10.0 STAGE II ERC - RISK CHARACTERIZATION

10.1 Purpose

The purpose of the risk characterization is to evaluate measurement results and determine whether they support a conclusion of no significant risk for each assessment endpoint. In preparing this ERC, the 1990 USFWS Report was the only document, except for the data presented earlier in this ERC, found that was considered relevant to the current investigation of ecological risk. For two of the assessment endpoints in this ERC, there was more than a single measurement endpoint. If the results of those measurements did 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 7.6 for more details).

10.2 Hazard Quotient or Toxicity Quotient Method

The basic approach for most assessment endpoints in this ERC is a hazard quotient (HQ) approach. HQ values were calculated for each species under different exposure scenarios and contaminant concentrations in prey by the use of equation 10-1 for comparison to benchmarks or criteria, equation 10-2 for tissue residue data, and equation 10-3 for dietary exposure.

$$HQ = \frac{\text{Exposure (mg/kg)}}{\text{Benchmark or screening value (mg/kg)}} \qquad \text{Eq. 10-1}$$

$$HQ = \frac{\text{Tssue concentration (mg/kg)}}{\text{Toxicity reference value (mg/kg)}} \qquad \text{Eq. 10-2}$$

$$HQ = \frac{ADD_{pot}\text{ (mg/kg)}}{\text{Toxicity reference value (mg/kg)}} \qquad \text{Eq. 10-3}$$

Because of the conservativeness of the exposure calculations, benchmarks, and TRVs, HQ values less than 1.0, indicate that no unacceptable risks will occur. For HQ values greater than 1.0 some potential for risk is inferred and there may be a need for further evaluation. While the Stage I screening-level ERC does not attempt to quantify the nature and extent of potential risks, results from the Stage II ERC, to the extent possible, do attempt to quantitatively and qualitatively describe the risks to the environment.

MADEP guidance recommends that when the hazard quotient approach is utilized for characterizing risk to wildlife that HQs are derived for both the lowest observed adverse effect level (LOAEL) and the no observable adverse effect level (NOAEL). Furthermore, MADEP states the following guidelines for characterizing risk using NOAEL- and LOAEL-based HQs:

- When the site dose exceeds the LOAEL and the LOAEL-based HQ is greater than 1.0, it is reasonable to conclude that the quotient evaluation method provides evidence of harm.

- When the site dose is less than the NOAEL and NOAEL-based HQ is less than 1.0, the risk assessor may reasonably conclude that the quotient evaluation method does not provide evidence of harm.
- When the site dose 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 COPEC has harmed or may harm the environment.

10.3 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 an overall qualitative score of high, medium, or low (refer to the section on Problem Formulation). 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. These latter two steps are presented in the following sections.

To determine the magnitude of response for each measurement endpoint, there are two main questions to address:

- Does the measurement endpoint indicate the presence or absence of harm (positive, negative, or undetermined)?
- Is the response low or high?

The presence or absence of harm is determined by whether or not the hazard quotient is > 1.0. If the hazard quotient is > 1.0, there is a positive indication for the risk of harm. If the hazard quotient is < 1.0, there is a negative indication for the risk of harm. The degree of response was arbitrarily evaluated by the magnitude of the hazard quotient. The response was considered "low" if the HQs were > 0.1 and < 10 (e.g., less than a factor of 10). The response was considered "high" if the HQs were either ≤ 0.1 or ≥ 10 (e.g., greater than a factor of 10). As a general rule-of-thumb, hazard quotients less than 10 are not considered potentially ecologically relevant. The rationale for the selection of this 10-fold cutoff for the degree of response is based on the conservativeness of the toxicological benchmarks and exposure assumptions utilized in this ERC. In the case of multiple COPECs, the worst-case COPEC (e.g., the one with the greatest hazard quotient) was utilized to set the magnitude of response.

The final component of the weight-of-evidence approach involves examining the concurrence of measurement endpoints as they relate to a specific assessment endpoint. In this ERC, each measurement endpoint (designated by a letter) was plotted on a matrix in which the weight of the measurement endpoint and its associated magnitude and direction of response are indicated. In this way, the matrix is a convenient presentation of the concurrence (or divergence) of measurement endpoints.

10.4 Assessment Endpoint #1 - Protection of Fish, Amphibians, and Aquatic Invertebrate Communities From Adverse Effects Related to Exposure to COPECs in Surface Water

Potential risks to aquatic receptors (aquatic invertebrates, fish, and amphibians) from exposure to COPECs outside of the "Area of Readily Apparent Harm" was characterized by use of a HQ approach (equation 10-1). Two measurement endpoints were utilized to evaluate this assessment endpoint.

10.4.1 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.

HQs for aquatic receptors are presented for two different times of the year (low water levels and periods of inundation; Table 10-1). The information in this table can be summarized as follows:

- The only exceedances of water quality criteria occur during conditions of low flow (or when the site is not inundated).
- Only copper and zinc exceeded the chronic water quality criteria (only during conditions of low flow).
- Only copper exceeded the acute water quality criteria (only during conditions of low flow).
- There are no exceedances of water quality criteria during periods of inundation.

Table 10-1. Comparison of water quality criteria to maximum water concentrations in locations outside of the "Area of Readily Apparent Harm".

	Water Quality Criteria				
COPEC	Acute	Chronic	Max. Conc. (µg/L)	HQ - Acute	HQ - Chronic
Low Flow					
Aluminum	750	87	66	0.09	0.76
Cadmium	5.31	2.60	1.6	0.30	0.62
Copper	16.26	10.64	39	2.40	3.67
Iron		1000	580		0.58
Zinc	278.14	140.21	210	0.76	1.50
Inundation					
Aluminum	750	87	22.9	0.03	0.26
Cadmium	1.99	1.33	0.1	0.05	0.08
Copper	6.92	4.90	4.5	0.65	0.92
Iron		1000	170		0.17
Zinc	128.98	62.68	23.4	0.18	0.37

Since there is an exceedance of water quality criteria when the site is not inundated, there is a positive indication of risk under these conditions. However, the magnitude of exceedances are not very great (HQs are between 1 and 10) and are limited to times of the year when the site is not inundated. Thus, the magnitude of response for this measurement endpoint is assigned a value of "low". At times of flooding, when fish and other aquatic species have greater access to the site, the concentrations of all COPECs are below WQC and thus there is a negative indication of risk under these conditions.

10.4.2 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

As described previously, there are other factors that can ameliorate the bioavailability and toxicity of metals in surface water, especially copper and to a lesser degree, zinc. For example, USEPA is considering adoption of criteria that will account for the ameliorating effect of dissolved organic matter (DOM) on the toxicity of copper (USEPA, 2000c and 2000d). This measurement endpoint was given greater weight because it uses site-specific information to address bioavailability of COPECs that exceeded water quality criteria (refer to the results for measurement endpoint #1). HQs for aquatic receptors are presented for only one time of the year (low water levels) and for only copper and zinc (Table 10-2). The information in this table can be summarized as follows:

- There are no exceedances of water quality criteria during conditions of low flow (or when the site is not inundated) when site-specific information is utilized to address bioavailability of copper and zinc.

Table 10-2. Comparison of water quality criteria to maximum water concentrations in locations outside of the "Area of Readily Apparent Harm".

	Water Quality Criteria				
COPEC[1]	Acute	Chronic	Max. Conc. (µg/L)	HQ - Acute	HQ - Chronic
Low Flow					
Copper	162.6	106.4	39	0.24	0.37
Zinc	556.28	280.42	210	0.38	0.75

[1]Note that only those COPECs that exceeded water quality criteria (Table 10-1) were evaluated for measurement endpoint B.

Since there are no exceedances of water quality criteria when site-specific information is utilized to address bioavailability of copper and zinc, there is a negative indication of risk under these conditions. However, the magnitude of response for this measurement endpoint was not very great (HQs are between 0.1 and 1.0). Thus, the magnitude of response is assigned a value of "low".

10.4.3 Concurrence of Measurement Endpoints as they Relate to Assessment Endpoint #1

In evaluating the concurrence of measurement endpoints, MADEP guidance recommends consideration of three factors: (1) the relative weights; (2) the attributes considered in the weighting process; and (3) whether the endpoints are functionally related to each other so that one result modifies another. In this case, the magnitudes of both measurement results are the same (low) although the indications for risk are opposing (one is positive and one is negative) (Table 10-3). However, the endpoints are functionally related to each other in that Measurement Endpoint B provides a measure of bioavailability, and that it shows that site-specific bioavailability for the COPECs (copper and zinc) are low. Furthermore, since the weight of Measurement Endpoint B is greater than that of Measurement Endpoint A, it is reasonable to conclude that there is no indication of risk of harm to aquatic receptors.

Table 10-3. Weight of Evidence Summary for Assessment Endpoint #1

MEASUREMENT RESULT	HIGH WEIGHT	MEDIUM WEIGHT	LOW WEIGHT
Positive – High			
Positive – Low		A	
Indeterminate			
Negative – Low	B		
Negative - High			

Measurement endpoints:

A = Water quality criteria were given a medium weight and produced a low positive result.

B = Literature-derived studies that were conducted under conditions of similar bioavailability to those at the site; given a high weight and produced a low negative result.

10.5 Assessment Endpoint #2 - Protection of Wetland Vegetation From Adverse Effects Related to Exposure to COPECs in Wetland Soils.

Potential risks to wetland vegetation from exposure to COPECs outside of the "Area of Readily Apparent Harm" was characterized by use of a HQ approach (equations 10-1 and 10-2). Three measurement endpoints were utilized to evaluate this assessment endpoint.

10.5.1 Measurement Endpoint A – Comparison of Concentrations of COPECs in Wetland Soils to Literature-Based Phytotoxicity Benchmarks that are Reported to be Protective of Vegetation.

Soil-based phytotoxic benchmarks from the literature were compared to exposure point concentrations in soil outside of the "Area of Readily Apparent Harm" (Table 10-4). The exposure point concentrations are based on the geometric mean and the arithmetic mean concentration of COPECs in wetland soil (on a dry weight basis) as two estimates of central tendency (refer to Section 8.2 for more information). Two different benchmarks were utilized for comparison to exposure concentrations. The information in this table can be summarized as follows:

- The relative order from greatest to least exceedance of the low soil-based benchmark for phytoxicity is:

  Chromium > copper > silver > lead

- Only chromium and copper exceeded the high soil-based benchmark (although high soil-based benchmarks are not available for all COPECs)

Table 10-4. Comparison of soil exposure concentrations from outside the "Area of Readily Apparent Harm" to screening benchmarks for phytotoxicity.

	Exposure		Effects		Risk Characterization			
	Soil Concentration[1] (mg/kg dw)		Benchmark[2] (mg/kg dw)		Hazard Quotient (HQ)[4]			
					Low benchmark HQ		High benchmark HQ	
COPEC	Geometric Mean	Mean	Low	High	Geomean	Mean	Geomean	Mean
Antimony	3.85	4.33	5	NA	0.77	0.87	-	-
Arsenic	9.43	14.9	37	NA	0.25	0.40	-	-
Cadmium	2.39	3.34	29	NA	0.08	0.12	-	-
Chromium	183	551	50	100	3.67	11.01	1.83	5.51
Chromium (6+)	20.3	50.9	50	500	0.41	1.02	0.04	0.10
Copper	243	585	100	200	2.43	5.85	1.21	2.92
Lead	199	267	196	494	1.01	1.36	0.40	0.54
Manganese	236	311	500	NA	0.47	0.62	-	-
Mercury	0.97	1.68	5	50	0.19	0.34	0.02	0.03
Silver	5.23	23.7	10	100	0.52	2.37	0.05	0.24
Tin	12.2	22.5	50	500	0.24	0.45	0.02	0.04
Vanadium	33.5	39.1	150	500	0.22	0.26	0.07	0.08
Zinc	105	130	190	NA	0.55	0.69	-	-
Acenaphthene[3]	0.03	0.06	2.5	25	0.01	0.022	0.00	0.00
Total PCBs	1.42	2.92	40	100	0.04	0.07	0.01	0.03

[1] Data from Table 4-13.

[2] See text for description

[3]Acenaphthene was used as a surrogate for total PAHs

[4]$HQ = C_{soil}$ / benchmark

NA = Not available

Since there is an exceedance of soil-based phytotoxicity benchmarks from the literature, there is a positive indication of risk under these conditions. For different COPECs, the magnitude of exceedances vary from low (HQs are between 1 and 10) to high (HQs are greater than 10). Thus, the magnitude of response for this measurement endpoint is assigned a value of "high".

10.5.2 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.

Tissue-based phytotoxic benchmarks from the literature were compared to exposure point concentrations in wetland vegetation outside of the "Area of Readily Apparent Harm" (Table 10-5). The exposure point concentrations are based on the maximum concentration of COPECs in wetland vegetation (on a dry weight basis). Two different benchmarks were utilized for comparison to exposure concentrations, one for cattail roots and one for buttonbush seedheads. The information in this table can be summarized as follows:

- None of the COPECs exceeded tissue-based benchmarks. However, the plant tissue concentrations that were nearest the benchmark were for chromium and copper for both plant species.

Table 10-5. Comparison of plant tissue concentrations from outside the "Area of Readily Apparent Harm" to screening benchmarks for phytotoxicity.

	Exposure		Effects		Risk Characterization	
	Max Plant Concentration[1] (mg/kg dw)		Benchmark[2] (mg/kg dw)		Hazard Quotient (HQ)	
COPEC	Typha[3]	Cephal.[4]	Typha[3]	Cephal.[4]	HQ for Typha[3]	HQ for Cephal.[4]
Antimony	0.06	0.02	0.1	0.1	0.60	0.19
Arsenic	0.37	0.05	11	1.7	0.03	0.03
Cadmium	0.44	0.06	3	3	0.15	0.02
Chromium	1.5	3.30	5	5	0.30	0.66
Chromium (6+)	NA	NA	NA	NA	-	-
Copper	12.7	12.50	100	20	0.13	0.63
Lead	6.5	0.36	300	50	0.02	0.01
Manganese	76.6	311	1000	1000	0.08	0.31
Mercury	0.02	0.01	3	0.5	0.01	0.01
Silver	0.12	0.31	1760	4	0.00	0.08
Tin	0.99	0.98	2	2	0.50	0.49
Vanadium	0.84	0.03	170	2	0.00	0.02
zinc	46.7	25.80	100	100	0.47	0.26
Total PAHs	NA	NA	NA	NA	-	-
Total PCBs	0.0154	0.0029	NA	NA	-	-

[1] Data from Tables 4-17 and 4-19.

[2] See text for description

[3]Typha latifolia (cattail roots)

[4]Cephalanthus occidentalis (buttonbush seedheads)

$HQ_{typha} = C_{typha} / benchmark_{typha}$

$HQ_{cephal} = C_{cephal} / benchmark_{cephal}$

NA = Not available

Since there are no exceedances of tissue-based phytotoxicity benchmarks from the literature, there is a negative indication of risk under these conditions. For different COPECs, the magnitude of exceedances vary from low (HQs are between 0.1 and 1.0) to high (HQ values less than 0.1). Thus, the magnitude of response for this measurement endpoint is assigned a value of "low".

10.5.3 Measurement Endpoint C - Comparison to Site-Specific, Field-Measured Effect Concentrations of COPECs in Soil That are Found in the Area of Stunted Vegetation.

Soil-based phytotoxic benchmarks from the site (field-based, not literature-based) were determined and then compared to exposure point concentrations in soil outside of the "Area of Readily Apparent Harm" (refer to sections on Exposure Assessment and Effects Assessment for details) (Table 10-6). To maximize conservatism, the exposure point concentrations are based on the 95% *lower* confidence limit of the arithmetic mean concentration of COPECs in wetland soil outside of the "Area of Readily Apparent Harm" and the site-specific, field-measured effect concentrations are based on the 95% *upper* confidence limit of the arithmetic mean of COPECs in wetland soil within the area of stunted vegetation. The information in this table can be summarized as follows:

Table 10-6. Comparison of field-measured, soil-based phytotoxicity effect concentrations for COPECs to concentrations of COPECs in wetland soil from locations outside of the "Area of Readily Apparent Harm".

COPEC[1]	Concentration in Wetland Soil[2] (95% UCL)	Soil-Based Phytotoxicity Effect Concentration (mg/kg, dry weight; 95% LCL)	Hazard Quotient
Copper	743	4295	0.17
Chromium	739	6495	0.11
Lead	306	661	0.46
Silver	34.7	172	0.20

[1]Only those COPECs for which soil concentrations exceeded literature-based phytotoxicity screening values are presented.
[2]Concentration in wetland soil outside of the "Area of Readily Apparent Harm".

Since there are no exceedances of field-measured, soil-based phytotoxicity effect concentrations, there is a negative indication of risk under these conditions. The magnitude of exceedances vary from low (HQ values less than 0.1) to high (HQ values greater than 0.1). Thus, the magnitude of response for this measurement endpoint is assigned a value of "low".

10.5.4 Concurrence of Measurement Endpoints as they Relate to Assessment Endpoint #2

Since there is visible evidence at the site of stressed vegetation (discussed previously) that occupies the same portion of the site where the concentrations of COPECs are the greatest, the HQ values for phytotoxicity in Tables 10-4 and 10-5 could potentially provide an indication of the causative agent. However, since the toxicity of plants has not been as well studied as mammalian and avian species, there is considerable uncertainty regarding the values selected for benchmarks. Most of the phytoxicity benchmarks have been determined from studies on agriculturally-relevant species. No studies were identified to derive benchmarks based on wetland plant species. Thus, due in part to these uncertainties, the weight was determined to be "medium" for the measurement endpoints "A" and "B" literature-based phytotoxicity benchmarks

Despite the areas of uncertainties discussed above, it appears that copper and chromium, and to a lesser extent silver, lead, antimony, or some combination of these metals are the most likely causes of phytotoxicity. It would be informative to have bioavailable concentrations of these metals in the soil water and then compare these concentrations to phytotoxicity benchmarks that have been derived from studies on plants grown in nutrient solutions. In addition, it would be informative to have chemical specific toxicity values for representative wetland plant species to understand the relative sensitivity of these plants to metals. While this information is not presently available in the scientific literature, the observation of stunted vegetation at the site can be viewed as an *in situ* phytoxicity test, in which native wetland plant species are being exposed to COPECs that have been aged in the wetland soils under "real-world" conditions (e.g., seasonal changes in temperature, inundation, bioavailability of COPECs, etc.). As such, information on the concentrations of COPECs in soil from locations within the area of stunted vegetation are potentially the most useful in determining a site-specific, soil-based phytotoxicity effect concentration. Thus, the weight for measurement endpoint "C", which utilized this site-specific information, was determined to be "high".

As discussed previously, MADEP guidance recommends consideration of three factors when evaluating the concurrence of measurement endpoints: (1) the relative weights; (2) the attributes considered in the weighting process; and (3) whether the endpoints are functionally related to each other so that one result modifies another. In this case, the magnitudes of two of the measurement results (Measurement Endpoints "B" and "C") are the same (low) and the indications for risk are the same (negative) (Table 10-7). This is countered to an extent by results for Measurement Endpoint "A" which indicates positive risk with a high magnitude. However, the weight of Measurement Endpoint "C" is greater than that of Measurement Endpoint "A". Furthermore, the endpoints are functionally related to each other in that Measurement Endpoint "C" provides a measure of site-specificity for bioavailability and native species sensitivity, whereas the literature-based Measurement Endpoints "A" and "B" are based on laboratory spiking studies with non-wetland species. In addition, both the cation exchange capacity and organic carbon content measured in the wetland soils at this site are sufficiently great that bioavailability of COPECs is likely to be greatly reduced. Taken together, based on the weight-of-evidence evaluation, it is reasonable to conclude that there is no indication of risk of harm to wetland vegetation outside of the "Area of Readily Apparent Harm".

Table 10-7. Weight of Evidence Summary for Assessment Endpoint #2

MEASUREMENT RESULT	HIGH WEIGHT	MEDIUM WEIGHT	LOW WEIGHT
Positive – High		**A**	
Positive – Low			
Indeterminate			
Negative – Low	**C**	**B**	
Negative - High			

<u>Measurement endpoints</u>:

A = Literature-based phytotoxicity benchmark; given a low weight and produced a weak positive result.

B = Plant tissue effect levels from the literature; given a low weight and produced a weak negative result.

C = Field-measure phytotoxicity benchmark that incorporates site-specific bioavailability; given a high weight and produced a strong negative result.

10.6 Assessment Endpoint #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

MADEP guidance recommends that when the hazard quotient approach is utilized for characterizing risk to wildlife that HQs are derived for both the lowest observed adverse effect level (LOAEL) and the no observable adverse effect level (NOAEL). Furthermore, MADEP states the following guidelines for characterizing risk using NOAEL- and LOAEL-based HQs:

- When the site dose exceeds the LOAEL and the LOAEL-based HQ is greater than 1.0, it is reasonable to conclude that the quotient evaluation method provides evidence of harm.
- When the site dose is less than the NOAEL and NOAEL-based HQ is less than 1.0, the risk assessor may reasonably conclude that the quotient evaluation method does not provide evidence of harm.
- When the site dose 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 COPEC has harmed or may harm the environment.

10.6.1 Mammalian Wildlife

Potential risks to mammalian receptors from exposure to COPECs outside the "Area of Readily Apparent Harm" are characterized by use of a HQ approach (equation 10-3). HQs for each of the mammalian receptors are presented (Tables 10-8 through 10-10). The exposure point concentrations are based on two different exposure levels (low dose and high dose) as described previously. The information in these tables can be summarized as follows:

- None of the mammalian receptors had NOAEL-based HQs greater than 1.0.
- None of the mammalian receptors had LOAEL-based HQs greater than 1.0.

Taken together, there is no indication of risk of harm to mammalian receptors. This is likely due to the relatively small size of the area where concentrations of COPECs are elevated and possibly from limited bioavailability of the COPECs at this site. In particular, available data demonstrate limited assimilation and accumulation of COPECs into wetland vegetation and small mammals.

Table 10-9. Estimation of doses and hazard quotients for meadow vole dietary exposure from outside the "Area of Readily Apparent Harm".

	Exposure Assessment[1]											Effects Assessment		Risk Characterization			
	C_{soil} (mg/kg ww)				C_{veg} (mg/kg ww)		IR_{veg}	C_{water} (mg/L)		APDD[2] (mg/kgBW/day)		TRV[3] (mg/kgBW/day)		Hazard Quotient (HQ)[4]			
														NOAEL-based HQ		LOAEL-based HQ	
COPEC	Geo. Mean	Mean	IR_{soil}	% Abs.	Mean	Max	(kg ww/day)	Mean	Max	Low	High	NOAEL	LOAEL	Low Dose	High Dose	Low Dose	High Dose
Antimony	4	4	0.0001	1%	0.0071	0.0155	0.005	0.00250	0.00250	0.0013	0.0022	4.4	NA	0.0003	0.0005	-	-
Arsenic	9	15	0.0001	1%	0.0683	0.0885	0.005	0.00180	0.00200	0.0083	0.0107	0.42	1.26	0.0197	0.0256	0.0066	0.0085
Cadmium	2	3	0.0001	1%	0.0748	0.1049	0.005	0.00116	0.00160	0.0087	0.0122	1	10	0.0087	0.0122	0.0009	0.0012
Chromium	183	551	0.0001	1%	0.5371	0.7082	0.005	0.00510	0.00540	0.0667	0.0962	24.5	NA	0.0027	0.0039	-	-
Chrom.(6+)	20	51	0.0001	1%	NA	NA	NA	0.00000	0.00000	0.0006	0.0014	22	NA	2.5E-05	6.3E-05	-	-
Copper	243	585	0.0001	1%	2.7597	4.2477	0.005	0.03000	0.03900	0.3243	0.5040	6.4	12.9	0.0507	0.0787	0.0251	0.0391
Lead	199	267	0.0001	1%	0.8490	1.4903	0.005	0.00080	0.00110	0.1020	0.1768	8	80	0.0128	0.0221	0.0013	0.0022
Manganese	236	311	0.0001	1%	39.7373	52.3026	0.005	0.77000	1.00000	4.6270	6.0883	88	284	0.0526	0.0692	0.0163	0.0214
Mercury	1	2	0.0001	1%	0.0031	0.0048	0.005	0.00010	0.00010	0.0004	0.0006	13.2	40	2.9E-05	4.6E-05	-	-
Silver	5	24	0.0001	1%	0.0352	0.0619	0.005	0.00030	0.00030	0.0042	0.0077	24.67	74	0.0002	0.0003	0.0001	0.0001
Tin	12	22	0.0001	1%	0.3038	0.3318	0.005	0.01000	0.01000	0.0362	0.0397	NA	NA	-	-	-	-
Vanadium	34	39	0.0001	1%	0.1210	0.1909	0.005	0.00130	0.00130	0.0148	0.0229	1.67	5	0.0089	0.0137	0.0030	0.0046
Zinc	105	130	0.0001	1%	9.7712	13.3360	0.005	0.19000	0.21000	1.1391	1.5476	160	320	0.0071	0.0097	0.0036	0.0048
B(a)P	0.4	1.0	0.0001	25%	NA	NA	NA	NA	NA	0.0003	0.0007	15.27	45.8	1.7E-05	4.6E-05	5.5E-06	1.5E-05
Total PCBs	1.4	2.9	0.0001	85%	0.0026	0.0038	0.005	NA	NA	0.0036	0.0072	0.32	1.5	0.0112	0.0225	0.0024	0.0048

[1]Exposure factors from Tables 8-2 and 8-3.

$C_{sediment\&soil} = (C_{soil} * 0.5) + (C_{sediment} * 0.5)$ to account for incidental ingestion of both flooded soil and sediment

[2]APDD = $(((IR_{soil} * C_{diet}$*absorption factor from soil) + ($IR_{veg} * C_{veg}$*absorption factor from food) + ($IR_{water} * C_{water}$*absorption factor from water))/BW)*site use factor

For metals, the percent absorption is assumed to be 100% from water, 50% from vegetation (see text), and 1% from soil (Pascoe et al., 1994).

For PAHs, the percent absorption is assumed to be 25% from soil (Hack and Selenka, 1996)

For PCBs, the percent absorption is assumed to be 100% from water, 100% from vegetation, and 85% from soil (Fries et al., 1989).

The chemical concentration in vegetation was calculated as 75% from plants above soil and 25%from plants below soil.

[3]TRV = Toxicity Reference Value from Table 9-4.

[4]HQ = $Dose_{diet}$ / TRV

NA = Not analyzed

B(a)P is an abbreviation for benzo(a)pyrene and was used as a surrogate for total PAH toxicity.

Table 10-9. Estimation of doses and hazard quotients for meadow vole dietary exposure from outside the "Area of Readily Apparent Harm".

	Exposure Assessment[1]											Effects Assessment		Risk Characterization			
	C_{soil} (mg/kg ww)				C_{veg} (mg/kg ww)		IR_{veg}	C_{water} (mg/L)		APDD[2] (mg/kgBW/day)		TRV[3] (mg/kgBW/day)		Hazard Quotient (HQ)[4] NOAEL-based HQ		LOAEL-based HQ	
COPEC	Geo. Mean	Mean	IR_{soil}	% Abs.	Mean	Max	(kg ww/day)	Mean	Max	Low	High	NOAEL	LOAEL	Low Dose	High Dose	Low Dose	High Dose
Antimony	4	4	0.0001	1%	0.0071	0.0155	0.005	0.00250	0.00250	0.0013	0.0022	4.4	NA	0.0003	0.0005	-	-
Arsenic	9	15	0.0001	1%	0.0683	0.0885	0.005	0.00180	0.00200	0.0083	0.0107	0.42	1.26	0.0197	0.0256	0.0066	0.0085
Cadmium	2	3	0.0001	1%	0.0748	0.1049	0.005	0.00116	0.00160	0.0087	0.0122	1	10	0.0087	0.0122	0.0009	0.0012
Chromium	183	551	0.0001	1%	0.5371	0.7082	0.005	0.00510	0.00540	0.0667	0.0962	24.5	NA	0.0027	0.0039	-	-
Chrom.(6+)	20	51	0.0001	1%	NA	NA	NA	0.00000	0.00000	0.0006	0.0014	22	NA	2.5E-05	6.3E-05	-	-
Copper	243	585	0.0001	1%	2.7597	4.2477	0.005	0.03000	0.03900	0.3243	0.5040	6.4	12.9	0.0507	0.0787	0.0251	0.0391
Lead	199	267	0.0001	1%	0.8490	1.4903	0.005	0.00080	0.00110	0.1020	0.1768	8	80	0.0128	0.0221	0.0013	0.0022
Manganese	236	311	0.0001	1%	39.7373	52.3026	0.005	0.77000	1.00000	4.6270	6.0883	88	284	0.0526	0.0692	0.0163	0.0214
Mercury	1	2	0.0001	1%	0.0031	0.0048	0.005	0.00010	0.00010	0.0004	0.0006	13.2	40	2.9E-05	4.6E-05	-	-
Silver	5	24	0.0001	1%	0.0352	0.0619	0.005	0.00030	0.00030	0.0042	0.0077	24.67	74	0.0002	0.0003	0.0001	0.0001
Tin	12	22	0.0001	1%	0.3038	0.3318	0.005	0.01000	0.01000	0.0362	0.0397	NA	NA	-	-	-	-
Vanadium	34	39	0.0001	1%	0.1210	0.1909	0.005	0.00130	0.00130	0.0148	0.0229	1.67	5	0.0089	0.0137	0.0030	0.0046
Zinc	105	130	0.0001	1%	9.7712	13.3360	0.005	0.19000	0.21000	1.1391	1.5476	160	320	0.0071	0.0097	0.0036	0.0048
B(a)P	0.4	1.0	0.0001	25%	NA	NA	NA	NA	NA	0.0003	0.0007	15.27	45.8	1.7E-05	4.6E-05	5.5E-06	1.5E-05
Total PCBs	1.4	2.9	0.0001	85%	0.0026	0.0038	0.005	NA	NA	0.0036	0.0072	0.32	1.5	0.0112	0.0225	0.0024	0.0048

[1]Exposure factors from Tables 8-2 and 8-3.

$C_{sediment\&soil} = (C_{soil} * 0.5) + (C_{sediment} * 0.5)$ to account for incidental ingestion of both flooded soil and sediment

[2]APDD = $(((IR_{soil} * C_{diet} * \text{absorption factor from soil}) + (IR_{veg} * C_{veg} * \text{absorption factor from food}) + (IR_{water} * C_{water} * \text{absorption factor from water}))/BW) * \text{site use factor}$

For metals, the percent absorption is assumed to be 100% from water, 50% from vegetation (see text), and 1% from soil (Pascoe et al., 1994).

For PAHs, the percent absorption is assumed to be 25% from soil (Hack and Selenka, 1996)

For PCBs, the percent absorption is assumed to be 100% from water, 100% from vegetation, and 85% from soil (Fries et al., 1989).

The chemical concentration in vegetation was calculated as 75% from plants above soil and 25%from plants below soil.

[3]TRV = Toxicity Reference Value from Table 9-4.

[4]HQ = $Dose_{diet}$ / TRV

NA = Not analyzed

B(a)P is an abbreviation for benzo(a)pyrene and was used as a surrogate for total PAH toxicity.

Table 10-10. Estimation of doses and hazard quotients for muskrat dietary exposure from outside the "Area of Readily Apparent Harm".

	Exposure Assessment[1]											Effects Assessment		Risk Characterization			
	$C_{sediment\&soil}$ (mg/kg ww)				C_{veg} (mg/kg ww)		IR_{veg}	C_{water} (mg/L)		APDD[2] (mg/kgBW/day)		TRV[3] (mg/kgBW/day)		Hazard Quotient (HQ)[4]			
														NOAEL-based HQ		LOAEL-based HQ	
COPEC	Geo. Mean	Mean	IR_{sed}	% Abs.	Mean	Max	(kg ww/day)	Mean	Max	Low	High	NOAEL	LOAEL	Low Dose	High Dose	Low Dose	High Dose
Antimony	4	4	0.012	2.5%	0.0185	0.0409	0.37	0.00250	0.00250	0.0038	0.0072	4.4	NA	0.0009	0.0016	-	-
Arsenic	9	12	0.012	2.5%	0.1952	0.2495	0.37	0.00180	0.00200	0.0311	0.0398	0.42	1.26	0.0740	0.0947	0.0247	0.0316
Cadmium	2	3	0.012	2.5%	0.2152	0.2966	0.37	0.00116	0.00160	0.0325	0.0448	1	10	0.0325	0.0448	0.0032	0.0045
Chromium	127	345	0.012	2.5%	0.9065	1.1281	0.37	0.00510	0.00540	0.1650	0.2500	24.5	NA	0.0067	0.0102	-	-
Chrom.(6+)	20	51	0.012	2.5%	NA	NA	NA	0.00000	0.00000	0.0049	0.0122	22	NA	0.0002	0.0006	-	-
Copper	176	403	0.012	2.5%	4.7456	8.9682	0.37	0.03000	0.03900	0.7461	1.4259	6.4	12.9	0.1166	0.2228	0.0578	0.1105
Lead	122	185	0.012	2.5%	2.4833	4.3621	0.37	0.00080	0.00110	0.3967	0.6901	8	80	0.0496	0.0863	0.0050	0.0086
Manganese	478	515	0.012	2.5%	52.6722	62.9857	0.37	0.77000	1.00000	7.9487	9.4956	88	284	0.0903	0.1079	0.0280	0.0334
Mercury	1	2	0.012	2.5%	0.0074	0.0123	0.37	0.00010	0.00010	0.0013	0.0022	13.2	40	0.0001	0.0002	0.0000	0.0001
Silver	5	24	0.012	2.5%	0.0595	0.0920	0.37	0.00030	0.00030	0.0101	0.0193	24.67	74	0.0004	0.0008	0.0001	0.0003
Tin	13	18	0.012	2.5%	0.6365	0.6993	0.37	0.01000	0.01000	0.0978	0.1084	NA	NA	-	-	-	-
Vanadium	33	36	0.012	2.5%	0.3555	0.5632	0.37	0.00130	0.00130	0.0607	0.0921	1.67	5	0.0363	0.0551	0.0121	0.0184
Zinc	107	120	0.012	2.5%	22.8811	32.2163	0.37	0.19000	0.21000	3.4217	4.8073	160	320	0.0214	0.0300	0.0107	0.0150
B(a)P	0	1	0.012	25%	NA	NA	NA	NA	NA	0.0252	0.070	15.27	45.8	0.0017	0.0046	0.0006	0.0015
Total PCBs	2	3	0.012	85%	0.0071	0.0104	0.37	NA	NA	0.0182	0.0281	0.32	1.5	0.0569	0.0877	0.0121	0.0187

[1]Exposure factors from Tables 8-2 and 8-3.

$C_{sediment\&soil} = (C_{soil} * 0.5) + (C_{sediment} * 0.5)$ to account for incidental ingestion of both flooded soil and sediment

When no sediment data was available $C_{sediment\&soil} = C_{soil}$. When only one sediment value was available this maximum value was used in place of the geometric mean or mean.

[2]APDD = $(((IR_{soil} * C_{diet}$*absorption factor from soil) + $(IR_{veg} * C_{veg}$*absorption factor from food) + $(IR_{water} * C_{water}$*absorption factor from water))/BW)*site use factor

For metals, the percent absorption is assumed to be 100% from water, 50% from vegetation (see text), and 2.5% from soil (Pascoe et al., 1994).

The chemical concentration in vegetation was calculated as 25% from plants above soil and 75% from plants below soil.

For PAHs, the percent absorption is assumed to be 25% from soil (Hack and Selenka, 1996)

For PCBs, the percent absorption is assumed to be 100% from water, 100% from vegetation, and 85% from soil (Fries et al., 1989).

[3]TRV = Toxicity Reference Value from Table 9-4.

[4]HQ = $Dose_{diet}$ / TRV

NA = Not analyzed

B(a)P is an abbreviation for benzo(a)pyrene and was used as a surrogate for total PAH toxicity.

10.6.2 Avian Wildlife

Potential risks to avian receptors from exposure to COPECs outside the "Area of Readily Apparent Harm" are characterized by use of a HQ approach (equation 10-3). HQs for each of the mammalian receptors are presented (Tables 10-11 and 10-12). The exposure point concentrations are based on two different exposure levels (low dose and high dose) as described previously. The information in these tables can be summarized as follows:

- None of the avian receptors had NOAEL-based hazard quotients greater than 1.0 for any of the COPECs.
- None of the avian receptors had LOAEL-based hazard quotients greater than 1.0 for any of the COPECs.

Taken together, there is no indication of risk of harm to avian receptors. This is likely due to the relatively small size of the area where concentrations of COPECs are elevated and possibly from limited bioavailability of the COPECs at this site. In particular, available data demonstrate very limited assimilation and accumulation of COPECs into wetland vegetation and small mammals.

Table 10-11. Estimation of doses and hazard quotients for mallard dietary exposure from outside the "Area of Readily Apparent Harm".

	Exposure Assessment[1]											Effects Assessment		Risk Characterization			
	$C_{sediment\&soil}$ (mg/kg ww)				C_{veg} (mg/kg ww)		IR_{veg}	C_{water} (µg/L)		APDD[2] (mg/kgBW/day)		TRV[3] (mg/kgBW/day)		Hazard Quotient (HQ)[4]			
														NOAEL-based HQ		LOAEL-based HQ	
COPEC	Geo. Mean	Mean	IR_{soil}	% Abs.	Mean	Max	(kg ww/day)	Mean	Max	Low	High	NOAEL	LOAEL	Low Dose	High Dose	Low Dose	High Dose
Antimony	4	4	0.00031	10%	0.0105	0.0231	0.1	0.00250	0.00250	0.0008	0.0015	NA	NA	-	-	-	-
Arsenic	9	12	0.00031	10%	0.1064	0.1368	0.1	0.00180	0.00200	0.0057	0.0073	10	40	0.0006	0.0007	0.0001	0.0002
Cadmium	2	3	0.00031	10%	0.1169	0.1624	0.1	0.00116	0.00160	0.0060	0.0083	1.45	20	0.0041	0.0057	0.0003	0.0004
Chromium	127	345	0.00031	10%	0.6479	0.8342	0.1	0.00510	0.00540	0.0367	0.0527	1.6	NA	0.0229	0.0330	-	-
Chrom. (6+	20	51	0.00031	10%	NA	NA	NA	0.00000	0.00000	0.0006	0.0016	NA	NA	-	-	-	-
Copper	176	403	0.00031	10%	3.3554	5.6639	0.1	0.03000	0.03900	0.1751	0.2982	9.4	12.3	0.0186	0.0317	0.0142	0.0242
Lead	122	185	0.00031	10%	1.3393	2.3518	0.1	0.00080	0.00110	0.0708	0.1234	0.23	2.26	0.3078	0.5365	0.0313	0.0546
Manganese	478	515	0.00031	10%	43.6177	55.5075	0.1	0.77000	1.00000	2.2450	2.8554	195	589	0.0115	0.0146	0.0038	0.0048
Mercury	1	2	0.00031	10%	0.0044	0.0071	0.1	0.00010	0.00010	0.0003	0.0004	0.09	0.18	0.0028	0.0046	0.0014	0.0023
Silver	5	24	0.00031	10%	0.0425	0.0709	0.1	0.00030	0.00030	0.0023	0.0043	1.4	2.77	0.0016	0.0031	0.0008	0.0016
Tin	13	18	0.00031	10%	0.4036	0.4420	0.1	0.01000	0.01000	0.0212	0.0233	NA	NA	-	-	-	-
Vanadium	33	36	0.00031	10%	0.1914	0.3026	0.1	0.00130	0.00130	0.0107	0.0163	11.4	34.2	0.0009	0.0014	0.0003	0.0005
Zinc	107	120	0.00031	10%	13.7042	19.0000	0.1	0.19000	0.21000	0.7007	0.9672	2.9	26.2	0.2416	0.3335	0.0267	0.0369
PAHs	4	12	0.00031	25%	NA	NA	NA	NA	NA	0.0003	0.0009	40	400	8.3E-06	2.3E-05	8.3E-07	2.3E-06
Total PCBs	2	3	0.00031	85%	0.0039	0.0058	0.1	NA	NA	0.0009	0.0014	0.12	0.36	0.0076	0.0115	0.0025	0.0038

[1]Exposure factors from Tables 8-2 and 8-3.

$C_{sediment\&soil} = (C_{soil} * 0.5) + (C_{sediment} * 0.5)$ to account for incidental ingestion of both flooded soil and sediment.

When no sediment data was available $C_{sediment\&soil} = C_{soil}$. When only one sediment value was available this maximum value was used in place of the geometric mean or mean.

[2]APDD = $(((IR_{soil} * C_{diet}$*absorption factor from soil) + $(IR_{veg} * C_{veg}$*absorption factor from food) + $(IR_{water} * C_{water}$*absorption factor from water))/BW)*site use factor

For metals, the percent absorption is assumed to be 100% from water, 50% from vegetation (see text), and 10% from soil (Pascoe et al., 1994).

The chemical concentration in vegetation was calculated as 60% from plants above soil and 40% from plants below soil (this 40% value is the sum of 25% of diet from plants below soil and 15% invertebrates assumed to have residue concentrations equal to those of plants below soil - see text for details).

For PAHs, the percent absorption is assumed to be 25% from soil (Hack and Selenka, 1996)

For PCBs, the percent absorption is assumed to be 100% from water, 100% from vegetation, and 85% from soil (Fries et al., 1989).

[3]TRV = Toxicity Reference Value from Table 9-5.

[4]HQ = $Dose_{diet}$ / TRV

NA = Not analyzed

Table 10-12. Estimation of doses and hazard quotients for red tail hawk dietary exposure from outside the "Area of Readily Apparent Harm".

	Exposure Assessment[1]					Effects Assessment		Risk Characterization	
	C_{prey} (mg/kg ww)			C_{water} (mg/L)	APDD[2] (mg/kgBW/day)	TRV[3] (mg/kgBW/day)		Hazard Quotient (HQ)[4] NOAEL-based HQ	LOAEL-based HQ
COPEC	max	IR_{prey}	% Abs.	Max	High	NOAEL	LOAEL	High Dose	High Dose
Antimony				0.00250	7.1E-05	NA	NA	-	-
Arsenic				0.00200	0.0001	2	8	2.8E-05	7.1E-06
Cadmium	0.0791	0.109	100%	0.00160	0.0039	0.29	4	0.0134	0.0010
Chromium	2.96	0.109	100%	0.00540	0.1433	1.6	NA	0.0896	-
Chrom. (6+)				0.00000	0.0000	NA	NA	-	-
Copper	4.51	0.109	100%	0.03900	0.2196	9.4	12.3	0.0234	0.0179
Lead	0.275	0.109	100%	0.00110	0.0133	0.23	2.26	0.0579	0.0059
Manganese	24.6	0.109	100%	1.00000	1.2191	195	589	0.0063	0.0021
Mercury	0.0305	0.109	100%	0.00010	0.0015	0.09	0.18	0.0164	0.0082
Silver				0.00030	8.5E-06	0.08	0.17	-	-
Tin				0.01000	0.0003	NA	NA	-	-
Vanadium				0.00130	3.7E-05	2.28	6.8	1.6E-05	-
Zinc	33.9	0.109	100%	0.21000	1.6446	2.9	26.2	0.5671	0.0628
PAHs				NA	0.0000	8	80	-	-
Total PCBs	0.005	0.109	100%	NA	0.0002	0.12	0.36	0.0020	0.0007

[1]Exposure factors from Tables 8-2 and 8-3.

[2]APDD = $(((IR_{prey} * C_{prey}) + (IR_{water} * C_{water}))/BW)$*site use factor

For metals, the percent absorption is assumed to be 100% from water and 50% from diet (see text.).

For PCBs, the percent absorption is assumed to be 100% from diet.

The site use factor for red-tailed hawks is assumed to be 50%.

[3]TRV = Toxicity Reference Value from Table 9-5.

[4]HQ = $Dose_{diet}$ / TRV

NA = Not analyzed

10.7 Consideration of Risk of Harm to Rare, Threatened, and Endangered Species

Since rare species (i.e., river bulrush) and state-listed threatened species (i.e., Northern Harrier Hawk) have been observed on site and it is possible that other rare, threatened, and endangered species can potentially occur at this site, this ERC considers the potential risk of harm to these species. For species other than the river bulrush and Northern Harrier Hawk, the current ERC is considered to be sufficiently conservative to be protective of these other potentially occurring species.

10.7.1 River Bulrush

In regards to the river bulrush, the occurrence at this site is primarily adjacent to the Sudbury River and its occurrence does not coincide with the locations within the "Area of Readily Apparent Harm" (refer to Figure 2 of Appendix A for a map showing the locations of river bulrush. The river bulrush was observed to be present in substantial numbers at each population area surveyed.

10.7.2 Northern Harrier Hawk

In regards to the Northern Harrier Hawk, the observations indicated that this individual was migrating and not a resident at this site. Nevertheless, the red-tailed hawk was evaluated for this site, which can act as a surrogate species for the Northern Harrier Hawk, and the predicted risks were substantially less than 1.0.

10.8 Evaluation of Effects Considered as Indicators of Environmental Harm

The MCP lists several effects that are considered "indicators of environmental harm", including absence of a species, reduction of a population or subpopulation, change in the structure of a community, bioconcentration/bioaccumulation, habitat degradation or destruction, loss or diminshment of ecological function. These "effects" are to be evaluated at sites to determine whether a significant risk of harm is present. The only "effects" from this list which were considered to apply to this site are bioconcentration/bioaccumulation and habitat degradation or destruction, both of which will be discussed below.

10.8.1 Bioconcentration/Bioaccumulation

Bioaccumulation, or the potential for bioaccumulation, is not by itself indicative of toxic effects. The MCP states that a "decision to consider bioaccumulation as an indication of harm, rather than just evidence of exposure, should be based on the toxicity of the chemical in question and the likely fate of the chemical in the food web." In this ERC, consideration was made for the potential bioaccumulation of PCBs to upper trophic level predators, such as mink, great blue herons, and bald eagles. However, other factors were considered such as the relatively small size of the PCB hot spot at the site, the location of the PCB hot spot which is within the "Area of Readily Apparent Harm", the transitional nature of this site to support aquatic and terrestrial organisms, and the nearly ubiquitous low level PCB concentrations in fish (approximately 1-4 mg/kg) measured in the late 1980's throughout the entire Sudbury and Concord River watersheds. Thus, it was determined that the amount of PCBs available for bioaccumulation to upper trophic level receptors at this site is likely to be low. Furthermore, it would be difficult to attribute the proportion of body burden attributable to uptake at the site. While extensive food chain modeling was not applied at this site to predict exposure of PCBs to upper trophic level receptors such as mink, great blue herons, and bald eagles, receptors were selected that are predicted to have relatively great exposures and home ranges that are more appropriate to the size of the site.

10.8.2 Habitat Degradation Or Destruction

MCP guidance defines habitat degradation or destruction as "the reduction of the area of a habitat or the reduction or elimination of structural vegetative components or critical features typically found within a habitat type.... The observation of stressed vegetation is evidence of habitat degradation, if the stress is due to contamination at the site." Thus, the observation at this site of a zone of stunted vegetation that correlates well to the hot spot of COPECs at this site fulfills the definition of habitat degradation and is, therefore, evidence of environmental harm (refer to the section on the Stage I Screening-Level ERC for more details).

11.0 CONCLUSIONS AND UNCERTAINTIES

11.1 Purpose

The purpose of this section is to integrate and summarize the overall conclusions of the environmental risk characterization and to present the results of an uncertainty analysis, to indicate the sources, magnitude, and direction of uncertainties that potentially influence the interpretation of results.

11.2 Conclusions

The conclusions regarding risk to ecological resources at the wetlands near the former Raytheon facility are based on the following:

- Site background and conceptual site model.
- Visible evidence of habitat degradation and the presence of an "Area of Readily Apparent Harm".
- Analytical data collected in 1998-2000.
- The assessment of exposure and effects.
- The characterization of potential risk presented.
- The integration of different lines of evidence collected for certain assessment endpoints.
- The evaluation of uncertainty.

11.2.1 Assessment Endpoint #1 - Protection of Fish, Amphibians, and Aquatic Invertebrate Communities From Adverse Effects Related to Exposure to COPECs in Surface Water

The assessment endpoint, protection of fish, amphibians, and aquatic invertebrate communities from adverse effects related to exposure to COPECs in surface water, was evaluated by using two measurement endpoints: (A) comparison of concentrations of COPECs in surface water from the wetland to surface water benchmarks that are designed to be protective of aquatic organisms; and (B) comparison of concentrations of COPECs in surface water from the wetland to surface water benchmarks literature-derived studies that were conducted under conditions of similar bioavailability to those at the site. Surface water data are available for two different times of year allowing a temporal assessment of potential risk in locations outside of the "Area of Readily Apparent Harm". Temporally, there is a difference in potential risk to aquatic organisms at this site. During conditions of low water at the site, there are exceedances of water quality criteria (WQC) for copper and zinc. However, during conditions of inundation at the site (*e.g.*, typically during the late winter, early spring and periodic times of flooding), there are no exceedances of WQC. This temporal difference is important because the timing of inundation coincides with potential spawning activities of fish from the Sudbury River.

While there are exceedances of WQC and thus, there exists a potential risk of adverse effects, the magnitude of potential risk is low. Thus, it is not likely that population-level effects are actually occurring because of the conservative nature of WQC. Moreover, the available information for Measurement Endpoint "B" suggests that bioavailability and toxicity of copper and, to a lesser degree, zinc, are reduced due to dissolved organic matter present in the surface water of the wetland. Thus, taken together in a weight-of-evidence approach, there is no indication of risk of harm to aquatic receptors.

11.2.2 Assessment Endpoint #2 - Protection of Wetland Vegetation From Adverse Effects Related to Exposure to COPECs in Wetland Soils.

The assessment endpoint, protection of wetland vegetation from adverse effects related to exposure to COPECs in wetland soils, was evaluated by using three measurement endpoints: (A) comparison of concentrations of COPECs in wetland soils to phytotoxicity benchmarks that are designed to be protective of vegetation; (B) comparison of concentrations of COPECs in plant tissues from the wetland to plant tissue residue effect levels that are designed to be protective of vegetation; and (C) comparison to site-specific, field-measured effect concentrations of COPECs in soil that are found in the area of stunted vegetation. The two most likely COPECs responsible for the observed adverse effects on vegetation at the site are copper and chromium, based on the magnitude of the literature-based hazard quotients for phytotoxicity. However, due to the presence of multiple COPECs and uncertainty associated with phytotoxicity benchmark data, it is difficult to assess cause and effect relationships. Taken together, based on the weight-of-evidence evaluation, it is reasonable to conclude that there is no indication of risk of harm to wetland vegetation outside of the "Area of Readily Apparent Harm".

11.2.3 Assessment Endpoint #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

The assessment endpoint, 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, was evaluated by using a single measurement endpoint: 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. None of the wildlife receptors considered in this ERC had calculated hazard quotients greater than 1.0 based on the NOAEL or the LOAEL. Taken together, there is no indication of risk of harm to avian and mammalian receptors.

11.3 Evaluation of Uncertainty

The evaluation of uncertainty involves identifying sources of uncertainty associated with the ERC process that may potentially affect the conclusions of the assessment. According to USEPA (1996), "uncertainty analyses increase credibility by explicitly describing the magnitude and direction of uncertainties, and they provide that basis for efficient data collection of or application of refined methods." Specifically, uncertainty associated with measurement endpoint results translates into uncertainty associated with the conclusions regarding risk at the wetlands near the former Raytheon facility. To reduce the potential for uncertainty resulting in underestimates of actual risks at this site, conservative methods and procedures were used throughout the assessment.

Sources of uncertainty have been identified based on a review of the assumptions used to develop this ERC (*e.g.*, assumptions associated with exposure parameter inputs to the dose equation and review of environmental data collected at this site). Identified sources of uncertainty are discussed in the following sections, which are organized according to the components of the ERC.

11.3.1 Uncertainty Associated With the Problem Formulation

11.3.1.1 Selection of Receptors

Risks to wildlife are assessed for a small subset of species that are likely to be present in the wetlands near the former Raytheon facility. The receptors that were selected for quantitative risk evaluation represent a range of taxonomic groups and foraging characteristics. An effort was made to select receptor species representing the greatest probability of exposure. However, these species may be either more or less sensitive to chemical exposures than other species within the area. In particular, the relative sensitivities of reptiles and amphibians, as compared to aquatic organisms or other wildlife at the site, are unknown due to a lack of high quality toxicity data. It is assumed that the risks to these organisms are at least qualitatively similar to risks of other wildlife at this site. Specifically, it is assumed that water quality criteria are sufficiently protective of amphibians, such that if WQC and related benchmarks are exceeded , then there exists some potential risk of adverse effects to amphibians. However, due to the conservative nature of WQC, it is likely that the risk to aquatic organisms, including amphibians is overestimated by using this approach.

11.3.1.2 Selection of Exposure Pathways

The exposure pathways selected for evaluation in this ERC are not inclusive of every potential exposure pathway for all ecological receptors. Additional pathways may be considered such as dermal exposures for wildlife and sediment ingestion for fish. However, it is likely that these pathways are minor relative to those pathways that were evaluated in this ERC.

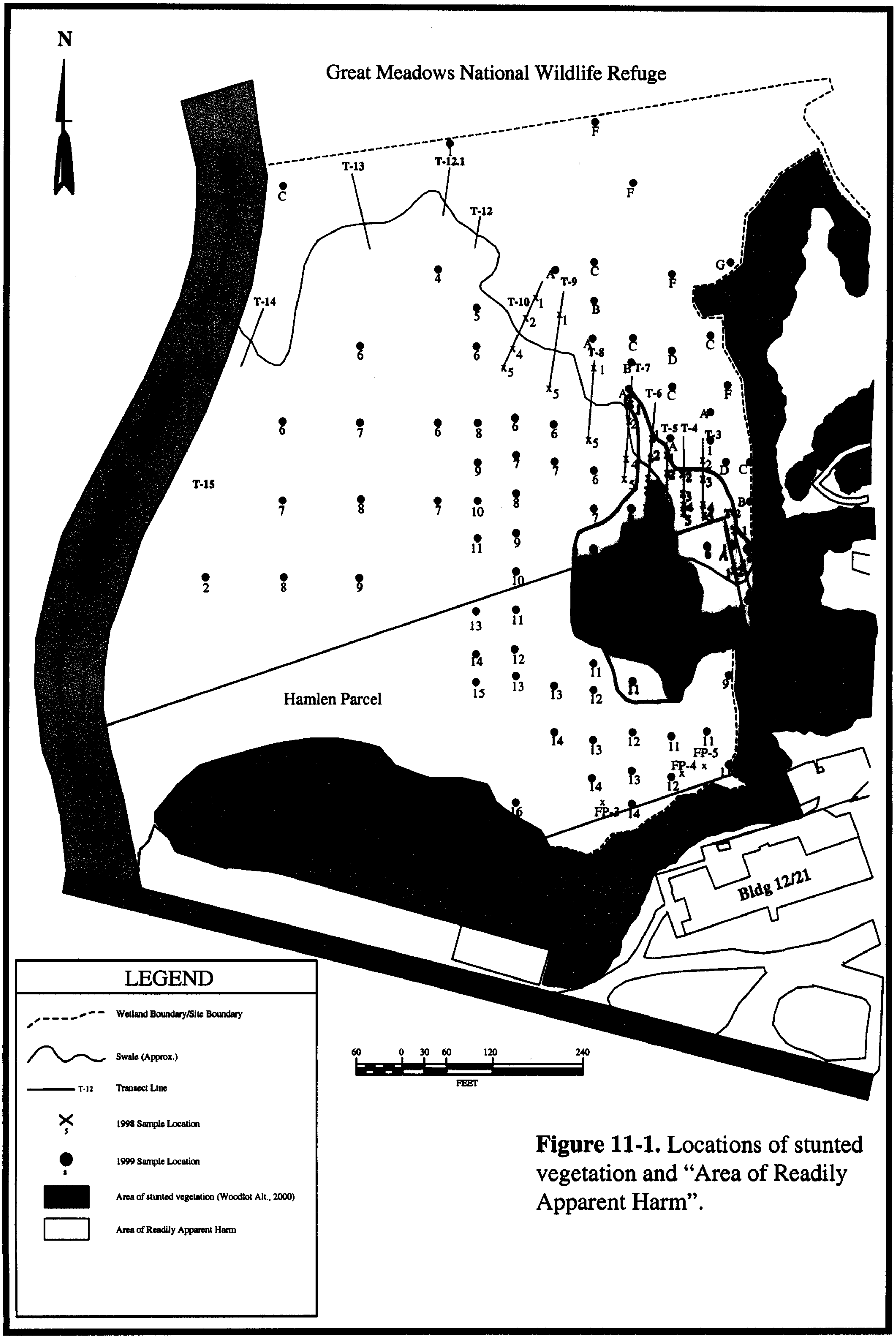


Figure 11-1. Locations of stunted vegetation and "Area of Readily Apparent Harm".

11.3.2 Uncertainty Associated With the Exposure Assessment

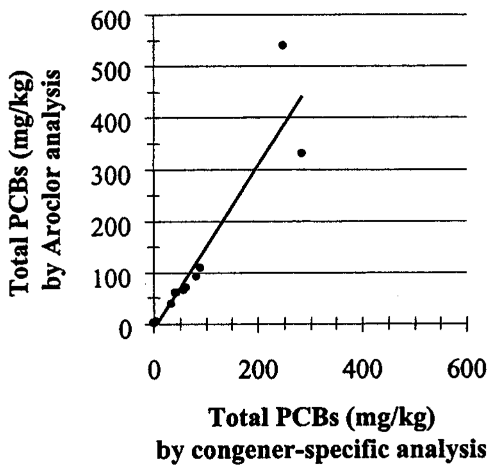
11.3.2.1 Data on Chemical Concentrations in Sediment and Soil

The concentrations of COPECs in sediment and soil have been well characterized spatially for most COPECs. In the case of PCBs, some of the samples were split and analyzed separately by either Aroclor analysis or by congener-specific analysis. The results of these analyses indicate that there is a bias with the Aroclor analysis in which the results of the Aroclor analysis overestimate the actual concentration of total PCBs (determined by congener analysis) when the concentration of total PCBs is greater than 2.5 mg/kg, dry weight. While the congener-specific analysis is a more accurate and appropriate analytical method for PCBs, especially for environmentally weathered mixtures such as the PCBs at this site, it is not economically feasible to routinely analyze all samples at a site using this methodology.

The limitations of Aroclor based analysis methods are well known and documented by the USEPA Region 9 BTAG, (1998). It is generally recommended that both congener-specific and Aroclor analyses be utilized to some extent to evaluate a site, although several factors should be considered to determine the most appropriate sampling and analysis strategy (USEPA Region IX, 1998; Blankenship et al., 2000). For Aroclor-based analysis and quantitation, PCB mixtures are extracted from environmental samples and only a few congener peaks are compared to commercial Aroclor mixtures. However, because the relative ratios of individual PCB congeners are constantly being altered in environmental matrices (water, soils and sediments) as a result of environmental weathering processes (including differential congener degradation, accumulation, metabolism and elimination processes), the congener mixtures found in environmental samples usually bear little similarity to the original technical mixtures. Thus, attempting to quantify these environmentally altered PCB mixtures as original technical PCB mixtures, which they no longer resemble, introduces great uncertainties (Blankenship et al., 2000).

The total PCB concentrations determined at this site from the PCB congener-specific analysis ranged from 1.0 to 285 mg/kg, dry weight compared to 1.3 to 540 mg/kg, dry weight for Aroclor analysis. A regression analysis was conducted for the PCB congener analyses and the Aroclor-based analyses. The relationships between congener-specific analyses and Aroclor based analyses appear to be concentration-dependent. At concentrations less than 2.5 mg/kg, (dry weight), there is good agreement between the two methods ($R^2 = 0.98$). At concentrations greater than 2.5 mg/kg, total PCBs as measured by the Aroclor-based analysis are consistently greater in concentration (by approximately 10-50%) than the congener-specific analysis.

The only exception to the observed relationships between Aroclor-based and congener-specific results 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. Since congener-specific analysis is more technically defensible than Aroclor-based analyses for weathered environmental samples, the congener-specific result is used in this ERA. The uncertainty associated with which PCB result to use is relatively insignificant (i.e., the hazard quotients are all less than 1.0 for PCBs) and does not alter the conclusions of this ERA. 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.



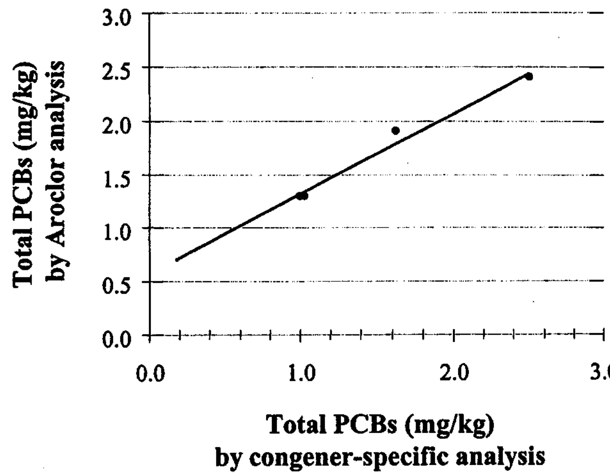


Figure 11-2. Correlational analysis of two different methods to analyze and quantify total PCBs using all data from split samples of sediment and soil from the wetlands near the former Raytheon facility. A total of 14 samples were analyzed. The regression equation is:

$y = 1.587(x) - 9.6412$
($R^2 = 0.8715$)

Figure 11-3. Correlational analysis of two different methods to analyze and quantify total PCBs using only data with concentrations of PCBS less than 2.5 mg/kg from split samples of sediment and soil from the wetlands near the former Raytheon facility. A total of 4 samples were analyzed. The regression equation is:

$y = 0.7493(x) + 0.5711$
($R^2 = 0.9814$)

11.3.2.2 Exposure (or Dose) Calculations

Because the parameters used to estimate dose (intake) are not always empirically measured, conservative assumptions were made which could result in an overestimate of exposure and risks. The dose calculations consider the concentration of the COPECs at an exposure point, physical characteristics of the receptor, and the exposure frequency. Each of these three inputs has varying degrees of uncertainty.

The concentrations of COPECs at the exposure point were directly measured (*i.e.* site-specific vegetation tissue, soil, and sediment data were collected). Therefore, food-chain analysis and modeling, which are typically sources of uncertainty, were not conducted. However, there were uncertainties associated with the assumptions made about the percent diet composition and foraging behavior of the receptors. The diet for the birds considered at the wetlands near the former Raytheon facility can be highly variable (*e.g.*, freshwater mollusks, polychaete worms, crustaceans, and vegetation), is dependent on specific prey availability, and includes a foraging range that varies with water levels and seasonal conditions at this site (refer to sections 3.5, 4.3.2, 4.3.3, 7.0, and 8.0 for more details). The assumption that the birds' diet consists solely of prey items from this site is, therefore, likely an over-estimate of exposure.

Foraging habits that impact the amount of incidental sediment ingested also directly affect exposure estimates. The percent sediment ingestion for the wildlife receptors were taken from the literature. The natural history information gathered for the wildlife receptors indicate that estimates for percent diet composition of prey and sediment are based on very conservative assumptions.

In addition, a fractional absorption value was included in the exposure model to account for the fraction of the oral dose that is absorbed through the gastrointestinal tract. The fractional absorption values were determined from the scientific literature and were specific to each class of COPECs (*e.g.*, metals, PAHs, and PCBs) and to each exposure medium (*e.g.*, soil and sediment ingestion, normal diet, water ingestion). This fractional absorption factor is especially important for incidental ingestion of sediments and soils. It has been shown that short-term contact of soil with a compound that can be sorbed reduces its bioavailability. For metals, the percent absorption was assumed to be 100% from water and 50% from vegetation. Support for the use of 50% absorption for metals in the diet comes from EPA reports on the toxicological reviews of metals for the Integrated Risk Information System (IRIS) and other sources in which the oral and gastrointestinal absorption was reported to be 0.4-3% for chromium, 2.5% for cadmium, 10% for silver (Eisler , 1996), 20-30% for zinc (Eisler, 1993). Thus, the estimate of 50% absorption of metals from foods is likely to overestimate the actual exposure.

The percent absorption of metals from sediment and soil was assumed to be 1% for meadow voles and 2.5% for muskrats, white-tailed deer, and mallards (Pascoe *et al.*, 1994a). The assumed value of 1% bioavailability from soil for meadow voles is actually 10-fold greater than the measured value by these same authors (Pascoe *et al.*, 1994b) to account for potential uncertainty due to differences in soil parameters for the site described in this ERC. The value of 2.5% reflects additional conservatism to account for potential species-specific differences in bioavailability (absorption) of metals from soils. Thus, the estimate of 2.5% absorption of metals from soils and sediments is likely to overestimate that actual exposure.

Little information is available on the absorption factor or matrix effect for organic chemicals in soils, especially aged chemicals in soils. There is considerable evidence that demonstrates a reduction in bioavailability for persistent organics with increasing time (*e.g.*, aging) in soil. For PAHs (benzo(a)pyrene is used in this ERC as a surrogate for total PAHs for mammals), the percent absorption is assumed to be 100% from water and 25% from soil. Support for the use of 25% absorption from soil is from a study that utilized a digestive tract model to measure the percent mobilization of PAHs from soils (Hack and Selenka, 1996). For PCBs, the percent absorption is assumed to be 100% from water, 100% from normal diet, and 85% from sediment and soil (Fries *et al.*, 1989). The actual absorption of organic compounds from ingestion of food, soil, and sediments is likely to be less than these assumed values and, therefore, the exposure estimates are likely to overestimate actual exposure.

Physical characteristics of the receptors that affect the dose calculation include body weight and daily ingestion rate. A mean body weight for the wildlife receptors were derived by taking a mean from available literature. However, since body weights vary widely, and lower (or greater) body weights are associated with greater (or lower) calculated doses. Therefore, the estimated dose may over- or under-estimate the actual dose to the population as a whole.

When daily ingestion rates were not available in the literature for wildlife species, an ingestion rate was estimated using an allometric equation developed by Nagy (1987) which is based on body weight. The allometric equation is based on the assumption that as body weight increases, ingestion rate would also increase by a constant rate. There is a large amount of uncertainty in estimating ingestion based on an allometric equation. However, the equation is designed to be conservative and would likely overestimate ingestion rates.

The exposure frequency for each receptor is based on the amount of time the species uses the site. Receptors used in the risk analysis for the wetlands near the former Raytheon facility were assumed to be year-round residents and have ranges such that they forage and live within the site 100%of the time (*i.e.*, a site use factor of 1 was used in the dose calculation), with the exception of white-tailed deer and red-tailed hawks, which were assumed to forage and live within the site 20% and 50% of the time, respectively. The natural history information for the white-tailed deer indicate that they are not resident at the site and their foraging range is much larger than the site. Likewise, for red-tailed hawks, the foraging range is much larger than the site and they would not be expected to forage on the site during times when the site is flooded. For the other wildlife receptors that were assumed to forage and live 100% of the time at the site, their actual exposure is likely less than that estimated in this ERC and therefore the potential risk to these receptors has been overestimated.

11.3.3 Uncertainty Associated With the Effects Assessment (Including Development of Benchmarks or Toxicity Reference Values to Evaluate Estimated Doses

Ambient water quality criteria were utilized as a measurement endpoint in this ERC. It is recognized that these criteria are conservative to be protective. In addition, there are numerous mechanisms that can reduce the bioavailability and hence, toxicity of chemicals in water, particularly metals. For example, many metals, particularly copper can be bound to complexes and dissolved organic carbon which reduces the bioavailable amount of copper to which aquatic organisms might be exposed. These factors are currently being considered by the USEPA, but as yet have not been adopted (USEPA, 2000c and 2000d). One of these factors (dissolved organic matter) was evaluated by collecting site-specific data and information from literature studies that were conducted under conditions similar to the site.

Phytotoxicity benchmarks were developed from multiple sources. However, the data on toxicity of chemicals to plants in soils is very limited. The direction and magnitude of uncertainty for the phytotoxicity benchmarks is not known.

For a few COPECs (antimony and tin), toxicity data were not available to derive a toxicity reference value. Thus, the potential risks from these COPECs will be underestimated. For the rest of the COPECs, sufficient toxicity data were available to derive TRVs for avian and mammalian wildlife. Uncertainty factors were applied as appropriate to account for unknown differences in species sensitivity, duration of exposure, and ecological relevance of the endpoint. It is likely that the use of these uncertainty factors will overestimate risk.

11.4 Overall Conclusions

Ecological endpoints (*i.e.*, assessment and measurement endpoints) are explicit statements which identify desired environmental goals and provide a means for determining whether an unacceptable effect may occur. The assessment and measurement endpoints for the wetlands near the former Raytheon facility represent those ecological resources selected for protection.

This ERC does not indicate that there is a risk of adverse effects for any of the assessment endpoints when evaluating locations outside of the "Area of Readily Apparent Harm". Based on the evaluation presented in this report, the following overall conclusions can be made:

- Evaluation of site conditions indicated that significant environmental harm is "readily apparent" for a limited portion of the site as defined by the MCP [310 CMR 40.0995(3)(b)], including:
  - visual evidence of stressed biota (*e.g.*, stunted vegetation) attributable to the release at the site; and
  - the existence of COPECs attributable to the site in concentrations which exceed USEPA Ambient Water Quality Criteria
- There is no evidence of potential risk from on-site COPECs to aquatic receptors in locations outside of the "Area of Readily Apparent Harm".
- There is no evidence of potential risk from on-site COPECs to wetland plants in locations outside of the "Area of Readily Apparent Harm".

- There is no evidence of potential risk from on-site COPECs to avian and mammalian receptors in locations outside of the "Area of Readily Apparent Harm".

As described in the MCP, there are two possible outcomes of an ERC:

3) No significant risk of harm to the environment exists or has been achieved at the site. In this case, no further remediation to protect the environmental receptors is required.

4) A significant risk of harm to the environment exists, and, therefore, remedial action must be implemented, if feasible.

At this site, there is an area where there is a condition of "readily apparent harm", which may require consideration of remedial actions. The result of a Stage II ERC indicates that no significant risk of harm to environmental receptors exists at the site in locations outside of the "Area of Readily Apparent Harm".

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