criteria and to literature–based values taking into account the relatively great concentration of dissolved organic matter in surface water from this wetland site. In this case, the weighting of the two lines of evidence favors the one that incorporates site-specific data indicating reduced bioavailability (Table 7-9). Similarly, for the assessment endpoint relating to wetland plants, the various measurement endpoints is weighed more towards site-specific considerations of bioavailability and toxicity (Table 7-10). Weighting the evidence of harm (positive, negative, or undetermined) and magnitude of harm (high or low) for each of the measurement endpoints for which the weight-of-evidence approach has been applied is presented in the section on Risk Characterization.

Table 7-4. Rationale of scoring measurement endpoint "A" of assessment endpoint #1. (Scoring of measurement endpoint is based on the 10 attributes. Refer to Tables 7-9 and 7-10 for additional details on the weighting and scoring of each measurement endpoint.)

Assessment Endpoint #1: Protection of fish, amphibians, and aquatic invertebrate communities from adverse effects related to exposure to COPECs in surface water.

Measurement Endpoint "A": Comparison of concentrations of COPECs in surface water from the wetland to surface water quality criteria that are designed to be protective of aquatic organisms.

ATTRIBUTE	RATIONALE FOR SCORING MEASUREMENT ENDPOINTS (Score 1-5)
Relationship between Measurements and Assessment Endpoints	
Degree of Association	Biological process directly links the measurement and assessment endpoints, although the specific effect, target organ, and mechanism of action evaluated are not the same (2)
Stressor/Response	Response is quantitatively correlated with magnitude of exposure, but correlation is not statistically significant (or data are not sufficient to test for statistical significance) (4)
Utility of Measure	Measure is well accepted and developed by a third party and has moderate certainty, applicability and scientific basis and benchmark is moderately sensitive (4)
Quality of Data	*
Study Design	
Site Specificity	Three of the six factors (i.e., data, media, species, environmental conditions, benchmark, habitat type) are derived from or reflects the site (2)
Sensitivity	Endpoint can detect changes between approximately 2X and 9X (4)
Spatial Representativeness	The locations of five of the following subjects overlap spatially: study area, sampling/measurement site, stressors, receptors, and points of potential exposure (5)
Temporal Representativeness	Measurements are collected during the same period that effects would be expected to be most clearly manifested; AND A single sampling or measurement event is conducted; AND Moderate variability in that parameter is expected over time. (3)
Quantitative Measure	Results are quantitative and may be tested for statistical significance, but such tests do not clearly reflect biological significance (4)
Standard Measure	A standard method exists, but its suitability for this purpose is questionable, and it must be modified to be applicable to site specific conditions (3)

*Quality of data was deemed adequate, the measurement endpoint is retained for consideration in the ERC, but the data quality is not considered in the weight-of-evidence evaluation.

Table 7-5. Rationale of scoring measurement endpoint "B" of assessment endpoint #1. (Scoring of measurement endpoint is based on the 10 attributes. Refer to Tables 7-9 and 7-10 for additional details on the weighting and scoring of each measurement endpoint.)

Assessment Endpoint #1: Protection of fish, amphibians, and aquatic invertebrate communities from adverse effects related to exposure to COPECs in surface water.

Measurement Endpoint "B": Comparison of concentrations of COPECs in surface water from the wetland to surface water benchmarks from literature-derived studies that were conducted under conditions of similar bioavailability to those at the site

ATTRIBUTE	RATIONALE FOR SCORING MEASUREMENT ENDPOINTS (Score 1-5)
Relationship between Measurements and Assessment Endpoints	
Degree of Association	Measurement and assessment endpoints are directly linked and the adverse effect, target organ, and mechanism of action are the same for both endpoints; however, the levels of ecological organization differ (3)
Stressor/Response	Measurement and assessment endpoints are directly linked and the adverse effect, target organ, and mechanism of action are the same for both endpoints; however, the levels of ecological organization differ (3)
Utility of Measure	Measure is well accepted and developed by a third party and has very high levels of certainty and applicability, as well as a very strong scientific basis and benchmark is very sensitive (5)
Quality of Data	*
Study Design	
Site Specificity	All six factors (i.e., data, media, species, env. conditions, benchmark, habitat type) are derived from or reflect the site (i.e., both data and benchmark reflect site conditions) (5)
Sensitivity	Endpoint can detect changes between approximately 2X and 9X (4)
Spatial Representativeness	The locations of five of the following subjects overlap spatially: study area, sampling/measurement site, stressors, receptors, and points of potential exposure (5)
Temporal Representativeness	Measurements are collected during a period that effects would be expected to be manifested; AND two sampling or measurement events are conducted; AND high variability in that parameter is expected over time. (3)
Quantitative Measure	Results are quantitative and may be tested for statistical significance; such tests clearly reflect biological significance (5)
Standard Measure	A standard method exists and it is directly applicable to the measurement endpoint, but it was not developed precisely for this purpose and requires slight modification OR the methodology is used in two peer-reviewed studies (3)

*Quality of data was deemed adequate, the measurement endpoint is retained for consideration in the ERC, but the data quality is not considered in the weight-of-evidence evaluation.

Table 7-6. Rationale of scoring measurement endpoint "A" of assessment endpoint #2. (Scoring of measurement endpoint is based on the 10 attributes. Refer to Tables 7-9 and 7-10 for additional details on the weighting and scoring of each measurement endpoint.)

Assessment Endpoint #2: Protection of wetland vegetation from adverse effects related to exposure to COPECs in wetland soils.

Measurement Endpoint "A": Comparison of concentrations of COPECs in wetland soils to literature-based phytotoxicity benchmarks that are reported to be protective of vegetation.

ATTRIBUTE	RATIONALE FOR SCORING MEASUREMENT ENDPOINTS (Score 1-5)
Relationship between Measurements and Assessment Endpoints	
Degree of Association	Measurement and assessment endpoints are directly linked and the adverse effect, target organ, and mechanism of action are the same for both endpoints; however, the levels of ecological organization differ (3)
Stressor/Response	In previous studies, endpoint response to stressor has been demonstrated, but response is not correlated with magnitude of exposure (3)
Utility of Measure	Measure is well accepted and developed by a third party but has either limited applicability or certainty or the scientific basis is weak or the benchmark is relatively insensitive (3)
Quality of Data	*
Study Design	
Site Specificity	Only one or two of the six factors (i.e., data, media, species, environmental. conditions, benchmark, habitat type) is derived from or reflects the site (1)
Sensitivity	Endpoint can detect changes between approximately 2X and 9X (4)
Spatial Representativeness	The locations of five of the following subjects overlap spatially: study area, sampling/measurement site, stressors, receptors, and points of potential exposure (5)
Temporal Representativeness	Measurements are collected during the same period that effects would be expected to be most clearly manifested; AND Two sampling or measurement events are conducted; AND Moderate variability in that parameter is expected over time. (4)
Quantitative Measure	Results are quantitative, but data are insufficient to test for statistical significance. (3)
Standard Measure	Method is one of the 6 listed methodologies, but the particular application is neither published nor standardized. (2)

*Quality of data was deemed adequate, the measurement endpoint is retained for consideration in the ERC, but the data quality is not considered in the weight-of-evidence evaluation.

Table 7-7. Rationale of scoring measurement endpoint "B" of assessment endpoint #2. (Scoring of measurement endpoint is based on the 10 attributes. Refer to Tables 7-9 and 7-10 for additional details on the weighting and scoring of each measurement endpoint.)

Assessment Endpoint #2: Protection of wetland vegetation from adverse effects related to exposure to COPECs in wetland soils..

Measurement Endpoint "B": Comparison of concentrations of COPECs in plant tissues from the wetland to literature-based plant tissue residue effect levels that are reported to be protective of vegetation.

ATTRIBUTE	RATIONALE FOR SCORING MEASUREMENT ENDPOINTS (Score 1-5)
Relationship between Measurements and Assessment Endpoints	
Degree of Association	Measurement and assessment endpoints are directly linked and the adverse effect, target organ, and mechanism of action are the same for both endpoints; however, the levels of ecological organization differ (3)
Stressor/Response	In previous studies, endpoint response to stressor has been suggested, but has not been definitely proven (2)
Utility of Measure	Measure is well accepted and developed by a third party but has either limited applicability or certainty or the scientific basis is weak or the benchmark is relatively insensitive (3)
Quality of Data	*
Study Design	
Site Specificity	Only one or two of the six factors (i.e., data, media, species, environmental. conditions, benchmark, habitat type) is derived from or reflects the site (1)
Sensitivity	Endpoint can detect changes between 10X and 99X (3)
Spatial Representativeness	The locations of five of the following subjects overlap spatially: study area, sampling/measurement site, stressors, receptors, and points of potential exposure (5)
Temporal Representativeness	Measurements are collected during the same period that effects would be expected to be most clearly manifested; AND A single sampling or measurement event is conducted; AND Moderate variability in that parameter is expected over time. (3)
Quantitative Measure	Results are quantitative, but data are insufficient to test for statistical significance. (3)
Standard Measure	Method is one of the 6 listed methodologies, but the particular application is neither published nor standardized. (2)

*Quality of data was deemed adequate, the measurement endpoint is retained for consideration in the ERC, but the data quality is not considered in the weight-of-evidence evaluation.

Table 7-8. Rationale of scoring measurement endpoint "C" of assessment endpoint #2. (Scoring of measurement endpoint is based on the 10 attributes. Refer to Tables 7-9 and 7-10 for additional details on the weighting and scoring of each measurement endpoint.)

Assessment Endpoint #2: Protection of wetland vegetation from adverse effects related to exposure to COPECs in wetland soils.

Measurement Endpoint "C": Comparison to site-specific, field-measured effect concentrations of COPECs in soil that are found in the area of stunted vegetation.

ATTRIBUTE	RATIONALE FOR SCORING MEASUREMENT ENDPOINTS (Score 1-5)
Relationship between Measurements and Assessment Endpoints	
Degree of Association	Assessment endpoint is directly measured and, therefore, is equivalent to the measurement endpoint. (5)
Stressor/Response	Statistically significant correlation is demonstrated (5)
Utility of Measure	Measure is personal index and has either limited applicability or certainty or the scientific basis is weak or the benchmark is relatively insensitive (2)
Quality of Data	*
Study Design	
Site Specificity	All six factors (i.e., data, media, species, environmental conditions, benchmark, habitat type) are derived from or reflect the site (i.e., both data and benchmark reflect site conditions) (5)
Sensitivity	Endpoint can detect changes between 2X and 9X (4)
Spatial Representativeness	The locations of five of the following subjects overlap spatially: study area, sampling/measurement site, stressors, receptors, and points of potential exposure (5)
Temporal Representativeness	Measurements are collected during the same period that effects would be expected to be most clearly manifested; AND Two sampling or measurement events are conducted; AND Moderate variability in that parameter is expected over time. (4)
Quantitative Measure	Results are quantitative and may be tested for statistical significance; such tests clearly reflect biological significance (5)
Standard Measure	Method is one of the 6 listed methodologies (impact assessment, field survey, toxicity test, benchmark approach, toxicity quotient, or tissue residue analysis), but the particular application is neither published nor standardized (2)

*Quality of data was deemed adequate, the measurement endpoint is retained for consideration in the ERC, but the data quality is not considered in the weight-of-evidence evaluation.

Table 7-9. Scoring Measurement Endpoints for Assessment Endpoint #1

Assessment Endpoint #1: Protection of fish, amphibians, and aquatic invertebrate communities from adverse effects related to exposure to COPECs in surface water

Attributes	Weighting Factor*	Measurement Endpoint "A"	Measurement Endpoint "B"
I. Relationship Between Measurement and Assessment Endpoint			
• Degree of Association	1.0	2	3
• Stressor/Response	0.6	4	5
• Utility of Measure	0.4	4	5
II. Data Quality			
• Quality of Data	**	**	**
III. Study Design			
• Site Specificity	0.5	2	5
• Sensitivity	0.5	4	4
• Spatial Representativeness	0.4	5	5
• Temporal Representativeness	0.2	3	3
• Quantitative Measure	0.2	4	5
• Standard Measure	0.2	3	4
(Sum Scores x Weighting Factors)/4		3.25	4.23
Convert Score to Low, Medium, or High* **		Medium	High

* Weighting factors for all attributes are directly from the Massachusetts Weight-of-Evidence Working Group (1995).

** Data quality was evaluated separately and found to be adequate for each measurement endpoint and thus data quality was not used in this weight-of-evidence. Weight-of-evidence evaluations can be made either with or without the attribute of data quality in the weighting process (Massachusetts Weight-of-Evidence Working Group, 1995).

*** The ranges of scores and their associated classifications are as follows:

Low: score = 0.1 to 1.66
Medium score = 1.67 to 3.33
High score = 3.34 to 5.00

Table 7-10. Scoring Measurement Endpoints for Assessment Endpoint #2

Assessment Endpoint #2: Protection of wetland vegetation from adverse effects related to exposure to COPECs in wetland soil

Attributes	Weighting Factor*	Measurement Endpoint "A"	Measurement Endpoint "B"	Measurement Endpoint "C"
I. Relationship Between Measurement and Assessment Endpoint				
• Degree of Association	1.0	3	3	5
• Stressor/Response	0.6	3	2	5
• Utility of Measure	0.4	3	3	2
II. Data Quality				
• Quality of Data	**	**	**	**
III. Study Design				
• Site Specificity	0.5	1	1	5
• Sensitivity	0.5	4	3	4
• Spatial Representativeness	0.4	5	5	5
• Temporal Representativeness	0.2	4	3	4
• Quantitative Measure	0.2	3	3	5
• Standard Measure	0.2	2	2	2
(Sum Score x Weighting Factor)/4		3.08	2.75	4.38
Convert Score to Low, Medium, or High* **		Medium	Medium	High

* Weighting factors for all attributes are directly from the Massachusetts Weight-of-Evidence Working Group (1995).

** Data quality was evaluated separately and found to be adequate for each measurement endpoint and thus data quality was not used in this weight-of-evidence. Weight-of-evidence evaluations can be made either with or without the attribute of data quality in the weighting process (Massachusetts Weight-of-Evidence Working Group, 1995).

*** The ranges of scores and their associated classifications are as follows:

Low: score = 0.1 to 1.66
Medium score = 1.67 to 3.33
High score = 3.34 to 5.00

7.7 Species not Selected as Receptors of Concern or Assessment Endpoint Species

Other receptors that were considered but were not included in the Stage II ERC include benthic invertebrates, terrestrial invertebrates, reptiles, avian species such as the American robin, red-winged blackbird, bald eagle, and great blue heron, and mammalian species such as the short-tailed shrew and mink. The MCP provides guidance for selecting endpoint species. In addition to considering susceptibility and biological relevance, there are other factors that should be considered in endpoint selection as well (MCP Chapter 9, pp. 9-19 through 9-27). One of these other factors is a consideration of relevance to MADEP risk managers and program objectives in terms of what kinds of effects are most likely to be valued and understood and what kinds of effects are least likely to be valued and understood. The importance of this factor is emphasized in the MCP in the description of Risk Characterization step (MCP Chapter 9, p. 9-49):

> *In MCP Environmental Risk Characterizations, selection of assessment endpoints is critically important because of their role in the risk assessment/risk management process. When a quantitative risk characterization detects a risk of harm for an assessment endpoint, the conclusion must be that a significant risk of harm to the environment exists, and that remediation must be considered. The biological significance of a potential effect and its relevance to policy goals should be considered when selecting the assessment endpoint(s). Only endpoints that potentially represent a significant effect should be selected for a MCP Environmental Risk Characterization.*

Specifically, for non-rare invertebrates, the MCP includes impacts on an individual population of non-rare invertebrates as an example of an assessment endpoint that is least likely to be valued and understood. As a general rule (MCP Chapter 9, p.9-24), effects on non-rare invertebrate populations should only be used as an assessment endpoint if one of the following is true:

1. *The population is a critical component of the prey base, and its function as such would not be replaced by other more tolerant species....If the depleted population and its function as a prey base is replaced by other organisms of the same ecological guild, there may be no significant risk of harm presented to the environment.*
2. *The population performs a critical ecological function, such as decomposing organic matter, and that function would not be replaced by other species.*
3. *The species has been identified as an "indicator species", and the risk assessor has determined that adverse effects on the invertebrate species in question can be used as surrogate measures of adverse effects for other species or the community as a whole.*

7.7.1 Benthic Invertebrates

In the case of benthic invertebrates in the drainage swale sediments, none of the above statements are true. In other words, the benthic invertebrates in the drainage swale sediments are not likely to form a critical component of the prey base or perform a critical ecological function, nor have they been identified as an indicator species. During times of the year when the site is not inundated, sediment samples that were collected from the drainage swale were evaluated for the presence of benthic invertebrates (Woodlot Alternatives, Inc., 2000). The results of this evaluation effort were inconclusive since few invertebrates were collected, attributed mostly to the time of year for sampling (late October), although the lack of availability of suitable substrate could have also played a role. Prior to installation of the industrial wastewater treatment plant (IWWTP) in 1975, there was not a well-defined drainage swale and thus, the habitat may not have been suitable historically nor presently to support substantial populations of benthic invertebrates.

Other factors to consider are related to the spatial and temporal abundance of invertebrate populations in the drainage swale sediments. For example, the proportion of the site that constitutes the drainage swale sediments is relatively small compared to the remainder of the site. During times of inundation, the entire site might be expected to contain aquatic invertebrates, although considerations should be made for how the timing of inundation coincides with the seasonal abundance of aquatic invertebrates and the seasonal foraging activities of insectivorous organisms. Thus, it is unlikely that benthic invertebrates residing in the drainage swale sediments constitute a critical component of the prey base for insectivorous biota at the site nor perform a critical ecological function. Furthermore, since other aquatic organisms have been selected as assessment endpoints and since the associated measurement endpoint is a comparison to water quality criteria and/or benchmarks which includes effects on aquatic invertebrates (e.g., *Daphnia*), the predominant invertebrate-based component of the prey base at this site is being evaluated.

7.7.2 Terrestrial Invertebrates

Similarly, the assessment of potential adverse impact of COPECs on terrestrial invertebrate communities is problematic since these communities are temporary due to the periodic flooding and relatively great degree of water saturation of wetland soil at this site (refer to section 3.5 for more details). As floodwaters recede and the wetland soils begin to dry up, it is likely that terrestrial invertebrates migrate onto the site opportunistically. However, populations of terrestrial invertebrates (e.g., earthworms) are ephemeral and it is unlikely that terrestrial invertebrate communities are well-established at this site. Related to the lack of terrestrial invertebrates, short-tailed shrews and robins were not included in the assessment because they primarily feed on terrestrial invertebrates.

Furthermore, Woodlot Alternatives Inc. (2000) conducted a site ecological survey and noted that this wetland site was not suitable habitat for earthworms or shrews due to annual flooding of the site for two or three months, bogginess of the soil for a couple more months, and episodic flooding during heavy rain events during the rest of the year. Thus, the factors contributing to the exclusion of short-tailed shrew and American robin as receptors of concern are due primarily to habitat suitability.

7.7.3 Reptiles

Reptiles, while present at the site, were not selected as receptors of concern because of a lack of toxicity data. Although basic ecological information is available for a large number of reptiles, "it is often the lack of sufficient toxicity data in the literature that precludes the use of reptiles as receptors in ecological risk assessments" (Sparling et al., 2000, p. 799). Literature-based information for reptiles and COPECs is limited to tissue residue data with no emphasis on actual effects on individuals or populations. Although toxicity benchmark or threshold values are available for a number of organisms including plants, fish, mammals, and birds, such values do not exist for reptiles, although research efforts are currently focusing on this data gap.

7.7.4 Avian Species

There are nearly 200 species of birds that could occur at this site at some time of the year. However, it is not feasible to evaluate exposures and risks for each of these avian species. For this reason, MCP guidance recommends selecting receptors that have a great likelihood of exposure and sensitivity to COPECs, ideally with home ranges that are of similar magnitude to the size of the site. Of the avian receptors that were selected, it is expected that mallards would have relatively great potential exposure due to their foraging behavior (including sediment ingestion and consumption of vegetation and aquatic invertebrates) and life history parameters. Furthermore, the available toxicological data indicate that waterfowl, such as mallards, are sufficiently sensitive to the toxic effects of the site-related COPECs, such that protection of waterfowl from the toxic effects of COPECs should be sufficiently protective of other avian species that likely have lesser exposures. An additional reason for selecting the mallard is that primary toxicological literature is available for mallards on the toxicity of many COPECs. Other species that were considered but not selected as receptors of concern include the American robin and red-winged blackbird, which would be expected to have lesser exposures or greater uncertainty regarding their exposure relative to the mallard. Thus, because of the great likelihood of exposure and sensitivity to site-related COPECs and because of the minimal uncertainty of the exposure and effects data for mallards, the mallard represents the best possible surrogate species for many of the other avian species at this site.

Additionally, while the bald eagle and great blue heron were included in the conceptual site model as top-level predators (Figure 7-1), they were not selected as receptors of concern because the foraging ranges of these species are too great relative to the size of the site. Furthermore, since these species are predominantly piscivorous, an additional consideration and reason for excluding these species as receptors of concern is the limited capacity (both spatially and temporally) to contain a substantial portion of the prey base for these species due to the periodic non-inundation and relative dryness of the wetland during substantial amounts time each year. The red-tailed hawk was included to ensure that at least one top-level avian predator was evaluated.

7.7.5 Mammalian Species

There are approximately 42 species of mammals that could occur at this site at some time of the year. However, it is not feasible to evaluate exposures and risks for each of these mammalian species. For this reason, MCP guidance recommends selecting receptors that have a great likelihood of exposure and sensitivity to COPECs, ideally with home ranges that are of similar magnitude to the size of the site. While the mink was included as a top-level predator in the conceptual model (Figure 7-1), mink were not selected as receptors of concern, in part, because the foraging ranges of mink are too great relative to the size of the site. Furthermore, since mink are predominantly piscivorous, an additional consideration and reason for excluding these species as a receptor of concern is the limited capacity (both spatially and temporally) to contain a substantial portion of the prey base for this species due to the periodic non-inundation and relative dryness of the wetland during substantial amounts time each year.