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TETRA TECH EC, INC.

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COMPREHENSIVE SITE ASSESSMENT REPORT
VOLUME II – APPENDICES A THROUGH C

FIREWORKS I
(FORMER FIREWORKS FACILITY)
HANOVER, MASSACHUSETTS
TIER IA PERMIT #100223
RTN: 4-0090

November 2005

Prepared for

The Fireworks Site Joint Defense Group

Prepared by

Tetra Tech EC, Inc.
133 Federal Street 6th Floor
Boston, Massachusetts 02110

SGS

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Appendix A
Final Comprehensive Site Assessment Report
Human Health Risk Characterization

TETRA TECH EC, INC.

APPENDIX A

FINAL
COMPREHENSIVE SITE ASSESSMENT REPORT
HUMAN HEALTH RISK CHARACTERIZATION

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ATTACHMENTS

ACRONYM LIST

ADD	Average Daily Dose
ATSDR	Agency for Toxic Substances and Disease Registry
bgs	below ground surface
COC	contaminant of concern
COPC	contaminant of potential concern
CSA	Comprehensive Site Assessment
CSF	Cancer Slope Factor
CSM	conceptual site model
DPW	Department of Public Works
ELCR	excess lifetime cancer risk
EPC	exposure point concentration
HEAST	Health Effects Assessment Summary Tables
HI	hazard index
HQ	hazard quotient
IRIS	Integrated Risk Information System
JEM	Johnson and Ettinger Model
LADD	Lifetime Average Daily Dose
LOAEL	Low Observable Adverse Effects Level
MADEP	Massachusetts Department of Environmental Protection
MCP	Massachusetts Contingency Plan
NOAEL	No Observable Adverse Effects Level
NPDWSA	Non-Potential Drinking Water Source Area
OHM	Oil or Hazardous Material
ORS	Office of Research and Standards
PAH	polycyclic aromatic hydrocarbon
PRG	Preliminary Remediation Goal
RAF	Relative Absorption Factor
RfC	Reference Concentration
RfD	Reference Dose
RTN	Release Tracking Number
SQL	sample quantitation limit
SVOC	semivolatile organic compound
TAL	target analyte list
TtEC	Tetra Tech EC, Inc.
TtFW	Tetra Tech FW, Inc.
UR	Unit Risk
USEPA	United States Environmental Protection Agency
VF	Volatilization Factor
VOC	volatile organic compound

1.0 INTRODUCTION

A risk characterization is the process used in the Massachusetts Contingency Plan (MCP) for describing and evaluating the risks posed by contamination at a site. It is performed to (1) determine whether a remedial response action is necessary at a disposal site; (2) to identify target cleanup levels in the event that a remedial action is required; and (3) to document that a condition of "No Significant Risk" of harm to human health, safety, public welfare, and the environment exists or has been achieved at a site.

The MCP provides three options for conducting a risk characterization to determine whether a level of "No Significant Risk" has been achieved at a site. A Method 1 is the characterization of risk through the use of promulgated standards for soil and groundwater. A Method 2 risk characterization allows for some supplements or adjustments to these Method 1 standards by considering limited site-specific information. A Method 3 is the characterization of risk through the application of site-specific methodologies. For the Fireworks Site (hereafter referred to as the Site), a Method 3 risk characterization was chosen, which employs site-specific information (particularly the potential for exposure to contaminants) to independently evaluate the risks of harm to human health. This risk characterization has been conducted in accordance with the Massachusetts Department of Environmental Protection (MADEP) *Guidance for Disposal Site Risk Characterization* (MADEP, 1996).

1.1 Human Health Risk Characterization

This Appendix presents an evaluation of potential human health risks associated with exposure to chemical contaminants detected in soil, groundwater, surface water, sediment, and fish tissue at the Site.

The risk of harm to human health was evaluated by assessing all current and foreseeable site-related exposures by comparing calculated carcinogenic and non-carcinogenic risks to risk limits promulgated in the MCP. This risk characterization relies on exposure factors and toxicity values provided in MADEP guidance documents and data sources as cited throughout the sections of this Appendix. In the absence of MADEP-recommended values, data from the scientific literature were used in consultation with MADEP Region 1 personnel.

Sections 1.1.1 and 1.1.2 present an overview of the risk characterization process and a guide to the overall organization of this human health risk characterization, respectively.

1.1.1 Overview of Risk Characterization Process

A human health risk characterization is generally conducted using a four-step process: data evaluation, exposure assessment, dose-response assessment, and risk characterization. These steps, including the process involved with each step, are discussed below.

1. Data Evaluation. In the first step of a risk characterization, the data regarding the chemicals detected in each medium are compiled and data quality issues are discussed. A conservative process of selecting contaminants of concern (COCs), designed to carry most oil or hazardous material (OHM) through the risk assessment process is performed. The contaminant of potential concern (COPC) lists, the summary of the data for each media, and the selected COCs are shown in Tables A-4-1 through A-4-36.

2. Exposure Assessment. In the second step of a risk characterization, the potential ways in which people may be exposed to the COCs are discussed and the pathways warranting evaluation are selected, as presented in Tables A-2-1 to A-2-9. For each pathway selected for quantitative evaluation, the chemical concentrations at the point of human exposure are

estimated. Exposure point concentrations (EPCs) are presented in Tables A-5-1 through A-5-35. Then the magnitude, frequency, and duration of exposure are estimated for each pathway and the exposure intakes are quantified. The algorithms used to calculate average daily doses (ADDs) and lifetime average daily doses (LADDs) are presented with the various exposure assumptions for each receptor in Tables A-6-1 through A-6-24.

3. Dose-Response Assessment. In the third step, the chemical-specific health effects criteria used in the characterization are presented. The health effects criteria are discussed according to non-carcinogenic (threshold) and carcinogenic (non-threshold) effects. Sources of toxicological information and criteria in order of preference (MADEP, 1996) are the Integrated Risk Information System (IRIS) (USEPA, 2004b), the Health Effects Assessment Summary Tables (HEAST) (USEPA, 1997), and other sources (i.e., MADEP Office of Research and Standards (ORS), Agency for Toxic Substances Disease Registry (ATSDR), California EPA, and Region 9 Preliminary Remediation Goals (PRGs)). Toxicity factors include non-carcinogenic reference doses and carcinogenic slope factors. Non-carcinogenic toxicity data are presented in Tables A-7-1 and A-7-2 and carcinogenic toxicity data are presented in Tables A-7-3 and A-7-4.

4. Risk Characterization. In the last step, quantitative risk estimates for each exposure pathway selected for evaluation are developed by combining the estimated ADDs and LADDs of the potentially exposed populations with toxicity criteria. The overall risk to each receptor is then calculated by summing the risks for each pathway contributing exposure to that receptor. A discussion of the major sources of uncertainty in the risk assessment that may contribute to over- or underestimation of the true risk is also presented. Non-carcinogenic and carcinogenic risks are summarized in Tables A-8-1 to A-8-14. Tables A2-1 to A2-188 in Attachment 2, and Tables A3-1 to A3-188 in Attachment 3 present the actual risk calculations.

1.1.2 Organization of Document

- Section 1.0 – Introduction.
- Section 2.0 – Selection of Exposure Pathways, including a discussion of the characterization areas, exposure pathways, and the conceptual site models (CSMs).
- Section 3.0 – Data Evaluation, including a discussion of the Site soil and groundwater categorization, Site background considerations, and the process used in the compilation and evaluation of the validated surface water, sediment, soil, fish tissue, and groundwater data.
- Section 4.0 – Identification of COCs, including a description of the screening process employed.
- Section 5.0 – Exposure Point Concentrations, including the methodology and calculation of EPCs.
- Section 6.0 – Exposure Assessment, including the identification of exposure parameters and assumptions chosen for each receptor and associated assessment of fate and transport models.
- Section 7.0 – Dose-Response Assessment, including a prioritized listing of the sources and toxicity values chosen for use in the characterization.
- Section 8.0 – Risk Characterization, the results of the non-carcinogenic and carcinogenic risk calculations.
- Section 9.0 – Uncertainty Analysis, discussion of the uncertainty factors associated with this human health risk characterization.

2.0 SELECTION OF EXPOSURE PATHWAYS

2.1 Characterization Areas

For purposes of site characterization, the Site was originally divided into three general areas based on past historical use (see Figure 1-2 of the Comprehensive Site Assessment (CSA)). The Northern Area was located north of Torrey Brook and was the location of the manufacturing and assembly operations areas at the Site. This area is currently used as a light industrial/commercial park and Town of Hanover Department of Public Works (DPW) operations. The Central Area was located south of Torrey Brook and north of the Factory Pond Road circle. This area was the principal location of the magazine and storage facilities. The Central Area is currently used as conservation open space and for P.A. Landers gravel and asphalt operations. The Southern Area was located south of the Factory Pond Road circle and north and east of Factory Pond. Historically, this area served as a testing and disposal area. This area is currently maintained as open space by the Hanover Conservation Commission.

In order to facilitate risk characterization activities, Tetra Tech EC, Inc. (TtEC) subdivided the three general areas into finer and more homogeneous risk characterization areas based on the Phase II sampling results, historical land use records, current ownership and activities, and projected future use. The resulting characterization area boundaries formed the basis for the subsequent site assessment and management activities performed relative to the Site. The boundaries for each characterization area are shown on Plate 1 of the CSA. These boundaries were applied for this human health risk characterization. The rationale for locating the boundaries as they appear on Plate 1 of the CSA can be found in Appendix C of the Phase IID Scope of Work (TtFW, 2003). Table A-2-1 shows how the Northern, Central, and Southern Areas were subdivided into small terrestrial and aquatic areas for assessment.

Table A-2-1 Risk Characterization Areas

Original Area	Risk Characterization Area
Northern	Upper North Area
	Lower North Area
	Eastern Channel Corridor
	Upper Drinkwater River Corridor
	Lower Drinkwater River Corridor (partially)
	North Area of No Historical Fireworks Use
	Potential Greenway Area (partially)
	West Area of No Historical Fireworks Use
Central	Central Commercial Area
	East Area of No Historical Fireworks Use
	Central Area of No Historical Fireworks Use
	Lily Pond/Upper Factory Pond (partially)
	Potential Greenway Area (partially)
Southern	Southern Conservation Commission Area
	Marsh Upland Area
	Southern Disposal Area
	Lily Pond/Upper Factory Pond (partially)
	Middle/Lower Factory Pond
	Cold Waste Area

The North, East, West, and Central Areas of No Historical Fireworks Use were broken out from the other characterization areas. These areas were not included in the risk characterization because no impacts from Fireworks operations have been observed. The North Area of No Historical Fireworks Use is an area within the northeastern portion of the historical Site boundary. The East Area of No Historical Fireworks Use is an area within the eastern portion of the historical Site boundary. The West Area of No Historical Fireworks Use (formerly not a part of a characterization area) is an area within the northwestern portion of the historical Site boundary. The Central Area of No Historical Use is the remaining portion of the former Central Area, the area east of Factory Pond Road, excluding the "Landers Area" as defined in the Phase IIB Investigation Report, and west of the historical Site boundary.

2.2 Current and Reasonably Foreseeable Future Use of the Site

As discussed in Section 1.4 of the CSA, the Site is a mixed use site. The northern portion of the Site consists of light industry and numerous abandoned structures. An estimated 150 to 175 people work in approximately 30 businesses in the northern portion of the Site. As discussed in section 2.1 above and shown in Table A-2-1, subdivided areas associated with the former Northern Area are the Upper North Area, the Lower North Area, the Eastern Channel Corridor, the Upper Drinkwater River Corridor, the Lower Drinkwater River Corridor, the Potential Greenway Area, the West Area of No Historical Fireworks Use, and the North Area of No Historical Fireworks Use (see Plate 1 of the CSA). Currently, commercial workers, utility workers, construction workers, commercial customers, and trespassers use the Upper North Area and Lower North Area for working and trespassing and are likely to continue to do so in the foreseeable future. Fishermen currently fish in the corridors and are likely to continue to do so in the foreseeable future, despite the fishing ban. In the future, construction workers may build an elevated boardwalk style walkway along the shoreline of the Potential Greenway Area.

As shown in Table A-2-1, the subdivided areas associated with the original Central Area are the Central Commercial Area, Lily Pond/Upper Factory Pond, the Potential Greenway Area, and the East Area of No Historical Fireworks Use (see Plate 1 of the CSA). In the Central Commercial Area, the Town of Hanover continues to maintain the area as a conservation district and has also built the Municipal Garage for the DPW on this parcel off of Ames Way (see Figure 1-2 of the CSA). Currently, commercial workers, trespassers, utility workers, construction workers, and commercial customers use the Central Commercial Area for working and trespassing and are likely to continue to do so in the foreseeable future. Due to the layout and nature of the areas not being utilized by the DPW, recreational use of the remaining portions of this area is not anticipated. Fishermen currently fish in the ponds and are likely to continue to do so in the foreseeable future, despite the fish ban. In the future, construction workers may build an elevated boardwalk style walkway along the shoreline of the Potential Greenway Area. Also, adult and child recreational users may wade or swim in Lily Pond/Upper Factory Pond.

In the southern portion of the Site there are open fields, dense foliage areas, and wetlands. Signs of random and indiscriminate dumping of household rubbish, appliances, motor vehicles, and automotive parts are visible across portions of this area. As shown in Table A-2-1, subdivided areas associated with the former Southern Area are the Southern Conservation Commission Area, the Marsh Upland Area, the Southern Disposal Area, the Cold Waste Area, Lily Pond/Upper Factory Pond, and Middle/Lower Factory Pond. Currently, recreational users and fishermen swim, wade, or fish in the ponds and are likely to do so in the foreseeable future. In the future, utility workers and construction workers may work in the Southern Conservation Commission Area, Marsh Upland Area, or the Southern Disposal Area building structures associated with the recreational use of this area and replacing or adding utilities.

2.2.1 Exposure Pathways

Figures A-2-1 to A-2-9 show the eight CSMs for potential exposures to chemical contaminants by people utilizing the Site. These CSMs display the primary and secondary sources and release mechanisms of Oil or Hazardous Material (OHM), the migration and transport processes, the media impacted by the OHM, and the potential receptors and intake routes associated with the OHM. The potential current and/or future receptors that would be exposed to OHM on the Site are adult commercial workers, adult utility workers, adult construction workers, adolescent trespassers, child and adult recreational users, and adult fishermen. The media from which each receptor is exposed to OHM is dependent upon the characterization area, as not all receptors are found in every area. This concept is further described in Figures A-2-1 to A-2-9. The exposure assumptions and factors for these receptors are discussed in detail in Section 6.0. However, some general comments and assumptions related to exposure are listed below:

- Only current and reasonably foreseeable future receptors are evaluated in this risk characterization in accordance with MCP requirements.
- Only accessible (surficial) soil (0-3 feet below ground surface (bgs)) and upper potentially accessible soil (3-6 feet bgs) are contacted by human receptors. This is because the depth to the first encountered groundwater is shallow in these areas across the Site where excavation activities involving utility and construction workers are most likely now and in the foreseeable future. Therefore, these workers are not likely to work below the water table (i.e., less than 6 feet bgs). It should be noted that the structures that have been built in the impacted portions of the Site are all slab-on-grade construction, very likely in response to these physical conditions.
- There are no private wells on the Site (NUS, 1986; SEA, 1994) and drinking water comes from the Hanover public water supply wells. Therefore, groundwater use for domestic purposes was not assessed.
- Since the risk characterization approach for the Site resulted in dividing the three larger original characterization areas into smaller, more homogeneous characterization areas, no "hot spots" in any media were identified for this Site based on an analysis of the Phase I and II sampling results in accordance with MCP requirements.
- Based on observations at the site, fishing is most frequently done by adults (despite the posted fishing bans due to the presence of high mercury levels in the fish tissue). Acknowledging the known risks associated with local fish ingestion, this risk assessment quantitatively evaluated the ingestion of locally caught fish by an adult fisherman. While a younger person (i.e., a child or adolescent) could catch and eat locally caught fish, the frequency of this occurrence is indicated to be less than for the adult. As such, the assessment of fish ingestion by an adult fisherman was considered to address the greatest potential for exposure and risk via this pathway. Anticipating that the projected risks due to the ingestion of locally caught fish would exceed target levels, fish ingestion was evaluated separately from the exposures to other site media (e.g., soil, sediment) by the other identified receptors who could conceivably catch a fish and eat it. The contribution of possible fish ingestion was then considered by adding the fish ingestion contribution to risk to the risks due to the exposure to the other media.

3.0 SITE CHARACTERIZATION

This section describes the regulatory context of the Site in terms of the soil and groundwater categorization, an examination of background conditions, and the compilation and evaluation of the data collected during the Phase I and II sampling events for use in the human health risk characterization. Section 3.1 discusses the soil and groundwater categorization for the Site under the MCP, Section 3.2 discusses the role of background concentrations with Site contaminants in the characterization, and Section 3.3 summarizes the compilation of the data used in this risk characterization.

3.1 Soil and Groundwater Categorization

The MCP has established categories of soil and groundwater that are utilized in characterizing the potential risks to human health posed by a site. These categories are important to the risk characterization, regardless of the risk characterization method used. In a Method 1 risk characterization, these categories determine which soil or groundwater standards should be applied to a site to best reflect the nature of the exposures that are currently taking or may take place in the future. In a Method 3 risk characterization, the categories help guide the selection of the exposure pathways that must be evaluated in a site-specific manner.

In performing the Method 3 risk characterization, the applicable soil and groundwater categories are considered (310 CMR 40.0993 (2)). These categories are identified and discussed below.

3.1.1 Soil Categorization

Three soil categories (S-1, S-2, and S-3) are defined in the MCP (310 CMR 40.0933). They describe a range of potential exposure to soil in terms of the frequency (high or low), intensity (high or low), and accessibility (accessible, potentially accessible, or isolated) of the potentially exposed receptor's interaction with the soil. Category S-1 soils are associated with the highest potential for exposure (e.g., frequent, intensive interaction with soil by a child), while category S-3 soils are associated with the lowest potential for exposure (e.g., occasional incidental contact with the soil by adults).

The MCP divides soils that are potential exposure points into accessible (surficial) soil (0-3 feet bgs in unpaved areas), potentially accessible soil (3-15 feet bgs in unpaved areas or 0-15 feet bgs in paved areas), and isolated subsurface soil (>15 feet bgs or under a building or permanent structure). As was discussed in Section 2.2.1, a receptor's potential exposure to soil at this Site is limited in depth by relatively shallow groundwater. Consequently, all exposure to soil currently or in the foreseeable future is expected to occur within the upper most six feet of soil. As such, the relevant MCP soil accessibility categories for this Site are the accessible (surficial) soil and the potentially accessible soil. Given the site-specific constraints on likely soil intrusion for construction or utility work, a project-specific refinement of the soil accessibility categories was made during the problem formulation process. The soil not within a building footprint in the depth range of 3-6 feet bgs was called "upper" potentially accessible soil, while the soil in the depth range of 6-15 feet bgs was called the "lower" potentially accessible soil. These names were used on the CSMs presented in Figures A-2-1 to A-2-9. As the CSMs indicated, subsurface exposures are considered likely at this Site only in relation to the "upper" potentially accessible soil.

Each upland characterization area was considered relative to the MCP soil categorization table in the context of its CSM. Two distinctly different situations were seen. In the Upper North Area, Lower North Area, and the Central Commercial Area, the following exposure possibilities were identified as likely:

- Adults present with high frequency/low intensity activities (i.e., Commercial Worker);
- Adults present with low frequency/high intensity activities (i.e., Construction Worker and Utility Worker); or
- Adolescents present with low frequency/low intensity activities (i.e., Trespasser).

All of these combinations result in a soil category of S-2. As such, an S-2 categorization is appropriate to these three risk characterization areas.

The second situation applies to the potential recreational use areas (i.e., Potential Greenway Area, Southern Conservation Commission Area, Marsh Upland Area, Southern Disposal Area, and Cold Waste Area). In these areas, the following exposure possibilities were identified as likely:

- Children present with low frequency/low intensity activities (i.e., Child Recreational User);
- Adult presents with low frequency/low intensity activities (i.e., Adult Recreational User); or
- Adult presents with low frequency/high intensity activities (i.e., Construction Worker and Utility Worker).

The first and third of these combinations result in a soil category of S-2, while the second combination results in a soil category of S-3 (i.e., less potential exposure). As such, an S-2 soil categorization is applicable to these five risk characterization areas as well.

3.1.2 Groundwater Categorization

Groundwater is categorized by the MCP (310 CMR 40.0932) as GW-1, GW-2, or GW-3 depending on the potential for exposure. GW-1 categorizes water within a current drinking water source area or a potential drinking water source area as defined in 310 CMR 40.0932. Groundwater that is located within 30 feet of an existing occupied building and an average annual depth to groundwater of 15 feet bgs or less is considered GW-2. All groundwater in the state is considered to potentially discharge to surface water according to 310 CMR 40.0932(2), and is therefore categorized as GW-3.

When the Site was first assigned a Release Tracking Number (RTN), most of the Site was classified as GW-1. Only a small part in the northwestern portion of the Site (in the Upper North Area) and the southern portion of the Site (including the southern portions of the Central Commercial Area and Potential Greenway Area and all of the Southern Conservation Commission Area, Southern Disposal Area, Marsh Upland Area, and the Cold Waste Area) were not originally classified as GW-1. Based on the nature of the Site and the current regulations, the MADEP reclassified the entire Fireworks Site in March 2004 as a Non-Potential Drinking Water Source Area (NPDWSA) per 310 CMR 40.0006 (MADEP, 2004a). The MADEP policy, WSC-97-701, more clearly defines a NPDWSA (MADEP, 1997). This groundwater reclassification reflects that groundwater from established urban areas of 100 acres or more would not likely be used as a future source of drinking water and, therefore, should not be subject to the remedial standards applicable to potential future drinking water supplies. Consequently, there is no groundwater at the Fireworks Site that is categorized as GW-1. All areas with the exception of the Southern Conservation Commission and Potential Greenway Areas are classified as GW-2 for current or future use, reflecting the presence of buildings that could be occupied now or in the foreseeable future and a depth to groundwater less than 15 feet bgs. The Southern Conservation Commission and the Potential Greenway Areas are not designated GW-2 since there are no current or planned occupiable buildings or structures in these areas. As noted previously, all areas are classified as GW-3 according to 310 CMR 40.0932(2) since all groundwater is considered a potential source of discharge to surface water.

3.1.3 Summary

In summary, soil is categorized as S-2 for all of the terrestrial/upland risk characterization areas and groundwater is categorized as GW-2 (in all terrestrial/upland risk characterization areas except for the Southern Conservation Commission and the Potential Greenway Areas) and GW-3 throughout the Site. Surface water and sediment are not classified under the MCP.

3.2 Background Considerations

"Background" is defined in 310 CMR 40.0006 as those levels of OHM that would exist in the absence of the disposal site of concern. The definition in the MCP provides two criteria that must both be met in order for a contaminant to be considered "background." These criteria are:

1. Ubiquitous and consistently present in the environment at and in the vicinity of the disposal site; and
2. Attributable to:
   - geologic or ecological conditions;
   - atmospheric deposition of industrial process or engine emissions;
   - coal ash or wood ash associated with fill material;
   - releases to groundwater from a public water supply system; and/or
   - petroleum residues that are incidental to the normal operation of motor vehicles.

The MADEP definition does not necessarily equate "background" with pristine conditions (MADEP, 1996, Section 2.3.1.1). MADEP also recognizes that historic human activities have resulted in the presence of some chemicals in the environment. Given this definition, the MADEP considers many metals and some polycyclic aromatic hydrocarbons (PAHs) as having background concentrations at sites subject to the requirements of the MCP. These specific families of contaminants may be present in multiple site media (e.g., soil, groundwater, air, sediment, and surface water) in varying amounts according to their physical and chemical properties. Although MADEP has published representative lists of background concentrations for soil (MADEP, 2002a), site-specific background concentrations were identified and used for this risk characterization. In general, anthropogenic volatile organic compounds (VOCs), other semivolatile organic compounds (SVOCs), pesticides, and explosive compounds or residues are expected to have non-detect background concentrations at MCP sites.

The MCP includes a comparison to background as part of the process for screening and selecting the inorganic constituents of concern (i.e., metals) to be carried through in the human health risk characterization. Four areas of No Historical Fireworks Use were identified and their boundaries specified when the risk characterization areas were established. These areas were labeled the North, West, East, and Central Areas of No Historical Fireworks Use (see Plate 1 of the CSA). TtEC and MADEP determined that no activities relating to the Fireworks Site were conducted in these areas during the problem formulation process. Therefore, these areas were considered as reflecting background conditions for the Site for soil and groundwater in terms of the MCP. The following samples were considered as background for soil (see Plate 1 of the CSA for locations). These samples were broken up into three depth intervals (0-1 feet bgs, 0-3 feet bgs, and 0-6 feet bgs) consistent with the depth intervals of the Site soil samples collected in each risk characterization area.

- 0-1 feet bgs: CA01 (0-0.5), CA02 (0-0.5), CCA08 (0-0.5), NA01 (0-0.5), SBGD01, WA01 (0-0.5), and WA02 (0-0.5)

- 0-3 feet bgs: CA01 (0-0.5), CA02 (0-0.5), CCA08 (0-0.5), NA01 (0-0.5), SBGD01, WA01 (0-0.5), WA02 (0-0.5), CDR09153, and SBGD02
- 0-6 bgs: CA01 (0-0.5), CA02 (0-0.5), CCA08 (0-0.5), NA01 (0-0.5), SBGD01, WA01 (0-0.5), WA02 (0-0.5), CDR09153, SBGD02, and SBKGD0136

PZ-16, PZ-22, and PZ-25 were considered background locations for groundwater (see Plate 1 of the CSA). The most recent groundwater analytical results and the shallowest screened interval from these locations were used to represent background conditions.

Background surface water samples were collected from the Northern Drinkwater River and Forge Pond (see Plate 1 of the CSA). Three surface grab samples (TR W01A-C, TR W08B-C, and NDTRA11SW) were collected in the Northern Drinkwater River and used as background relative to the Eastern Channel Corridor and the Upper and Lower Drinkwater River Corridors (i.e., the riverine environment). One sample (FPTRA12SW) was collected in Forge Pond and used as background for Lily Pond/Upper Factory Pond and Middle/Lower Factory Pond (i.e., the lacustrine environment).

Background sediment samples were collected from the Northern Drinkwater River and Forge Pond (see Plate 1 of the CSA). Seven samples were collected from the Northern Drinkwater River: NDRTRA10 (0-0.5), TR S01A-C (0-0.5), TR S01B-L (0-0.5), TR S01C-R (0-0.5), TR S08A-C (0-0.5), TR S08B-C (0-0.5), and TR S08C-L (0-0.5). These samples were used to characterize the sediment background concentrations for the Eastern Channel Corridor, the Upper and Lower Drinkwater River Corridors, and the Marsh Upland Area. Three samples were collected from the banks of Forge Pond: TR S05A-R (0-0.5), TR S05A-L (0-0.5), and TR S09N-R (0-1.0). These samples were used as background for Lily Pond/Upper Factory Pond and Middle/Lower Factory Pond bank sediment.

In all of the media described, only inorganics and PAH data were considered to be potentially present in the background consistent with the MCP policy.

3.3 Data Compilation

As discussed in Section 4.0 of this CSA, six media at the Site were investigated during the Phase I and Phase II site investigations. These media include soil, sediment, surface water, groundwater, fish tissue, and soil gas. Data for all sampled media, except soil gas, were used in the human health risk characterization. These data are summarized below.

3.3.1 Soil

For the human health risk characterization, the soil samples collected from the Site were evaluated separately for each individual risk characterization area.

Soil samples were collected in 1997, 2000, 2002, and 2003. In 1997, soil samples were collected from 0-1 feet bgs, 1-3 feet bgs, and 3-5 feet bgs in the Upper North Area, Lower North Area, Southern Disposal Area, and Marsh Upland Area. These samples were analyzed for target analyte list (TAL) metals and explosives. Samples from the Marsh Upland Area were also analyzed for VOCs, SVOCs, pesticides and PCBs. In 2000, composite soil samples were collected from depths of 0-1.5 feet bgs and 1.5-3 feet bgs in the Southern Conservation Area, Southern Disposal Area, Cold Waste Area, and Central Commercial Area. Also in the Central Commercial Area, samples were collected in 2-foot intervals to a depth of 15 feet bgs. Composite samples were collected from 0-2 feet bgs, 0-3 feet bgs, 2-4 feet bgs, and 4-6 feet bgs in the Marsh Upland Area. In the Upper North Area and Lower North Area, composite samples were collected from 0-3 feet bgs and 3-6 feet bgs. Samples were analyzed for TAL metals, lead, mercury, VOCs, SVOCs, and explosives depending on the sampling area. In 2002, surficial soil samples (0-0.5 feet bgs) were collected from the Upper North Area and Southern Disposal Area and analyzed for VOCs, lead, mercury, and chromium (VI). In the Upper North Area, soil samples between 1 and 6 feet bgs were collected and analyzed for VOCs. In the Southern Disposal Area, samples were collected at two depth intervals, 0-1.5 feet and 1.5-3 feet bgs and were analyzed for VOCs, total mercury, and lead. In the Marsh Upland Area, samples were collected from a 0-3 feet depth interval or refusal and were analyzed for VOCs, SVOCs, TAL metals, and methyl mercury. Some samples were also analyzed for explosives. In the Lower North Area, composite soil samples from 0-3 feet bgs were analyzed for explosives. In 2003, soil samples from 0-0.5 feet bgs and 3-6 feet bgs were collected from the Upper North Area, Central Commercial Area, Southern Conservation Commission Area, and Potential Greenway Area. These samples were analyzed for TAL metals, total mercury, methyl mercury, total cyanide, VOCs, SVOCs, and explosives. Two samples were collected from the 100-year flood plain area (note: these samples are identified as FEMA in the sample name). These samples were analyzed for TAL metals, total mercury, methyl mercury, VOCs, SVOCs, and explosives.

Background soil samples were collected from 0-0.5 feet bgs and 3-6 feet bgs in 2002 and 2003 from the No Historical Fireworks Use Areas. These samples were analyzed for TAL metals, total mercury, methyl mercury, VOCs, SVOCs, explosives, and total cyanide. Please see Tables A-4-37 to A-4-39 for summaries of this soil background data.

3.3.2 Sediment

The sediment samples were also evaluated separately by risk characterization area for the human health risk characterization. However, bank sediments were separated out in the pond areas since they would be more likely to be contacted by the receptors performing activities such as fishing, wading, and swimming, than would be the sediments in the deeper water areas. Given thc relatively soft and vegetated bottom of the ponds in most locations and the relative shallowness of the water in the central portions of the ponds (typically 2-3 feet - see Figure 2-2 in the CSA for the pond depths) significant exposure to the sediments away from the shorelines was not considered likely.

Sediment samples were collected in 2002 and 2003. Samples collected in 2002 were taken from transects (lines running perpendicular to the direction of flow) in the Eastern Channel Corridor, Upper Drinkwater River Corridor, Lower Drinkwater River Corridor, Lily Pond/Upper Factory Pond, and Middle/Lower Factory Pond. All samples were analyzed for TAL metals, total mercury, methyl mercury, PAHs, and total organic carbon (TOC). Some of these samples were also analyzed for VOCs, SVOCs, explosives, Acid Volatile Sulfides/Simultaneously Extractable Metals (AVS/SEM), and chromium (VI). A sediment sample was also collected in the Marsh Upland Area and was sampled for chromium (VI). In 2003, sediment samples were collected in the Eastern Channel Corridor, Upper Drinkwater River Corridor, Lower Drinkwater River Corridor, Lily Pond/Upper Factory Pond, and Middle/Lower Factory Pond. All sediment samples were analyzed for TAL metals, total mercury, methyl mercury, PAHs, TOC, VOCs, SVOCs, explosives, AVS/SEM, pesticides, PCBs, percent solids, and grain size.

Background sediment samples were collected in 2002 and 2003 from the Northern Drinkwater River (the Drinkwater River above Forge Pond) and Forge Pond. Samples collected in 2002 were analyzed for TAL metals, total mercury, methyl mercury, chromium (VI), PAHs, and TOC. Samples collected in 2003 were analyzed for TAL metals, total mercury, methyl mercury, PAHs, TOC, VOCs, SVOCs, explosives, AVS/SEM, pesticides, PCBs, percent solids, and grain size. Please see Tables A-4-40 and A-4-41 for summaries of this sediment background data.

3.3.3 Surface water

The surface water samples were also evaluated separately by aquatic risk characterization area for the human health risk characterization.

Surface water samples were collected in 1998, 2002, and 2003. The surface water sample collected in 1998 was taken in the Middle/Lower Factory Pond and was analyzed for mercury and lead. Samples collected in 2002 were collected from the Site ponds, Lily Pond/Upper Factory Pond (Lily Pond) and Middle/Lower Factory Pond (Factory Pond), and the Site streams, Eastern Channel Corridor (Northern Area Diversion Creek), the Upper Drinkwater River Corridor, and Lower Drinkwater River Corridor (Drinkwater River). These samples were analyzed for TAL metals, total mercury, and methyl mercury. Additionally, some surface water samples were also analyzed for VOCs, silver, perchlorate, and chlorate. The surface water samples in 2003 were collected from the Eastern Channel Corridor, Upper Drinkwater River Corridor, Lower Drinkwater River Corridor, Lily Pond/Upper Factory Pond, and Middle/Lower Factory Pond. They were analyzed for TAL metals, total mercury, methyl mercury, VOCs, and SVOCs.

Background surface water samples were collected in Forge Pond and the Northern Drinkwater River (the Drinkwater River above Forge Pond) in 2002 and 2003. In 2002, they were analyzed for silver, perchlorate and chlorate and in 2003, they were analyzed for TAL metals, total mercury, methyl mercury, VOCs, and SVOCs. Please see Tables A-4-42 and A-4-43 for summaries of this surface water background data.

3.3.4 Groundwater

The shallow groundwater samples collected and analyzed for the human health risk characterization were evaluated separately for each risk characterization area.

Groundwater samples were collected across the Site between 1997 and 2001 and in 2003. Given the nature of the anticipated exposures of the receptors to the groundwater, the human health risk characterization only considered the most recent groundwater data from the shallowest wells in each risk characterization area. Given that some wells were not sampled in every year, a summary of all groundwater samples collected at the Site is presented below.

In 1997, groundwater samples were collected from wells in the Upper North Area, Lower North Area, Southern Disposal Area, and Marsh Upland Area. These samples were analyzed for VOCs, SVOCs, pesticides, PCBs, TAL metals, and explosives. In 1998, samples were collected from wells located in the same areas as in 1997 and were analyzed for VOCs, freon, inorganics, nitrate, mercury, and lead. In some of these locations, the samples were also analyzed for full TAL metals. Also, the sample collected at the one well location in the Southern Disposal Area was only analyzed for VOCs, lead, and mercury. In 1999, one well in the Marsh Upland Area was sampled and analyzed for mercury. In 2000, existing and newly installed wells in the Upper North Area, Lower North Area, Southern Disposal Area, Potential Greenway Area, and the Marsh Upland Area were sampled. They were analyzed for metals and VOCs. In 2001, groundwater samples were collected in all areas of the Site and were analyzed for TAL metals, VOCS, SVOCs, and explosives. Also in 2001, samples collected in the Southern Disposal Area, Marsh Upland Area, Upper North Area, Lower North Area, and Southern Conservation Commission Area were analyzed for perchlorate and chlorate. In 2003, samples were collected from newly installed wells in the Lower North Area and analyzed for VOCs.

Background groundwater samples were collected in 2003 from three piezometers located in the Eastern and Central Areas of No Historical Fireworks Use. These samples were analyzed for TAL metals and explosives. Please see Table A-4-44 for a summary of this groundwater background data.

3.3.5 Fish Tissue

Fillet fish tissue samples were collected and analyzed for the human health risk characterization. The samples were evaluated separately relative to the bodies of water they were collected from on-site.

In 2003 fish fillet tissue samples (largemouth bass) were collected from the Site ponds (Lily Pond/Upper Factory Pond and Middle/Lower Factory Pond) and Site rivers (Eastern Channel Corridor and Lower Drinkwater River). In each area, three adult individuals of the targeted fish species were collected and composited into a single sample for total mercury, methyl mercury, percent lipids, and TAL metals analyses.

Reference or background fish fillet tissue samples were collected in 2003 from Forge Pond and the Northern Drinkwater River. In both areas, three adult individuals of the targeted fish species were collected and composited into a single sample for total mercury, methyl mercury, percent lipids, and TAL metals analyses. Please see Tables A-4-45 and A-4-46 for summaries of this fish tissue background data.

3.3.6 Soil Gas

No soil gas data was used in the human health risk characterization due to the locations of the samples taken and the fact that no potential exposure to receptors would occur there. The following is a summary of this soil gas data.

In 2002 soil gas samples were collected from 39 locations in a portion of the Upper North Area and the Southern Disposal Area (see Plate 1 of the CSA for the locations and Table A-4-47 for the data summary). A total of 62 samples were collected from one or two depths between 1 and 4 feet bgs, depending on the depth of the water table. The soil gas samples were analyzed for select chlorinated VOCs and freon TF.

4.0 CONTAMINANTS OF CONCERN

A conservative process of selecting COCs, designed to carry most detected OHM through the risk characterization process at a Site, is laid out in the Guidance for Disposal Site Risk Characterization (MADEP, 1996, Section 2.4). The COPCs are first selected based on the list of all OHM detected, in samples collected from current or foreseeable future exposure areas. The COPC lists for each media (i.e., soil (accessible and potentially accessible), sediment, surface water, groundwater, and fish tissue) were developed from the data collected during the Phase I and Phase II investigations. Summary tables for the data collected during Phases I and II for each media are presented in Appendix D of the CSA. Detected OHM include those constituents that were detected above the sample quantitation limit (SQL), including those constituents that were reported with a "J" (estimated) qualifier from the laboratory. A COPC may be eliminated as a COC provided certain specified criteria are met. These criteria are:

- OHM with low frequencies of detection *and* low concentration;
- OHM less than or consistent with background values; or
- OHM that are field or laboratory contaminants not related to the OHM release.

No toxicological screening or risk-based benchmarks were used as criteria for eliminating COPCs. Finally, no COPC was eliminated on the basis of being an essential human nutrient. The criteria for eliminating COPCs and a discussion pertaining to the chemicals that were eliminated are presented below. Tables summarizing this process for each media are presented as Tables A-4-1 through A-4-36. Summary statistics shown include the chemical group, OHM, CAS number, frequency of detection, minimum detected concentration, maximum detected concentration, arithmetic mean, median, range of detection limits, background values (when available), whether or not that OHM was selected as a COC for this human health risk characterization, and the rationale for the OHM's deletion or selection.

4.1 OHM with Low Frequencies of Detection and Low Concentration

OHM are considered to have a low frequency of detection only if the constituent meets the following criteria (MADEP, 1996):

- It was analyzed for in at least 10 samples;
- It was detected at a frequency of less than 1 detection per 20 samples analyzed with no identifiable spatial grouping (i.e., no indication of a "hot spot"); and
- It is not associated with the historical or present use at a site.

MADEP stated that OHM are at a low concentration when the constituent is not present consistently enough or at a high enough concentration to contribute to exposure (MADEP, 1996). Specifically, OHM are eliminated on the basis of very low concentration if the maximum detected concentration is less than the minimum SQL among all detected samples in the media analyzed for the constituent.

COPCs were eliminated due to low detection frequency and concentration in soil. For sediment, surface water, groundwater, and fish tissue, no COPCs were eliminated on the basis of this criterion.

4.2 OHM Less Than or Consistent with Background Values

Under the MCP, if a constituent is detected at levels consistent with background and is not related to disposal at the site, then the constituent can be eliminated as a COC (MADEP, 1996). Background samples were collected for accessible soil (0-3 feet bgs), accessible and upper potentially accessible soil (0-6 feet bgs), sediment, surface water, and groundwater across the Site as discussed in Section 3.3. The mean and maximum background concentrations of SVOCs and inorganics were used for screening against the Site data. As stated in Section 2.3.3.2 of the Guidance for Disposal Site Risk Characterization (MADEP, 1996), a COPC can be eliminated as a COC based on being consistent with background levels if:

- The median value of the site data is less than or equal to the median value of the background data, and the maximum value of the site data is no more than 50% greater than the maximum value for the background data; or
- If the maximum value of the site data is less than or equal to the maximum value of the background data, and the median value of the site data is no more than 50% greater than the median value for the background data.

COPCs were eliminated based on a comparison to background levels in soil. No COPCs were eliminated from the human health risk characterization for sediment, surface water, groundwater, or fish tissue based on the consistency of the site data with background.

4.3 OHM that are Field or Laboratory Contaminants

MADEP states that when assessing the potential for field or laboratory contamination in sample results, the following factors should be considered:

- The concentrations of the constituents detected in both the environmental (Site) and the blank samples;
- The types of contaminants detected in the samples, with particular attention to chemicals commonly used in a laboratory; and
- Historical information regarding chemical use at the site.

No COPCs were eliminated from the human health risk characterization for any media on the basis of being a field or laboratory contaminant.

5.0 EXPOSURE POINT CONCENTRATIONS

In order to quantify the magnitude of exposure that occurs to a receptor, exposure point concentrations (EPCs) must first be estimated for the identified COCs from available and applicable data. An EPC is the concentration of a COC in a specific medium to which a human receptor may contact at an exposure point. The EPCs are used in conjunction with other exposure factors to calculate ADDs and LADDs of the COCs by the receptor.

A summary of the EPCs that were calculated for the human health risk characterization is presented in Tables A-5-1 through A-5-35. EPCs were calculated for each COC in each relevant exposure medium (i.e., soil, sediment, surface water, groundwater, and fish tissue) for each applicable risk characterization area in accordance with 310 CMR 40.0926. EPCs were calculated based on an average concentration within each exposure point (risk characterization area). When a COC was not detected in a sample, half the SQL was used as the concentration for that sample for purposes of calculating the EPC. In addition, when a field duplicate sample was collected in a location, the original sample and the field duplicate sample were averaged together, prior to inclusion into the EPC average calculation.

5.1 Soil EPCs

There are eight risk characterization areas identified for exposure to soil. All areas, except the Potential Greenway Area and the Cold Waste Area, contain two individual exposure points for soil: accessible (surficial) soil (0-3 feet bgs) and accessible (surficial) and upper potentially accessible soil (0-6 feet bgs). The Potential Greenway Area and Cold Waste Area each contain only one exposure point: (0-1 feet bgs) and accessible (surficial) soil (0-3 feet bgs), respectively. Samples collected during the Phase I and Phase II site investigations were used to calculate the soil EPCs. EPCs were calculated by averaging the results from all soil samples in the specified depth intervals within each risk characterization area. See Tables A-5-1 to A-5-14 for a summary of the calculated soil EPCs.

5.2 Sediment EPCs

Six individual exposure points were identified for sediment. Two of these exposure points are related to pond sediment, three to river sediment, and one to wetland sediment. The EPCs for the pond sediment exposure points were calculated by averaging the results from all sediment samples collected from the bank of each of the individual ponds. The EPCs for the river sediment and wetland area exposure points were calculated by averaging the results from all sediment samples taken in those individual water bodies. The individual samples that were used in the calculation of these averages are listed in each table. Tables A-5-15 to A-5-17 are the EPCs for the river sediment exposure points, Table A-5-18 shows the EPCs for the wetland area sediment, and Tables A-5-19 and A-5-20 are the EPCs for the pond sediment exposure points.

5.3 Surface Water EPCs

Five individual exposure points were identified for surface water. The EPCs for each exposure point were calculated by averaging the results from only the surface water samples collected within each individual water body. The individual samples that were used in the calculation of these averages are listed in Tables A-5-21 through A-5-25.

5.4 Groundwater EPCs

Under the MCP, for the human health risk characterization, each groundwater well is treated as a separate and distinct exposure point. Typically this is done to reflect that any point could be a point of drinking water exposure. In this assessment, however, due to the nature of the potential exposures at this Site, each risk characterization area was treated as an exposure point for the groundwater to indoor air and groundwater to ambient air evaluations. In discussions with MADEP, it was concluded that, since the wells themselves were not being evaluated as individual exposure points (i.e., not as drinking water wells), using all the data collected in a particular risk characterization area to calculate an area-wide average would provide the most representative groundwater concentrations for use in the inhalation pathway evaluations. Consequently, six individual exposure points were identified for groundwater. The EPCs for each exposure point were calculated by averaging the results from the most recent sampling round within each risk characterization area. The EPCs for all groundwater exposure points are listed in Tables A-5-26 to A-5-31.

5.5 Fish Tissue EPCs

Four individual exposure points, two relating to rivers and two relating to ponds, were identified relative to the ingestion of fish tissue by human receptors. The fish tissue EPCs for each exposure point are the results from the one sample collected within each individual water body. These EPCs are listed in Tables A-5-32 through A-5-35.

6.0 EXPOSURE ASSESSMENT

The exposure assessment describes, both qualitatively and quantitatively, the interaction between the characterized contamination at the Site and the people who are potentially affected by the contamination. The exposure assessment addressed the potential pathways of human exposure associated with both current use and reasonably foreseeable future uses (310 CMR 40.0923).

Based on the CSMs (Figures A-2-1 to A-2-8), eight potential human receptors were identified for the Site in accordance with 310 CMR 40.0921. These receptors include the following:

- Adult Commercial Worker
- Adult Commercial Customer
- Adult Utility Worker
- Adult Construction Worker
- Adolescent Trespasser
- Adult Recreational User
- Child Recreational User
- Adult Fisherman

Exposure points were identified for each of the impacted media based on the primary sources and release mechanisms, secondary sources, and migration and transport processes believed to be associated with each risk characterization area as shown on Figures A-2-1 to A-2-8 in accordance with 310 CMR 40.0924. The exposure points considered are as follows:

- Since there were no preferential exposure areas identified on any portion of the soil within each of the risk characterization areas at the Site, the exposure point was identified to be the entire risk characterization area for accessible (surficial) soil (0-3 feet bgs) and accessible soil and upper potentially accessible soil (0-6 bgs). The risk characterization areas evaluated for soil exposure were: the Upper North Area, Lower North Area, Central Commercial Area, Southern Conservation Commission Area, Marsh Upland Area, Southern Disposal Area, Cold Waste Area, and Potential Greenway Area.
- Likewise, the particulates from soil that are swept into the ambient air could originate from any point within each risk characterization area, thus one exposure point was identified for ambient air relative to each risk characterization area identified above for soil.
- It was determined that human receptors would more likely come into contact with bank sediments in the pond risk characterization areas, as opposed to the sediments located in the middle of the ponds (See Figure 2-2 in the CSA). Therefore the exposure points relative to sediment in the ponds were identified using only the bank sediment samples. Bank sediment exposure points were identified for Lily Pond/Upper Factory Pond and Middle/Lower Factory Pond. Exposure points consisting of all river sediment (typically in a shallow water body more uniformly accessible to human receptors) were identified in the Eastern Channel Corridor, Lower Drinkwater River Corridor, and Upper Drinkwater River Corridor. An exposure point consisting of the wetland sediment was identified in the Marsh Upland Area.
- For surface water, each surface water body was identified as a separate potential exposure point. These surface water exposure points were established for the: Eastern Channel Corridor, Lower Drinkwater River Corridor, Upper Drinkwater River Corridor, Lily Pond/Upper Factory Pond, and Middle/Lower Factory Pond.

- For fish tissue, exposure points were established to reflect the only samples taken in each water body. These were the Eastern Channel Corridor, Lower Drinkwater River Corridor, Lily Pond/Upper Factory Pond, and Middle/Lower Factory Pond.

Human receptors may come into contact with the OHM at these exposure points via one or more of the exposure routes. Exposure routes identified for this Site in accordance with 310 CMR 40.0925 were:

- Incidental ingestion
- Dermal absorption (through dermal contact)
- Inhalation of particulates or gaseous OHM in the air
- Inhalation, coughing up, and the subsequent swallowing of particulates in air (construction worker exposure scenario only)

Exposure profiles and quantitative exposure factors were developed for each identified receptor based on the CSMs (see Figures A-2-1 to A-2-8) and are discussed in Section 6.1 below. The quantitative exposure factors were used to calculate the ADD and the LADD for each COC, for each identified receptor and exposure pathway. The equations used in these calculations are shown on Tables A-6-1 through A-6-24. The quantitative exposure assessment is meant to describe a conservative estimate of a representative individual within a subpopulation, but not necessarily the "worst case exposure scenario" (MADEP, 1996).

6.1 Exposure Profiles

6.1.1 Commercial Worker

The exposure factors for the commercial worker are presented in Tables A-6-1 and A-6-2. A commercial worker is assumed to be an adult working full time at a business in the Upper North Area, Lower North Area, or the Central Commercial Area. He/she would spend nearly all of his/her time working indoors, with limited time outdoors. The commercial worker is assumed to be exposed to the accessible (surficial) soil layer (0-3 feet bgs) during breaks by incidental ingestion, dermal absorption, and thc inhalation of particulates and volatiles. Exposure to volatile contaminants that may exist and migrate up into the indoor air of a commercial building from the groundwater is also assumed.

The commercial worker's body weight is assumed to be 57.1 kg. This value corresponds to the 50th percentile body weight for female adults between the ages of 18 and 25 years (MADEP, 1996). The commercial worker's exposure frequency for incidental ingestion and dermal absorption exposure to soil is estimated to be 3 days per week for 30 weeks a year, the equivalent of 90 events/year, based on MADEP judgment. The exposure frequency for exposure to soil or groundwater through inhalation is 1 event/day. The exposure duration for the commercial worker is assigned a value of 1 day/event by definition for incidental ingestion and dermal absorption (MADEP, 1996). The exposure duration for the inhalation of soil particulates or volatile organics or groundwater volatiles is 8 hours/day, based on a standard 8-hour workday. The exposure period for the commercial worker for all media is assumed to be 25 years, based on MADEP judgment (MADEP, 2004b).

The soil ingestion rate for the commercial worker is assumed to be 50 mg/day (MADEP, 1996). A value of 3,477 cm^2/day was chosen as the exposed skin surface area for dermal exposure to soil, which corresponds to a female adult worker between the ages of 18 and 76 years wearing short sleeves and pants (i.e., face, forearms, hands, and feet exposed) (MADEP, 2002b). The soil-to-skin adherence factor is assumed to be 0.004 mg/cm^2-event, corresponding to an industrial/outdoor commercial worker (MADEP, 2002b). The ventilation rate for the commercial worker was assumed to be 1.20 m^3/hour, corresponding to light exertion for a worker between 18 and 75 years (MADEP, 1995). The concentration of respirable particulates in the air was conservatively assumed to be 32 ug/m^3, based on an open field scenario (MADEP, 1996). The averaging period for non-carcinogenic effects was set equal to the exposure period (i.e., 25 years) by definition (MADEP, 1996). The averaging period for carcinogenic effects was assigned a lifetime value of 75 years (MADEP, 1996).

Tables A-6-27 to A-6-29 present the OHM concentrations in air ($[OHM]_{air}$) calculations that were used to estimate soil VOC inhalation intakes for the commercial worker. Tables A-6-25 and A-6-26 present the input and chemical-specific values used in the $[OHM]_{air}$ calculations.

6.1.2 Commercial Customer

The commercial customer is assumed to be a child or adult patronizing one of the businesses in the Upper North Area, Lower North Area, or the Central Commercial Area. He/she would spend nearly all of his/her time indoors. They would be exposed to the outdoor air at the Site only for a very limited time as they entered or left the businesses. Any contact with accessible soil would be extremely brief in duration and incidental in nature. Depending on the manner of commercial development, this incidental contact would likely be with clean landscaping material or clean-engineered fill used to establish a new grade for the Site. Because the commercial worker has similar exposures and a greater potential for exposure to Site contaminants than the commercial customer, the commercial customer was not quantitatively evaluated.

6.1.3 Utility Worker

The exposure factors for the utility worker are presented in Tables A-6-3 and A-6-4. The utility worker is assumed to be an adult currently working periodically at the Site to install or repair utilities existing in the Upper North Area, Lower North Area, or Central Commercial Area. In the future, the utility worker may also install utilities in the Southern Conservation Commission Area, Marsh Upland Area, or the Southern Disposal Area as part of a recreational development effort. The portions of the Site that the utility worker would access would be the locations where buried utilities would have been placed to serve buildings or possibly corridors currently containing existing buried utilities that were not deactivated and removed during demolition. The utility worker would be exposed to the accessible (surficial) and upper potentially accessible soil (0-6 feet bgs) that would be encountered by digging and excavation activities by incidental ingestion, dermal absorption, and inhalation of particulates or volatiles. If the utility installation or repair work was in an area where the groundwater was sufficiently near the surface, the utility worker could potentially come into contact with the groundwater. In this case, exposure to groundwater contaminants by inhalation of potential volatile releases could be expected. Direct absorption of the groundwater during utility work, and any incidental ingestion or dermal absorption, would be negligible.

The utility worker's body weight is assumed to be 57.1 kg. This value corresponds to the 50th percentile body weights for female adults, ages 18-25 years (MADEP, 1996). The utility worker's exposure frequeney for incidental ingestion and dermal absorption exposure to soil is estimated to be 1 event/year, corresponding to the incidence of utility repairs and the rotation of work crews (MADEP, 1996). The exposure frequency for exposure to soil or groundwater through inhalation is 1 event/day. The exposure duration for the utility worker is assigned a value of 1 day/event by definition for ineidental ingestion and dermal absorption of soil (MADEP, 1996). The exposure duration for inhalation of soil particulates or volatiles or groundwater volatiles is 8 hours/day, based on a standard 8-hour workday. The exposure period for the commercial worker for all media is assumed to be 25 years, based on MADEP judgment (MADEP, 2004b).

The soil ingestion rate assumed for the utility worker is 100 mg/day, corresponding to a utility/heavy construction worker (MADEP, 2002c). A value of 3,477 cm^2/day was chosen as the exposed skin surface area for dermal exposure, which corresponds to a female adult utility worker between the ages of 18 and 76 years wearing short sleeves and pants (i.e., face, forearms, hands, and feet exposed) (MADEP, 2002b). The soil-to-skin adherence factor was assumed to be 0.29 mg/cm^2-event, corresponding to a utility worker/heavy construction worker (MADEP 2002b). The ventilation rate for the utility worker was assumed to be 3.60 m^3/hour, corresponding to heavy exertion for a worker between 18 and 75 years (MADEP, 1996). The concentration of respirable particulates in the air was assumed to be 60 ug/m^3, based on an excavation scenario (MADEP, 1996). The averaging period for non-carcinogenic effects was set equal to the exposure period (i.e., 25 years) by definition (MADEP, 1996). The averaging period for carcinogenic effects was assigned a lifetime value of 75 years (MADEP, 1996).

Tables A-6-30 to A-6-35 present the $[OHM]_{air}$ calculations that were used to estimate soil VOC inhalation intakes for the utility worker. Tables A-6-25 and A-6-26 present the input and chemical-specific values used in the $[OHM]_{air}$ calculations. Tables A-6-56 and A-6-57 contain the input parameters and calculation of the groundwater volatilization factor (VF) that was used to estimate groundwater VOC inhalation intakes for the utility worker in a trench repairing utilities.

6.1.4 Construction Worker

The exposure factors for the construction worker are presented in Tables A-6-5 and A-6-8. The construction worker is assumed to be an adult working currently in the Upper North Area and the Lower North Area. The construction worker would be potentially involved in the demolition and removal of existing warehouses, relict foundations, possible subgrade utilities and existing paving, or other historical site infrastructure as well as the construction of new buildings and structures. In the future, it was assumed that the construction worker would also work in the Central Commercial Area, Southern Conservation Commission Area, and the Potential Greenway Area, during possible redevelopment of these areas. In the Southern Conservation Commission Area, Marsh Upland Area, and Southern Disposal Area, the construction worker may build recreational structures. In all of these areas, the construction worker would be exposed to the accessible (surficial) and upper potentially accessible soil (0-6 feet bgs) that would be encountered by digging and excavation activities by incidental ingestion, dermal absorption, and the inhalation of particulates and volatiles into the respiratory tract (and ultimately, in some cases, into the gastrointestinal tract). Also, if work is performed where the groundwater is sufficiently near the surface, exposure to volatile releases from the groundwater to the ambient air could occur. In the Potential Greenway Area, the construction worker may build platforms to support a walkway. Since these platforms would be assembled and placed into the water bodies, exposure to surface water and sediment through incidental ingestion and dermal absorption is assumed.

The construction worker's body weight is assumed to be 57.1 kg. This value corresponds to the 50^{th} percentile body weight for female adults between the ages of 18 and 25 years (MADEP, 1996). The construction worker's exposure frequency to accessible and upper potentially accessible soil is assumed to be 5 days a week for 6 months, the equivalent of 120 events/year (MADEP, 1996). The exposure frequency assumed for surface water and sediment is 40 events/year, based on an assumption of 5 days per week for 2 months in the summer. The exposure frequency for the inhalation pathway for soil and groundwater exposure was assumed to be 1 event/day. The exposure duration for the construction worker for all media was assigned a value of 1 day/event by definition for incidental ingestion and dermal absorption (MADEP, 1996). For the inhalation pathway, the exposure duration was chosen as 8 hours/event, based on a standard 8-hour workday. The exposure period for exposure to soil and groundwater was assumed to be 6 months over a 1 year period. This value corresponds to the default exposure period for the typical construction project (MADEP, 1996). The exposure period for surface water and sediment exposure was assumed to be the exposure frequency converted to years, 0.17 years (i.e., 2 months).

The soil ingestion rate for the construction worker was assumed to be 100 mg/day, corresponding to utility/heavy construction workers (MADEP, 2002c). This value is considered appropriate for sediment ingestion also. The volume of water ingested was chosen to be 0.05 L/hr, corresponding to incidental ingestion of water during swimming, which is conservative for this receptor (MADEP, 1996). A value of 3,477 cm^2/day was chosen as the exposed skin surface area for dermal exposure to soil, surface water, and sediment, which corresponds to a female adult heavy construction worker between the ages of 18 and 76 years wearing short sleeves and pants (i.e., face, forearms, hands, and feet exposed) (MADEP, 2002b). The soil-to-skin adherence factor was assumed to be 0.29 mg/cm^2-event, corresponding to a utility worker/heavy construction worker (MADEP 2002b). The sediment-to-skin adherence factor was assumed to be 1 mg/cm^2-event, corresponding to the default for exposure to sediment (MADEP, 2002b). The ventilation rate for the construction worker was assumed to be 3.60 m^3/hour, corresponding to heavy exertion for a worker between 18 and 75 years (MADEP, 1996). The concentration of respirable particulates in the air was assumed to be 60 ug/m^3, based on an excavation scenario (MADEP, 1996). The averaging period for non-carcinogenic effects was set equal to the exposure period (i.e., 0.5 years) by definition (MADEP, 1996). The averaging period for carcinogenic effects was assigned a lifetime value of 75 years (MADEP, 1996).

Tables A-6-36 to A-6-42 present the $[OHM]_{air}$ calculations that were used to estimate soil VOC inhalation intakes for the construction worker. Tables A-6-25 and A-6-26 present the input and chemical-specific values used in the $[OHM]_{air}$ calculations. Tables A-6-58 and A-6-59 contain the input parameters and calculation of the groundwater VF that was used to estimate groundwater VOC inhalation intakes for the construction worker in an excavation scenario. Table A-6-26 also presents the chemical-specific values for the calculation of dermal exposure to surface water.

6.1.5 Trespasser

The exposure factors for the trespasser are presented in Tables A-6-9 and A-6-11. The trespasser is assumed to be an adolescent who would periodically access those portions of the Upper North Area, Lower North Area, and the Central Commercial Area not covered by buildings or pavement, currently or in the foreseeable future. Assuming the Site is unfenced and open, the trespasser may choose to cut across the Site to get to or from adjacent streets or businesses. The trespasser could also be exposed to the Eastern Channel Corridor and thc Upper and Lower Drinkwater River Corridors while cutting across these properties. During these limited periods, there would be the potential for exposure to contamination that may be present in these areas. The trespasser is assumed to access the Site for a very short period of time on a more or less regular basis. He/She would spend all of his/her limited time at the Site outdoors. He/She could be exposed via incidental ingestion, dermal absorption, or the inhalation of particulates or volatile organics, relative to any accessible (surficial) soil (0-3 feet bgs) that is not covered by asphalt paving, sidewalks, or buildings. The trespasser might also be exposed to the sediments and surface water contained in the adjacent water bodies. However, the trespasser would not be exposed to the local groundwater that may be present at the Site.

The trespasser's body weight is assumed to be 50.6 kg. This value corresponds to the average 50^{th} percentile body weights for female adolescents, ages 11-18 years (MADEP, 1996). For all media, the exposure frequency for the trespasser is assumed to be 52 events/year based on an assumption of being onsite two days per week for 6 months (April to October). The exposure frequency for the inhalation pathway for soil exposure was assumed to be 1 event/day. The exposure duration for the trespasser for all media is assigned a value of 1 day/event by definition (MADEP, 1996). For the soil inhalation pathway, the exposure duration was chosen as 4 hours/event. The exposure period for the trespasser for all media is assumed to be 7 years. This value is consistent with the age range of the adolescent trespasser.

The soil ingestion rate for incidental ingestion of soil by the trespasser is assumed to be 50 mg/day. This value corresponds to the daily soil ingestion rate for all people ages six years and older (MADEP, 1996). According to MADEP, the soil ingestion rate is also appropriate for use as the sediment ingestion rate (MADEP, 1996). The volume of water incidentally ingested is estimated to be 0.05 L/hr. This value is the default value for incidental ingestion of water during swimming and is likely to be conservative for this potential wading scenario (MADEP, 1996). The trespasser is assumed to typically wear long pants, a short sleeve shirt, and no shoes. Thus for exposure to soil, the exposed skin surface area (2,928 cm^2/day) is the sum of the median skin surface area values for the forearms, hands, and feet of a female adolescent between the ages of 11 and 18 years (MADEP, 2002b). For exposure to surface water while wading, the exposed skin surface area is assumed to be 6,195 cm^2/day, assuming head, hands, forearms, lower legs, and feet are exposed for a female adolescent between the ages of 11 and 18 years (MADEP, 1996). For exposure to sediment while wading, the exposed skin surface area is assumed to be 4,829 cm^2/day, assuming hands, forearms, lower legs, and feet are exposed for a female adolescent between the ages of 11 and 18 years (MADEP, 2002b). The soil-to-skin adherence factor is assumed to be 0.14 mg/cm^2-event. This value corresponds to a trespasser (MADEP, 2002a). The sediment-to-skin adherence factor was assumed to be 1 mg/cm^2-event, corresponding to the default for exposure to sediment (MADEP, 2002b). The ventilation rate for the trespasser was assumed to be 0.90 m^3/hour, corresponding to light exertion for someone between 11 and 18 years (MADEP, 1996). The concentration of respirable particulates in the air was assumed to be 32 ug/m^3, based on an open field scenario (MADEP, 1996). The averaging period for non-carcinogenic effects is set equal to the exposure period (i.e., 7 years) by definition (MADEP, 1996). The averaging period for carcinogenic effects is assigned a lifetime value of 75 years (MADEP, 1996).

Tables A-6-43 to A-6-45 present the $[OHM]_{air}$ calculations that were used to estimate soil VOC inhalation intakes for the trespasser. Tables A-6-25 and A-6-26 present the input and chemical-specific values used in the $[OHM]_{air}$ calculations. Table A-6-26 also presents the chemical-specific values for the calculation of dermal exposure to surface water.

6.1.6 Adult Recreational User

The exposure factors for the adult recreational user are presented in Tables A-6-12 and A-6-16. The adult recreational user is assumed to be an adult over 18 years old, who uses parts of the Southern Conservation Commission Area, Marsh Upland Area, Southern Disposal Area, Cold Waste Area, and the Potential Greenway Area for recreational and leisure activities (i.e., exercise, hiking) currently or in the foreseeable future. The adult recreational user is assumed to access the areas on a semi-regular basis, for a moderate amount of time depending on the activity. He/She would spend his/her entire time outdoors and therefore would not be exposed to any possible indoor air contaminants. He/She could be exposed via incidental ingestion, dermal absorption, or the inhalation of particulates or volatile organics relative to any accessible (surficial) soil (0-3 feet bgs) that is not covered by asphalt paving, sidewalks, or buildings. The adult recreational user could also come into direct contact with surface water and sediment while swimming or wading in the river/pond areas (Lily Pond/Upper Factory Pond, Middle/Lower Factory Pond, Upper Drinkwater River Corridor, and the Lower Drinkwater River Corridor) and be exposed via incidental ingestion or dermal absorption. The adult recreational user may also be exposed to sediments in the Marsh Upland Area. The adult recreational user would not be exposed to the local groundwater.

The adult recreational user's body weight is assumed to be 57.1 kg. This value corresponds to the 50^{th} percentile body weights for female adults, ages 18-25 years (MADEP, 1996). For soil, the exposure frequency for the adult recreational user is assumed to be 40 events/year based on an assumption of being onsite two days/week for 3 months (June to August) and one day/week for 4 months (April, May, September, October). For sediment and surface water, the exposure frequency for the adult recreational user is assumed to be 6 events/year based on an assumption of contacting the sediment and surface water while swimming or wading two days/month for the three summer months (June, July and August). The exposure duration for the adult recreational user for all media is assigned a value of 1 day/event by definition (MADEP, 1996). For the soil inhalation pathway, the exposure duration was chosen as 8 hours/event. The exposure period for the adult recreational user for all media is assumed to be 30 years. This value corresponds to a residential exposure, since the adult recreational user is likely to live nearby the Site.

The ingestion rate for incidental ingestion of soil by the adult recreational user is assumed to be 50 mg/day. This value corresponds to the daily soil ingestion rate for all people ages six years and older (MADEP, 1996). According to MADEP, the soil ingestion rate is also appropriate for use as the sediment ingestion rate (MADEP, 1996). The volume of water potentially ingested is estimated to be 0.05 L/hr. This value corresponds to the default value for incidental ingestion of water during swimming (MADEP, 1996). It is likely to be a conservative estimate for this receptor. The soil-to-skin adherence factor is assumed to be 0.07 mg/cm^2-event. This value corresponds to a recreational adult (MADEP, 2002b). The sediment-to-skin adherenee factor was assumed to be 1 mg/cm^2-event, corresponding to the default for exposure to sediment (MADEP, 2002b).

The adult recreational user is assumed to typically wear shorts, a short sleeve shirt, and no shoes. Thus, the exposed skin surface area for exposure to soil (5,657 cm^2/day) is the sum of the median skin surface area values for face, forearms, lower legs, hands, and feet of a female recreational user between the ages of 18 and 76 years (MADEP, 2002b). For exposure to the sediment in Lily Pond/Upper Factory Pond and Middle/Lower Factory Pond during swimming, the skin surface area was assumed to be 4,137 cm^2/day, corresponding to median values for hands, lower legs, and feet for a female recreational user between the ages of 18 and 76 years (MADEP, 2002b). For exposure to the sediment in the Marsh Upland Area and the Upper and Lower Drinkwater River Corridors during wading, the skin surface area was assumed to be 3,320 cm^2/day, corresponding to median values for lower legs and feet for the same age range (MADEP, 2002b). For exposure to the surface water in Lily Pond/Upper Factory Pond and Middle/Lower Factory Pond during swimming, the skin surface area was assumed to be 16,900 cm^2/day, corresponding to the 50^{th} percentile value for whole body for a female recreational user between the ages of 18 and 75 years (MADEP, 1996). For exposure to the surface water in the Upper and Lower Drinkwater River Corridors during wading, the skin surface area was assumed to be 5,287 cm^2/day, corresponding to the 50^{th} percentile value for forearms, lower legs, feet, and hands for a female recreational user between the ages of 18 and 75 years (MADEP, 1996).

The ventilation rate for the adult recreational user was assumed to be 1.20 m^3/hour, corresponding to light exertion for someone between 18 and 75 years (MADEP, 1996). The concentration of respirable particulates in the air was assumed to be 32 ug/m^3, based on an open field scenario (MADEP, 1996). The averaging period for non-carcinogenic effects is set equal to the exposure period (i.e., 30 years) by definition (MADEP, 1996). The averaging period for carcinogenic effects is assigned a lifetime value of 75 years (MADEP, 1996).

Tables A-6-46 to A-6-50 present the $[OHM]_{air}$ calculations that were used to estimate soil VOC inhalation intakes for the adult recreational user. Tables A-6-25 and A-6-26 present the input and chemical-specific values used in the $[OHM]_{air}$ calculations. Table A-6-26 also presents the chemical-specific values for the calculation of dermal exposure to surface water.

6.1.7 Child Recreational User

The exposure factors for the child recreational user are presented in Tables A-6-17 and A-6-21. The child recreational user is assumed to be between the ages of 0-6 years and uses parts of the Southern Conservation Commission Area, Marsh Upland Area, Southern Disposal Area, Cold Waste Area, and the Potential Greenway Area for recreational and leisure activities (i.e., exercise, hiking). The child recreational user may be exposed to the same media as the adult recreational user: accessible (surficial) soil (0-3 feet bgs), sediment, and surface water. The child recreational user is assumed to access the areas on a semi-regular basis, generally with the adult recreational user, for a moderate amount of time depending on the activity. He/She would spend his/her entire time outdoors and therefore would not be exposed to any indoor air contaminants. He/she could be exposed via incidental ingestion, dermal absorption, or the inhalation of particulates or volatile organics relevant to any accessible (surficial) soil (0-3 feet bgs) that is not covered by asphalt paving, sidewalks, or buildings. The child recreational user could also come into direct contact with the surface water and sediment while swimming or wading in the river/pond areas (Lily Pond/Upper Factory Pond, Middle/Lower Factory Pond, Upper Drinkwater River Corridor, and the Lower Drinkwater River Corridor) and be exposed via incidental ingestion or dermal absorption. The child recreational user may also be exposed to sediments in the Marsh Upland Area. The child recreational user would not be exposed to the local groundwater.

The child recreational user's body weight is assumed to be 13.6 kg. This value corresponds to the 50^{th} percentile body weights for female children, ages 0-6 years (MADEP, 1996). For soil exposure, the exposure frequency for the child recreational user is assumed to be 40 events/year based on an assumption of being onsite two days/week for 3 months (June to August) and one day/week for 4 months (April, May, September, October). For sediment and surface water, the exposure frequency for the child recreational user is assumed to be 24 events/year based on an assumption of contacting the sediment and surface water while swimming or wading two days/week for the three summer months (June, July and August). The exposure duration for the child recreational user for all media is assigned a value of 1 day/event by definition (MADEP, 1996). For the soil inhalation pathway, the exposure duration was chosen as 8 hours/event. The exposure period for the child recreational user for all media is assumed to be 6 years. This value is consistent with the age range of the child recreational user.

The ingestion rate for incidental ingestion of soil by the child recreational user is assumed to be 100 mg/day. This value corresponds to the daily soil ingestion rate for people ages six years and younger (MADEP, 1996). According to MADEP, the soil ingestion rate is also appropriate for use as the sediment ingestion rate (MADEP, 1996). The volume of water potentially ingested by the child recreational user is estimated to be 0.05 L/hr. This value corresponds with the default value for incidental ingestion of water during swimming (MADEP, 1996). This is likely to be a conservative estimate for this receptor. The soil-to-skin adherence factor is assumed to be 0.35 mg/cm^2-event. This value corresponds to a recreational child (MADEP, 2002b). The sediment-to-skin adherence factor was assumed to be 1 mg/cm^2-event, corresponding to the default for exposure to sediment (MADEP, 2002b).

The child recreational user is assumed to typically wear shorts, a short sleeve shirt, and no shoes. Thus, the exposed skin surface area for exposure to soil (2,434 cm^2/day) is the sum of the median skin surface area values for face, forearms, lower legs, hands, and feet of a female recreational user between the ages of 1 and 8 years (MADEP, 2002b). For exposure to the sediment in Lily Pond/Upper Factory Pond and Middle/Lower Factory Pond during swimming, the skin surface area was assumed to be 2,105 cm^2/day, corresponding to median values for hands, forearms, lower legs, and feet for a female recreational user between the ages of 1 and 8 years (MADEP, 2002b). For exposure to the sediment in the Marsh Upland Area and the Upper and Lower Drinkwater River Corridors during wading, the skin surface area was assumed to be 1,254 cm^2/day, corresponding to median values for lower legs and feet for the same age range (MADEP, 2002b). For exposure to the surface water in Lily Pond/Upper Factory Pond and

Middle/Lower Factory Pond during swimming, the skin surface area was assumed to be 6,022 cm^2/day, corresponding to the 50^{th} percentile value for whole body for a female recreational user between the ages of 0 and 6 years (MADEP, 1996). For exposure to the surface water in the Upper and Lower Drinkwater River Corridors during wading, the skin surface area was assumed to be 1,748 cm^2/day, corresponding to the 50^{th} percentile value for forearms, lower legs, feet, and hands for a female recreational user between the ages of 0 and 6 years (MADEP, 1996).

The ventilation rate for the child recreational user was assumed to be 0.30 m^3/hour, corresponding to light exertion for someone between 0 and 6 years (MADEP, 1996). The concentration of respirable particulates in the air was assumed to be 32 ug/m^3, based on an open field scenario (MADEP, 1996). The averaging period for non-carcinogenic effects is set equal to the exposure period (i.e., 6 years) by definition (MADEP, 1996). The averaging period for carcinogenic effects is assigned a lifetime value of 75 years (MADEP, 1996).

Tables A-6-51 to A-6-55 present the $[OHM]_{air}$ calculations that were used to estimate soil VOC inhalation intakes for the child recreational user. Tables A-6-25 and A-6-26 present the input and chemical-specific values used in the $[OHM]_{air}$ calculations. Table A-6-26 also presents the chemical-specific values for the calculation of dermal exposure to surface water.

6.1.8 Fisherman

The exposure factors for the fisherman are presented in Tables A-6-22 and A-6-24. The fisherman is assumed to be an adult, over the age of 18 years old, who is exposed to sediment and surface water as he/she accesses parts of the Eastern Channel Corridor, Upper Drinkwater River Corridor, Lower Drinkwater River Corridor, Lily Pond/Upper Factory Pond, and Middle/Lower Factory Pond for fishing activities. He/she is also exposed to the fish tissue caught in these water bodies by ingestion.

The fisherman's body weight is assumed to be 57.1 kg. This value corresponds to the 50^{th} percentile body weights for female adults, ages 18-25 years (MADEP, 1996). The exposure frequency for the fisherman is assumed to be 60 events/year, two days per week for 30 weeks/year, as estimated by MADEP (MADEP, 2004b). The exposure duration for the fisherman for surface water and sediment is assigned a value of 1 day/event by definition (MADEP, 1996). The exposure duration for the ingestion of fish was assumed to be 1 meal/day. The exposure period for the fisherman for all media is assumed to be 48 years, as estimated by MADEP (MADEP, 2004b).

The sediment ingestion rate for incidental ingestion of sediment by the fisherman is assumed to be 50 mg/day. This value corresponds to the daily soil ingestion rate for people ages six years and older, appropriate for use relative to sediment ingestion (MADEP, 1996). The volume of water incidentally ingested is estimated to be 0.05 L/hr. This value is the default value for incidental ingestion of water during fishing and is likely to be a conservative estimate for this receptor (MADEP, 1996). The fraction of fish ingestion was assumed to be 26,000 mg/meal, the MADEP default value for fish ingestion (MADEP, 1996). The sediment-to-skin adherence factor is assumed to be 1 mg/cm^2-event. This value corresponds to the default value for exposure to sediment (MADEP, 2002b). The fisherman is assumed to typically wear shorts, a short sleeve shirt, and possibly no shoes. Thus, the exposed skin surface area for sediment and surface water exposure (5,287 cm^2/day) is the sum of the median skin surface area values for the forearms, hands, lower legs and feet of a female adult recreational user between the ages of 18 and 76 years (MADEP, 2002a). The bioavailability adjustment factor for fish ingestion assumed is 1, as discussed with MADEP (TtFW, 2004). The averaging period for non-carcinogenic effects is set equal to the exposure period (i.e., 48 years) by definition (MADEP, 1996). The averaging period for carcinogenic effects is assigned a lifetime value of 75 years (MADEP, 1996).

Table A-6-26 presents the chemical-specific values for the calculation of dermal exposure to surface water.

6.2 Chemical-Specific Parameters

Chemical-specific values used in the intake calculations are presented in Table A-6-26. These chemical-specific values were compiled mainly from United States Environmental Protection Agency (USEPA) sources. The references for each parameter are listed below.

- Soil Organic Carbon-Water Partition Coefficient - USEPA, 2002
- Diffusivity in Air (Di) - USEPA, 2002
- Diffusivity in Water (Dw) - USEPA, 2002
- Henry's Law Constant (H) - USEPA, 2002
- Dermal Permeability Coefficient of Compound in Water (Kp) - USEPA, 2004a

6.3 Fate and Transport Parameters

The intermedia transfer of COCs at the Site was identified to include transfers from soil to ambient air, from groundwater to ambient air, and from groundwater to indoor air. The approaches used to conservatively model these transfers are summarized in the sections that follow.

6.3.1 Soil to Ambient Air (Volatiles)

The quantitative approach for estimating the release of volatiles associated with contaminated soil into the outdoor air, as described in the Supplemental Guidance for Developing Soil Screening Levels at Superfund Sites (USEPA, 2002), was applied when surface or exposed subsurface soil may be expected to release VOCs into the ambient air where they could be inhaled by a receptor. The VF described in this guidance corresponds to the MADEP transport parameter $[OHM]_{air}$. This volatilization parameter, $[OHM]_{air}$, is dependent on both the physical characteristics of the area where the volatilization may occur and the duration of the period over which exposure may occur (which varies by receptor). The parameters used to calculate the area- and receptor-specific $[OHM]_{air}$ parameters are presented in Table A-6-25. Table A-6-26 presents the chemical-specific parameters used in the $[OHM]_{air}$ calculations. Tables A-6-27 to A-6-55 contain the $[OHM]_{air}$ parameter calculations for each receptor and area-specific combination where contaminant volatilization from soil is a possibility.

6.3.2 Groundwater to Ambient Air (Volatiles)

Individuals may be exposed to volatile emissions released from standing groundwater into the ambient air when the groundwater is exposed to the open air at an excavation. Based on the types of excavations that may occur at the Site, two different scenarios were evaluated: 1) standing groundwater in the bottom of a relatively long, shallow trench; and 2) a broader open-air excavation with pooled, standing groundwater. The trench scenario was considered to be more representative of the utility worker while the open-air excavation scenario was considered to be more representative of potential construction worker exposures. The geometry and dispersion characteristics of these two cases result in two different quantitative scenarios, as described below:

6.3.2.1 Excavation Trench (Volatiles)

The USEPA WATER8 model (USEPA, 1995) was used in combination with a simple "box-model" for well-mixed air dispersion to estimate the ambient air concentration in the breathing zone directly above the trench. Standing groundwater in an excavation trench may release volatile chemicals into the ambient air within the trench where they could be inhaled by a person working there. A quantitative approach was developed to evaluate this exposure pathway using a VF. The VF_{gwt} is defined as the ratio of the concentration of the dissolved volatile chemical in groundwater to the concentration of the volatile chemical in the trench breathing space. The approach used was to model the emission of the volatile COC from the dissolved phase in the groundwater into the air using the WATER8 model (USEPA, 1995). This volatile emission rate was then assumed to mix completely with a volume of ambient air reflecting the geometry of the trench and the characteristic ventilation of the trench volume by the natural air flow. The site-specific parameters used to develop the VF_{gwt} for the excavation trench (relating to both the volatile emission rate estimation and the box model mixing) are shown on Table A-6-56. The details of this VF calculation are presented in Table A-6-57.

6.3.2.2 Open Air Excavation (Volatiles)

Standing groundwater in an open-air excavation (such as would be created to install the foundation or floor slab for a new building) may also release volatile chemicals into the ambient air where they could be inhaled by a person. A slightly different quantitative approach was developed to evaluate this exposure pathway using a suitably defined VF. The VF_{gwoe}, in this case, is defined as the ratio of the concentration of the dissolved volatile chemical in groundwater to the concentration of the volatile chemical in the ambient air breathing space. Once again, the emission of the volatile COC from the dissolved phase in the groundwater into the air was estimated using the WATER8 model (USEPA, 1995). In this case, however, the mixing and dispersion of the released volatile COC in the open air above the excavation was modeled using the dispersion factor approach defined in the Supplemental Guidance for Developing Soil Screening Levels at Superfund Sites (USEPA, 2002). This dispersion factor (Q/C) reflects near field Gaussian dispersion in the close proximity of a source, and is estimated using regional meteorology and the approximate size of the contaminated volatile source. The site-specific parameters used to develop the VF_{gwoe} for the open air excavation (relating to both the volatile emission rate estimation and the empirical Gaussian dispersion modeling) are shown on Table A-6-58. The details of this VF calculation are presented in Table A-6-59.

6.3.3 Groundwater to Indoor Air (Volatiles)

The possible diffusion and migration of VOC contamination originating from groundwater beneath the Site was modeled to indoor air using the Johnson and Ettinger Model (JEM) for Subsurface Vapor Intrusion into Buildings (USEPA, 2003). Indoor air was considered to be a potential exposure medium for the commercial worker in those portions of the Site where COCs were detected in the groundwater. The potential indoor air concentrations of the volatile COCs identified for the groundwater were estimated using the infinite source attenuation coefficient parameter calculated by the JEM. This attenuation coefficient, when multiplied by the dissolved groundwater concentration of the volatile COC (with the required unit conversions), provides an estimate of the indoor air concentration. This indoor air volatile COC concentration was then combined with inhalation intake parameters to calculate an inhalation dose and risk. The exposure parameters used to estimate this dose for the commercial workers potentially working indoors are shown on Table A-6-2. The estimation of the infinite source attenuation coefficient was performed separately for each identified volatile groundwater COC in the Upper North Area and the Lower North Area (the areas where commercial indoor exposures were considered a possibility) since the parameter is dependent on a set of site- and location-specific parameters. This pathway evaluation was limited to only those constituents that are considered "volatile" according to the criteria that the constituent's vapor pressure is greater than 0.01 Torr (0.01 mm Hg) (the MADEP definition in the MCP – 310 CMR 40.0000). Location-specific depths to groundwater, soil type, stratigraphy, characteristic commercial building sizes, and chemical-specific properties were used in the estimation of the attenuation coefficient for each volatile COC in each of these two risk characterization areas. The groundwater to indoor air modeling equations were incorporated into the calculation of overall risk to the specific potentially exposed receptors.

As stated earlier in Section 3.1.2, there are no current and no identified plans to construct an occupiable building or structure in the Southern Conservation Commission Area or the Southern Disposal Area. Physical conditions would also preclude the construction of a building in the Marsh Upland Area. Consequently, no pathway exists or is considered likely for indoor air exposure in these areas. However, (as noted in MADEP's comments on the Draft Human Health Risk Characterization (MADEP, 2005)) if it is possible that an occupiable building could be built in areas in the future that would result in the potential for vapor intrusion and indoor air inhalation exposure, an Activity and Use Limitation (AUL) might need to be applied to that area unless it is demonstrated that a level of no significant risk would be associated with this scenario. Therefore, the possible release and migration of VOC contamination from the groundwater beneath the Southern Conservation Commission Area and the Southern Disposal Area into hypothetical future indoor air for a hypothetical indoor Conservation Commission Worker was modeled using the JEM for Subsurface Vapor Intrusion into Buildings (USEPA, 2003). Please see Attachment 4 for the Technical Memorandum that describes this evaluation and presents the resulting calculations and conclusions.

7.0 DOSE-RESPONSE ASSESSMENT

The dose-response assessment is used to evaluate the potential non-carcinogenic (threshold) and carcinogenic (non-threshold) effects caused by exposures to OHM at the Site. The dose-response relationships for each COC have been established based on the type and frequency of occurrence of effects that have been observed in humans and/or laboratory animals associated with a particular dose of the COC. The information obtained from the dose-response assessment is used in conjunction with the exposure assessment to characterize risk associated with each COC via the identified exposure pathways. Toxicological data for the selected COCs were obtained using following the priority as defined by MADEP (MADEP, 1996): IRIS (USEPA, 2004b), HEAST (USEPA, 1997), and other sources (i.e., MADEP ORS, ATSDR, California EPA, and Region 9 PRGs). A summary of the toxicity data for each non-carcinogenic and carcinogenic COC is presented in Tables A-7-1 to A-7-4. Toxicity profiles for each COC are provided in Attachment 1.

Part of the dose-response assessment also includes the identification of chemical-specific relative absorption factors (RAFs). The RAF accounts for differences in the absorption of a COC relative to the exposure route and experimental conditions on which the dose-response value (either non-carcinogenic or carcinogenic) is based. RAFs are discussed in Section 7.2.

7.1 Non-Carcinogenic (Threshold Effects) Dose-Response

The non-carcinogenic dose-response assessment is based on the assumption that there is a COC level that exists at or below which no adverse health effects would be expected. The toxicity values associated with threshold effects are Reference Doses (RfDs) for the oral and dermal exposure routes and Reference Concentrations (RfCs) for inhalation exposures. These toxicity values provide the estimate of the daily dose of the COC to which an individual may be exposed to without an appreciable risk of adverse health effects, including organ damage or reproductive effects. The chronic RfDs and RfCs are derived from either an available No Observable Adverse Effects Level (NOAEL) or the Lowest Observable Adverse Effects Level (LOAEL). Sub-chronic RfD and RfC values are based on exposures that are less than 7 years. Chronic RfD and RfC values are applied to all scenarios since they are usually conservative for sub-chronic exposures. Uncertainty and Modifying Factors are applied to the NOAEL and LOAEL to account for interspecies differences, the duration of the critical study, protection of sensitive populations, and any additional uncertainties in the data study.

An inhalation RfD (RfD_i) is calculated from the RfC using an inhalation rate of 20 m^3/day and a body weight of 70 kg:

$$RfD_i\left[{}^{mg}\!/_{kg-day}\right] = RfC\left[{}^{mg}\!/_{m^3}\right] \cdot \frac{20\left[{}^{m^3}\!/_{day}\right]}{70[kg]}$$

The chronic RfD values used in this risk characterization and the sources from which they were obtained are listed in Tables A-7-1 and A-7-2.

7.2 Carcinogenic (Non-Threshold Effects) Dose-Response

The USEPA has developed a system for characterizing chemicals according to their likelihood as a human carcinogen. This system is based on 5 classes that make up the "weight-of-evidence" system of carcinogenicity that can be used to classify each compound. The weight-of-evidence classification system is summarized in Table A-7-5.

The toxicity values used to evaluate carcinogenicity are Cancer Slope Factors (CSFs) for the oral and dermal exposure routes and Unit Risks (URs) for the inhalation exposure route. These values reflect the relative probability that the incidence of cancer increases in target populations exposed to that constituent. An inhalation CSF (CSF_i) is calculated from the UR using an inhalation rate of 20 m^3/day and a body weight of 70 kg:

$$CSF_i\left[\left({}^{mg}/_{kg-day}\right)^{-1}\right] = UR\left[\left({}^{mg}/_{m^3}\right)^{-1}\right] \cdot \frac{70[kg]}{20\left[{}^{m^3}/_{day}\right]}$$

The CSF values used in this risk characterization and the sources from which they were obtained are shown in Tables A-7-3 and A-7-4.

7.3 Relative Absorption Factors

RAFs account for differences in the absorption of a COC relative to the exposure route and experimental conditions on which the dose-response value (either non-carcinogenic or carcinogenic) was based. The RAF is used to adjust the available toxicity data for a COC to the appropriate exposure conditions at a site. A unique RAF is determined for each COC for each exposure pathway and toxicity value combination.

RAFs are developed by identifying two factors:

- The absorption efficiency for the COC via the route and medium of exposure being evaluated at a site; and
- The absorption efficiency for the COC for the route and medium of exposure of the critical experimental study which was the basis of the dose-response value for the COC.

Once these factors have been quantitatively identified using the matrix in Table B-11 in MADEP, 1996, the RAF is calculated as follows:

$$RAF = \frac{Absorption\ Efficiency_{SITE\ route/medium\ of\ exposure}}{Absorption\ Efficiency_{STUDY\ route/medium\ of\ exposure}}$$

MADEP has derived a number of RAFs and has listed these values in the Background Documentation for the Development of the MCP Numerical Standards (MADEP, 1994). Where available, the MADEP-derived values were used and for those COCs that did not have MADEP-derived values, RAFs were calculated using the established methodology. The RAFs used in this risk characterization are presented in Tables A-7-6 through A-7-9 for non-carcinogenic (chronic) COCs and Tables A-7-10 through A-7-13 for carcinogenic (cancer) COCs.

8.0 RISK CHARACTERIZATION

The risk characterization combines the hazard identification, exposure assessment, and the dose-response assessment to characterize the risk of harm to human health. Non-carcinogenic and carcinogenic risks were calculated for each receptor for all appropriate COCs and exposure points at the Site. These chemical- and medium-specific risk values were combined to generate cumulative non-carcinogenic and carcinogenic risks for each receptor, which were then compared to the MADEP Cumulative Receptor Risk Limits (310 CMR 40.0933(6)) to assess the condition of "No Significant Risk" at the Site. Additionally, as stipulated by the MCP, EPCs were compared to Applicable or Suitably Analogous Public Health Standards to evaluate the condition of "No Significant Risk."

A condition of "No Significant Risk" of harm to human health exists if:

- No EPC is greater than an applicable or suitably analogous public health standard;
- No Cumulative Receptor Cancer Risk calculated is greater than the Cumulative Cancer Risk Limit of 1×10^{-5}; and
- No Cumulative Receptor Non-Cancer Risk is greater than the Cumulative Receptor Non-Cancer Risk Limit of 1.0.

8.1 Estimates of Chemical Intake

To evaluate the risk of harm to human health, the intake of each COC must first be estimated. This quantitative evaluation involves assessing the amount of contaminant projected to come into contact with the receptor and the amount potentially available for absorption by the body. This assessment is achieved through the calculation of an ADD or LADD for each COPC for each potentially complete exposure pathway. Chemical-specific and exposure route-specific RAFs are used in the ADD/LADD equations to convert an exposure to an absorbed dose (amount per unit time and body weight). The RAFs are discussed in Section 7.3 and are listed in Tables A-7-6 through A-7-13.

ADDs and LADDs were calculated for each receptor, for each applicable ingestion, dermal absorption, and inhalation pathway using the calculated EPCs. The ADDs and LADDs were calculated to quantitatively assess potential risks to human health associated with present and future use scenarios. ADDs and LADDs are expressed as the amount of a chemical an individual would be exposed to per unit body weight per day (e.g., mg/kg-day). The formula used in the calculation of the ingestion of a COC in soil, sediment, or surface water was (MADEP, 1996):

$$ADD_{ing} \text{ or } LADD_{ing} = \frac{[OHM] \cdot IR \cdot RAF \cdot EF \cdot ED \cdot EP \cdot C}{BW \cdot AP}$$

The formula used in the calculation of dermal absorption of a COC in soil or sediment was (MADEP, 1996):

$$ADD_{derm} \text{ or } LADD_{derm} = \frac{[OHM] \cdot SA \cdot AF \cdot RAF \cdot EF \cdot ED \cdot EP \cdot C}{BW \cdot AP}$$

The formula used in the calculation of dermal contact with a COC in surface water was (MADEP, 1996):

$$ADD_{derm}\ or\ LADD_{derm} = \frac{[OHM] \cdot SA \cdot Kp \cdot RAF \cdot EF \cdot ED \cdot EP \cdot C}{BW \cdot AP}$$

The formula used in the calculation of the inhalation of contaminated particulates and volatile organics released from soil for the commercial worker, utility worker, trespasser, and recreational users was (MADEP, 1996):

$$ADD_{inhal}\ or\ LADD_{inhal} = \frac{[OHM]_{soil} \cdot \left[\left([RP_{air}] \cdot C \right) + \left(\frac{1}{[OHM]_{air}} \right) \right] \cdot VR \cdot RAF \cdot EF \cdot ED \cdot EP}{BW \cdot AP}$$

The formula used in the calculation of inhalation followed by gastrointestinal ingestion of contaminated particulates released from the soil for the construction worker was: (MADEP, 2002d):

$$ADD_{inhal-GI}\ or\ LADD_{inhal-GI} = \frac{[OHM]_{soil} \cdot 2 \cdot [RP_{air}] \cdot C \cdot VR \cdot RAF \cdot EF \cdot ED \cdot EP}{BW \cdot AP}$$

The formula used in the calculation of the inhalation of contaminated particulates and volatile organics released from soil for the construction worker was: (MADEP, 2002d):

$$ADD_{inhal}\ or\ LADD_{inhal} = \frac{[OHM]_{soil} \cdot 0.5 \cdot \left[\left([RP_{air}] \cdot C \right) + \left(\frac{1}{[OHM]_{air}} \right) \right] \cdot VR \cdot RAF \cdot EF \cdot ED \cdot EP}{BW \cdot AP}$$

The formula used in the calculation of ingestion of a COC in fish tissue was (MADEP, 1996):

$$ADD_{ing}\ or\ LADD_{ing} = \frac{[OHM]_{fish} \cdot FI \cdot BAF \cdot EF \cdot ED \cdot EP \cdot C}{BW \cdot AP}$$

where:

ADD	=	Average Daily Dose [mg/kg-day]
LADD	=	Lifetime Average Daily Dose [mg/kg-day]
[OHM]	=	Concentration of oil or hazardous material in a certain exposure medium (i.e., soil, surface water, sediment, air, fish tissue) [mg/kg, mg/L, or m^3/kg]
$[RP]_{air}$	=	Concentration of Respirable Particulates [ug/m^3]
IR	=	Ingestion Rate [mg/day or L/hr]
VR	=	Ventilation Rate [m^3/hour]
FI	=	Fraction Ingested [mg/meal]
RAF	=	Relative Absorption Faetor, non-carcinogenic or carcinogenic [unitless]
BAF	=	Bioavailability Adjustment Factor [unitless]
SA	=	Exposed Skin Surface Area [cm^2/day]
AF	=	Soil-to-Skin Adherence Factor [mg/cm^2-event]
Kp	=	Permeability Constant, ehemical-specifie [cm/hour]
EF	=	Exposure Frequency [events/year or events/day]

ED = Exposure Duration [days/event, hours/event, or meals/day]
EP = Exposure Period [years or days]
BW = Body Weight [kg]
AP = Averaging Period, non-carcinogenic or carcinogenic [days]
C = Conversion Factor

8.2 Risk Characterization Methods

8.2.1 Non-Carcinogenic Risk Characterization

Non-carcinogenic risk is measured by calculating the hazard quotient (HQ) for each COC for each receptor and pathway combination. The HQ for a given COC is the ratio of a receptor's exposure level (i.e., ADD) to the "acceptable" exposure level (i.e., RfD). The exposure route-specific hazard index (HI) for each receptor and pathway combination is the sum of these COC-specific HQs. A cumulative HI for each receptor was then calculated by summing the HIs for each pathway. This cumulative HI accounts for exposures a receptor may receive from multiple COCs and multiple exposure routes. This cumulative HI is called a Screening HI (MADEP, 1996) because it is conservatively based on all COCs in all exposure routes at all exposure points. However, COCs with non-carcinogenic effects produce adverse effects on multiple organ systems and different mechanisms of action. Calculating a true health endpoint-specific HI involves segregating HIs by effect, mechanism of action, and higher dose effects. To be conservative, the risk characterization for this Site calculated the Screening HI and, where appropriate, target organ-specific HIs.

A cumulative HI of 1.0 or less indicates that the receptor's exposure is equal to or less than the allowable exposure level, and it is considered unlikely that adverse health effects will occur (MADEP, 1996). If the cumulative HI is less than 1.0, then a condition of "No Significant Risk" of harm to human health has been achieved based on non-carcinogenic effects (310 CMR 40.0993(6)). A cumulative HI above 1.0 for any receptor indicates that adverse effects due to non-carcinogenic effects *may* occur, and true health endpoint-specific HIs should be evaluated. If a true health endpoint-specific HI (i.e., the cumulative HI for all COCs impacting the same target organ or system) is above 1.0, then the risk characterization must conclude that the site poses "Significant Risk" of harm to human health based on non-carcinogenic effects.

8.2.2 Carcinogenic Risk Characterization

Carcinogenic risk is measured by calculating the Excess Lifetime Cancer Risk (ELCR) for each receptor and pathway. The ELCR is calculated for each COC by multiplying a receptor's ADD by the CSF or UR for the specific exposure route. The exposure route-specific ELCR for each receptor is the sum of the ELCRs calculated for each COC. The cumulative ELCR for each receptor is then calculated by summing the exposure route-specific ELCRs for all pathways. The cumulative ELCR accounts for exposures a receptor may receive from multiple chemicals and multiple exposure routes. MADEP requires that the ELCR be calculated for all Class A and B carcinogens (MADEP, 1996). In this risk characterization, however, ELCRs were conservatively calculated for Class C carcinogens also. COCs with carcinogenic effects are not segregated by target organ in the same manner as the COCs with non-carcinogenic effects.

The cumulative ELCRs for each receptor are compared to the MCP Cumulative Receptor Cancer Risk Limit of 1×10^{-5} (310 CMR 40.0993(6)). An exceedance of this Cancer Risk Limit indicates that the site poses a "Significant Risk" of harm to human health based on carcinogenic health effects.

8.3 Summary of Cumulative Hazard Indices and Cumulative Cancer Risks

The cumulative HIs and ELCRs were calculated based on the exposure and toxicity factors and the methods described above. Attachment 2 includes the ELCR calculation tables (see Tables A2-1 to A2-188) for each receptor, area, and pathway combination. Attachment 3 includes HI calculation tables (see Tables A3-1 to A3-188), for each receptor, area, and pathway combination. The following sections summarize the HIs and ELCRs for each risk characterization area by receptor.

8.3.1 Upper North Area (Eastern Channel Corridor and Upper Drinkwater River Corridor)

8.3.1.1 Commercial Worker

The total cumulative ELCR and HI potentially associated with current/future exposure to the commercial worker to accessible (surficial) soil (0-3 feet bgs) and the upper overburden groundwater from the Upper North Area were calculatcd to be 9.09 x 10^{-6} and 0.29 (see Tables A-8-1 and A-8-2). Both the ELCR and the HI estimates are below their acceptable MADEP benchmarks of 1 x 10^{-5} and 1.0, respectively.

8.3.1.2 Utility Worker

The total cumulative ELCR and HI potentially associated with current/future exposure to the utility worker to accessible (surficial) and upper potentially accessible soil (0-6 feet bgs) and the upper overburden groundwater from the Upper North Area were calculated to be 8.69 x 10^{-6} and 0.68 (see Tables A-8-3 and A-8-4). Both the ELCR and the HI estimates are below their acceptable MADEP benchmarks of 1 x 10^{-5} and 1.0, respectively.

8.3.1.3 Construction Worker

The total cumulative ELCR and HI potentially associated with current/future exposure to the construction worker to accessible (surficial) and upper potentially accessible soil (0-6 feet bgs) and the upper overburden groundwater from the Upper North Area were calculated to be 1.10 x 10^{-6} and 3.61 (see Tables A-8-5 and A-8-6). The ELCR estimate is below the acceptable MADEP benchmark of 1 x 10^{-5} while the HI estimate is slightly above the MADEP acceptable benchmark of 1.0. Manganese, and to a lesser extent arsenic, are the primary contributors to this HI via the inhalation, coughing up, and subsequent swallowing of particulates from soil. These results for manganese and arsenic are not considered to represent a concern relative to human health exposure and risk. This is because manganese primarily targets the central nervous system and arsenic primarily targets the skin. As such, these HI contributions should be considered separately. The chemical-specific HI for arsenic, 0.42, does not exceed the MADEP acceptable benchmark of 1.0 individually and therefore, it is not indicated to pose a significant human health concern. Although the manganese HI of 1.86 did exceed the MADEP benchmark value, it is not considered to represent a risk to human health due to the following rationale:

- The contamination at the Site relative to this CSA is primarily chemicals used to process fireworks and munitions components that may have been released. Although manganese was chosen as a COC (based on the prescribed screening process and criteria), it is not clearly linked to or related to the Site activities.
- The inhalation toxicity value for manganese includes a combined uncertainty/modifying factor of 1000, reflecting considerable uncertainty in this parameter. This uncertainty factor indicates that exposures 10 to 100 times greater than that reflected in the published toxicity value may not lead to any adverse effect.

8.3.1.4 Trespasser

The total cumulative ELCR and HI potentially associated with current/future exposure to the trespasser to accessible (surficial) soil (0-3 feet bgs) from the Upper North Area and surface water and sediment from the Eastern Channel Corridor were calculated to be 1.64 x 10^{-5} and 3.05 (see Tables A-8-7 and A-8-8). Both the ELCR and the HI estimates are slightly above their MADEP acceptable benchmarks. Benzo(a)pyrene is the primary contributor to the ELCR and mercury is the primary contributor to the HI, both via dermal absorption of sediment. The results indicate that the exceedances of both the cumulative ELCR and the HI are due to the trespasser's exposure to the Eastern Channel Corridor's sediments. Exposure to the Upper North Area soil and the Eastern Channel Corridor surface water is not indicated to pose a human health concern.

The total cumulative ELCR and HI potentially associated with current/future exposure to the trespasser to accessible (surficial) soil (0-3 feet bgs) from the Upper North Area and surface water and sediment from the Upper Drinkwater River Corridor were calculated to be 9.52 x 10^{-7} and 0.07 (see Tables A-8-7 and A-8-8). Both the ELCR and the HI estimates are below their MADEP acceptable benchmarks of 1 x 10^{-5} and 1.0, respectively.

8.3.1.5 Summary

The results for the receptors exposed to the Upper North Area and the adjacent water bodies (i.e., Eastern Channel Corridor and the Upper Drinkwater River Corridor) indicated the following:

- No significant carcinogenic or non-carcinogenic risks associated with exposure to the Upper North Area soils;
- No significant carcinogenic or non-carcinogenic risks associated with exposure to the Upper North Area upper overburden groundwater;
- No significant carcinogenic or non-carcinogenic risks associated with exposure of the trespasser to the Eastern Channel Corridor's and Upper Drinkwater River Corridor's surface water; and
- Significant carcinogenic and non-carcinogenic risks associated with exposure of the trespasser to the Eastern Channel Corridor sediment. Benzo(a)pyrene and mercury are the COCs in these sediments increasing the projected risks most significantly through dermal absorption.

8.3.2 Lower North Area (Lower Drinkwater River Corridor)

8.3.2.1 Commercial Worker

The total cumulative ELCR and HI potentially associated with current/future exposure to the commercial worker to accessible (surficial) soil (0-3 feet bgs) and the upper overburden groundwater from the Lower North Area were calculated to be 1.61 x 10^{-5} and 0.10 (see Tables A-8-1 and A-8-2). The ELCR estimate is slightly above the MADEP acceptable benchmark of 1 x 10^{-5}, while the HI estimate is below the acceptable MADEP benchmark of 1.0. Benzo(a)pyrene via the incidental ingestion of soil, carbazole via the inhalation of soil particulates, and trichloroethylene via the inhalation of volatiles migrating from groundwater into indoor air are the primary contributors to the ELCR.

The projected ELCR reflected conservative estimates of inhalation exposure to wind entrained soil dust (through the MADEP default $[RP]_{air}$ value) and the groundwater to indoor air vapor intrusion modeling performed using the JEM model. The dust entrainment/inhalation pathway was modeled using the default $[RP]_{air}$ concentration associated with an open field scenario. The dust concentrations in the Lower North Area are likely to be appreciably lower than this default concentration since portions of the area are paved and covered by trees. Both of these conditions tend to reduce the potential for surface soil entrainment into the ambient air for subsequent inhalation. The quantitative evaluation of the potential vapor intrusion into indoor air was performed using conservative assumptions to account for variability in conditions and characteristics of the area. This assessment assumed the most permeable soil type (i.e., sand), the shallowest depth to groundwater measured in any well in the vicinity of the DPW garage, and building parameters generally reflective of a residential structure and not a commercial one. The size and construction of the DPW garage was also considered in the specification of the modeling input parameters, but it is likely that greater air exchange is actually occurring than the modeling took credit for. Overall, the predicted indoor air concentrations are expected to be higher than would actually be generated by the subsurface groundwater contamination. Taking both of these conservative aspects of the approach together, the slight exceedance of the ELCR relative to the MADEP benchmark is not considered to represent a concern relative to human health.

8.3.2.2 Utility Worker

The total cumulative ELCR and HI potentially associated with current/future exposure to the utility worker to accessible (surficial) and upper potentially accessible soil (0-6 feet bgs) and the upper overburden groundwater from the Lower North Area were calculated to be 1.78×10^{-5} and 0.88 (see Tables A-8-3 and A-8-4). The ELCR estimate is slightly above the MADEP acceptable benchmark of 1×10^{-5}, while the HI estimate is below the acceptable MADEP benchmark of 1.0. Carbazole and chromium are the primary contributors to the ELCR via the inhalation of particulates in soil.

The projected ELCR reflected conservative estimates of inhalation exposure to wind entrained soil dust (through the MADEP default $[RP]_{air}$ value). The dust entrainment/inhalation pathway was modeled using the default $[RP]_{air}$ concentration associated with an excavation scenario. The dust concentrations in the Lower North Area are likely to be appreciably lower than this default concentration since portions of the area are paved and covered by trees. Both of these conditions tend to reduce the potential for surface soil entrainment into the ambient air for subsequent inhalation. Therefore, the slight exceedance of the ELCR relative to the MADEP benchmark is not considered to represent a concern relative to human health.

8.3.2.3 Construction Worker

The total cumulative ELCR and HI potentially associated with current/future exposure to the construction worker to accessible (surficial) and upper potentially accessible soil (0-6 feet bgs) and the upper overburden groundwater from the Lower North Area were calculated to be 3.55×10^{-6} and 4.42 (see Tables A-8-5 and A-8-6). The ELCR estimate is below the acceptable MADEP benchmark of 1×10^{-5} while the HI estimate is slightly above the MADEP acceptable benchmark of 1.0. Manganese and aluminum are the primary contributors to this HI via the inhalation, coughing up, and subsequent swallowing of particulates from soil. These results for manganese and aluminum are not considered to represent a concern relative to human health exposure and risk. This is because manganese primarily targets the central nervous system and aluminum causes a decrease in body weight. As such, these HI contributions should be considered separately. The chemical-specific HI for aluminum (1.02) is effectively equal to the MADEP acceptable benchmark of 1.0 individually and therefore, it is not indicated to pose a significant human health concern. Although the manganese HI of 1.70 did exceed the MADEP benchmark value, it is not considered to represent a risk to human health due to the following rationale:

- The contamination at the Site relative to this CSA is primarily chemicals used to process fireworks and munitions components that may have been released. Although manganese was chosen as a COC (based on the prescribed screening process and criteria), it is not clearly linked to or related to the Site activities.
- The inhalation toxicity value for manganese includes a combined uncertainty/modifying factor of 1000, reflecting considerable uncertainty in this parameter. This uncertainty factor indicates that exposures 10 to 100 times greater than that reflected in the published toxicity value may not lead to any adverse effect.

8.3.2.4 Trespasser

The total cumulative ELCR and HI potentially associated with current/future exposure to the trespasser to accessible (surficial) soil (0-3 feet bgs) from the Upper North Area and surface water and sediment from the Lower Drinkwater River Corridor were calculated to be 5.20 x 10^{-6} and 0.66 (see Tables A-8-7 and A-8-8). Both the ELCR and the HI estimates are below their MADEP acceptable benchmarks of 1 x 10^{-5} and 1.0, respectively.

8.3.2.5 Summary

The results for the receptors exposed to the Lower North Area and the adjacent water body (i.e., Lower Drinkwater River Corridor) indicated the following:

- No significant carcinogenic or non-carcinogenic risks associated with exposure to the Lower North Area soils;
- No significant carcinogenic or non-carcinogenic risks associated with exposure to the Lower North Area upper overburden groundwater; and
- No significant carcinogenic or non-carcinogenic risks associated with exposure of the trespasser to the Lower Drinkwater River Corridor's sediment and surface water.

8.3.3 Central Commercial Area

8.3.3.1 Commercial Worker

The total cumulative ELCR and HI potentially associated with current/future exposure to the commercial worker to accessible (surficial) soil (0-3 feet bgs) and the upper overburden groundwater from the Central Commercial Area were calculated to be 3.46 x 10^{-6} and 0.18 (see Tables A-8-1 and A-8-2). Both the ELCR and the HI estimates are below their acceptable MADEP benchmarks of 1 x 10^{-5} and 1.0, respectively.

8.3.3.2 Utility Worker

The total cumulative ELCR and HI potentially associated with current/future exposure to the utility worker to accessible (surficial) and upper potentially accessible soil (0-6 feet bgs) and the upper overburden groundwater from the Central Commercial Area were calculated to be 1.10 x 10^{-5} and 0.76 (see Tables A-8-3 and A-8-4). The ELCR estimate is slightly above the MADEP acceptable benchmark of 1 x 10^{-5}, while the HI estimate is below the acceptable MADEP benchmark of 1.0. Carbazole and chromium are the primary contributors to the ELCR via the inhalation of particulates in soil.

The projected ELCR reflected conservative estimates of inhalation exposure to wind entrained soil dust (through the MADEP default $[RP]_{air}$ value). The dust entrainment/inhalation pathway was modeled using the default $[RP]_{air}$ concentration associated with an excavation scenario. The dust concentrations in the Central Commercial Area are likely to be appreciably lower than this default concentration since portions of the area are paved and covered by trees. Both of these conditions tend to reduce the potential for surface soil entrainment into the ambient air for subsequent inhalation. Therefore, the slight exceedance of the ELCR relative to the MADEP benchmark is not considered to represent a significant concern relative to human health.

8.3.3.3 Construction Worker

The total cumulative ELCR and HI potentially associated with current/future exposure to the construction worker to accessible (surficial) and upper potentially accessible soil (0-6 feet bgs) and the upper overburden groundwater from the Central Commercial Area were calculated to be 1.40 x 10^{-6} and 4.06 (see Tables A-8-5 and A-8-6). The ELCR estimate is below the acceptable MADEP benchmark of 1 x 10^{-5} while the HI estimate is slightly above the MADEP acceptable benchmark of 1.0. Manganese, aluminum, and arsenic are the primary contributors to this HI via the inhalation, coughing up, and subsequent swallowing of particulates from soil. These results for manganese, arsenic, and aluminum are not considered to represent a concern relative to human health exposure and risk. This is because manganese primarily targets the central nervous system, arsenic primarily targets the skin, and aluminum causes a decrease in body weight. As such, these HI contributions should be considered separately. The chemical-specific HIs for arsenic and aluminum (0.58 and 0.66, respectively) do not exceed the MADEP acceptable benchmark of 1.0 individually and therefore, they are not indicated to pose a significant human health concern. Although the manganese HI of 1.41 did exceed the MADEP benchmark value, it is not considered to represent a risk to human health due to the following rationale:

- The contamination at the Site relative to this CSA is primarily chemicals used to process fireworks and munitions components that may have been released. Although manganese was chosen as a COC (based on the prescribed screening process and criteria), it is not clearly linked to or related to the Site activities.
- The inhalation toxicity value for manganese includes a combined uncertainty/modifying factor of 1000, reflecting considerable uncertainty in this parameter. This uncertainty factor indicates that exposures 10 to 100 times greater than that reflected in the published toxicity value may not lead to any adverse effect.

8.3.3.4 Trespasser

The total cumulative ELCR and HI potentially associated with current/future exposure to the trespasser to accessible (surficial) soil (0-3 feet bgs) and the upper overburden groundwater from the Central Commercial Area were calculated to be 6.73 x 10^{-7} and 0.035 (see Tables A-8-7 and A-8-8). Both the ELCR and the HI estimates are below their MADEP acceptable benchmarks of 1 x 10^{-5} and 1.0, respectively.

8.3.3.5 Summary

The results for the receptors exposed to the Central Commercial Area indicated the following:

- No significant carcinogenic or non-carcinogenic risks associated with exposure to the Central Commercial Area soils; and

- No significant carcinogenic or non-carcinogenic risks associated with exposure to the Central Commercial Area upper overburden groundwater.

8.3.4 Southern Conservation Commission Area

8.3.4.1 Utility Worker

The total cumulative ELCR and HI potentially associated with current/future exposure to the utility worker to accessible (surficial) and upper potentially accessible soil (0-6 feet bgs) and the upper overburden groundwater from the Southern Conservation Commission Area were calculated to be 7.67×10^{-6} and 1.17 (see Tables A-8-3 and A-8-4). The ELCR estimate is below the MADEP acceptable benchmark of 1×10^{-5}, while the HI estimate is slightly above the acceptable MADEP benchmark of 1.0. Manganese and arsenic are the primary contributors to the HI via the inhalation of particulates in soil. These results for manganese and arsenic are not considered to represent a concern relative to human health exposure and risk. This is because manganese primarily targets the central nervous system and arsenic primarily targets the skin. As such, these HI contributions should be considered separately. The chemical-specific HIs for manganese and arsenic (0.49 and 0.28, respectively) do not exceed the MADEP acceptable benchmark of 1.0 individually and therefore, they are not indicated to pose a significant human health concern.

8.3.4.2 Construction Worker

The total cumulative ELCR and HI potentially associated with current/future exposure to the construction worker to accessible (surficial) and upper potentially accessible soil (0-6 feet bgs) and the upper overburden groundwater from the Southern Conservation Commission Area were calculated to be 9.46×10^{-7} and 6.15 (see Tables A-8-5 and A-8-6). The ELCR estimate is below the MADEP acceptable benchmark of 1×10^{-5}, while the HI estimate is slightly above the acceptable MADEP benchmark of 1.0. Manganese and arsenic, and to a lesser extent aluminum and barium, are the primary contributors to the HI via the inhalation, coughing up, and subsequent swallowing of particulates from soil. These results for manganese, arsenic, and barium are not considered to represent a concern relative to human health exposure and risk. This is because manganese primarily targets the central nervous system, arsenic primarily targets the skin, and barium primarily targets the fetus. As such, these HI contributions should be considered separately. The chemical-specific HIs for aluminum and barium (0.74 and 0.61, respectively) do not exceed the MADEP acceptable benchmark of 1.0 individually and therefore, they are not indicated to pose a significant human health concern. The chemical-specific HI for arsenic, 1.10 is just slightly over the MADEP acceptable benchmark of 1.0. This HI is based on using a default $[RP]_{air}$ or PM10 value of 60 ug/m^3, indicative of an excavation scenario. This default concentration represents the arithmetic mean of the 24-hour maximum PM10 values from 17 sampling locations in Massachusetts during 1993 (MADEP, 1996) and is considered to be conservative. Therefore, since the [RP]air/PM10 value is a critical parameter in the HI calculation, the HI value calculated for arsenic is not indicated to pose a significant human health concern.

Although the manganese HI of 1.94 did exceed the MADEP benchmark value, it is not considered to represent a risk to human health due to the following rationale:

- The contamination at the Site relative to this CSA is primarily chemicals used to process fireworks and munitions components that may have been released. Although manganese was chosen as a COC (based on the prescribed screening process and criteria), it is not clearly linked to or related to the Site activities.

- The inhalation toxicity value for manganese includes a combined uncertainty/modifying factor of 1000, reflecting considerable uncertainty in this parameter. This uncertainty factor indicates that exposures 10 to 100 times greater than that reflected in the published toxicity value may not lead to any adverse effect.

8.3.4.3 Summary

The results for the receptors exposed to the Southern Conservation Commission Area indicated the following:

- No significant carcinogenic or non-carcinogenic risks associated with exposure to the Southern Conservation Commission Area soils; and
- No significant carcinogenic or non-carcinogenic risks associated with exposure to the Southern Conservation Commission Area upper overburden groundwater.

8.3.5 Marsh Upland Area

8.3.5.1 Utility Worker

The total cumulative ELCR and HI potentially associated with current/future exposure to the utility worker to accessible (surficial) and upper potentially accessible soil (0-6 feet bgs) and upper overburden groundwater from the Marsh Upland Area were calculated to be 5.04×10^{-7} and 0.17 (see Tables A-8-3 and A-8-4). Both the ELCR and the HI estimates are below their MADEP acceptable benchmarks of 1×10^{-5} and 1.0, respectively.

8.3.5.2 Construction Worker

The total cumulative ELCR and HI potentially associated with current/future exposure to the construction worker to accessible (surficial) and upper potentially accessible soil (0-6 feet bgs) and the upper overburden groundwater from the Marsh Upland Area were calculated to be 8.60×10^{-8} and 6.63 (sec Tables A-8-5 and A-8-6). The ELCR estimate is below the MADEP acceptable benchmark of 1×10^{-5}, while the HI estimate is above the acceptable MADEP benchmark of 1.0. Mercury is the primary contributor to the HI via the incidental ingestion and dermal absorption of soil.

8.3.5.3 Summary

The results for the receptors exposed to the Marsh Upland Area indicated the following:

- No significant carcinogenic risk associated with exposure to the Marsh Upland Area soils; and
- Significant non-carcinogenic risk associated with exposure to the Marsh Upland Area soils. Mercury is the COC contributing to the projected non-carcinogenic risk to the construction worker relative to exposures to accessible (surficial) and upper potentially accessible soil (0-6 feet bgs) through incidental ingestion and dermal absorption.

8.3.6 Southern Disposal Area

8.3.6.1 Utility Worker

The total cumulative ELCR and HI potentially associated with current/future exposure to the utility worker to accessible (surficial) and upper potentially accessible soil (0-6 feet bgs) and upper overburden groundwater from the Southern Disposal Area were calculated to be 1.79 x 10^{-4} and 2.98 (see Tables A-8-3 and A-8-4). Both the ELCR and the HI estimates are above their MADEP acceptable benchmarks of 1 x 10^{-5} and 1.0, respectively. 1,1-Dichloroethene, chromium, and trichloroethene are the primary contributors to the ELCR via the inhalation of soil particulates. Manganese, arsenic, and barium are the primary contributors to the HI also via the inhalation of soil particulates.

The results for manganese, arsenic, and barium are not considered to represent a concern relative to human health exposure and risk. This is because manganese primarily targets the central nervous system, arsenic primarily targets the skin, and barium primarily targets the fetus. As such, these HI contributions should be considered separately. The chemical-specific HIs for manganese, arsenic, and barium (0.77, 0.44, and 0.39, respectively) do not exeeed the MADEP aceeptable benchmark of 1.0 individually and therefore, they are not indicated to pose a significant human health concern.

8.3.6.2 Construction Worker

The total cumulative ELCR and HI potentially assoeiated with eurrent/future exposure to the construetion worker to aceessible (surfieial) and upper potentially accessible soil (0-6 feet bgs) and upper overburden groundwater from the Southern Disposal Area were calculated to be 2.45 x 10^{-5} and 18 (see Tables A-8-5 and A-8-6). Both the ELCR and the HI estimates are above their MADEP acceptable benchmarks of 1 x 10^{-5} and 1.0, respectively. 1,1-Dichloroethene, and to a lesser extent trichloroethene, are the primary contributors to the ELCR via the inhalation of soil particulates into the respiratory tract. Lead (via the incidental ingestion and the inhalation, coughing up, and subsequent swallowing of particulates from soil), arsenic and barium (via the inhalation, coughing up, and subsequent swallowing of particulates from soil), cis-1,2-dichloroethene, trans-1,2-dichloroethene, and trichloroethene (via the inhalation of soil particulates or volatiles), and manganese (via the inhalation of soil particulates or volatiles and the inhalation, coughing up, and subsequent swallowing of particulates from soil), are the primary contributors to the HI. An evaluation of the target organ-specific HIs indicated that the MADEP benchmark of 1.0 was exceeded relative to effects on the skin, fetus, central nervous system, liver, and the blood in the soils of the Southern Disposal Area. The chemical-specific HIs for arsenic and barium, 17.3 and 1.54, respectively, are just slightly over the MADEP acceptable benchmark of 1.0. These HIs are based on using a default $[RP]_{air}$ or PM10 value of 60 ug/m^3, indicative of an excavation scenario. This default concentration represents the arithmetic mean of the 24-hour maximum PM10 values from 17 sampling locations in Massachusetts during 1993 (MADEP, 1996) and is considered to be conservative. Therefore, since the [RP]air/PM10 value is a critical parameter in the HI calculation, the HI values calculated for arsenic and barium are not indicated to pose a significant human health concern. Although the manganese HI did exceed the MADEP benchmark value, it is not considered to represent a risk to human health due to the following rationale:

- The contamination at the Site relative to this CSA is primarily chemicals used to process fireworks and munitions components that may have been released. Although manganese was chosen as a COC (based on the prescribed screening process and criteria), it is not clearly linked to or related to the Site activities.
- The inhalation toxicity value for manganese includes a combined uncertainty/modifying factor of 1000, reflecting considerable uncertainty in this parameter. This uncertainty factor

indicates that exposures 10 to 100 times greater than that reflected in the published toxicity value may not lead to any adverse effect.

8.3.6.3 Summary

The results for the receptors exposed to the Southern Disposal Area indicated the following:

- Significant carcinogenic and non-carcinogenic risks associated with exposure to the Southern Disposal Area soils. 1,1-Dichloroethene, chromium, trichloroethene, lead, cis-1,2-dichloroethene, and trans-1,2-dichloroethene are the COCs contributing significantly to the projected risks for the utility and construction workers in the Southern Disposal Area relative to projected exposures to accessible (surficial) and upper potentially accessible soil (0-6 feet bgs) via incidental ingestion and the inhalation of particulates and volatiles. Since the total ELCR for this area was conservatively calculated with Class C carcinogens and 1,1-dichlorethene is a Class C carcinogen, it will be determined at a later date if it will be focused on in the Phase III investigation; and
- No significant carcinogenic or non-carcinogenic risks associated with exposure to the Southern Disposal Area upper overburden groundwater.

8.3.7 Potential Greenway Area (Upper and Lower Drinkwater River Corridors)

8.3.7.1 Construction Worker

The total cumulative ELCR and HI potentially associated with future exposure to the construction worker to accessible (surficial) and upper potentially accessible soil (0-6 feet bgs) from the Potential Greenway Area and surface water and sediment from the Lower Drinkwater River Corridor were calculated to be 6.16×10^{-7} and 0.17 (see Tables A-8-5 and A-8-6). Both the ELCR and the HI estimates are below their MADEP acceptable benchmarks of 1×10^{-5} and 1.0, respectively.

The Upper Drinkwater River Corridor is also associated with the Potential Greenway Area exposure for the construction worker. Since the construction worker's exposure to the surface water and sediment in the Lower Drinkwater River Corridor is likely to be greater than the exposure to the surface water and sediment in the Upper Drinkwater River Corridor, the contributions to the risks associated with exposure to the Lower Drinkwater River Corridor were used in the cumulative ELCR calculation.

8.3.7.2 Summary

The results for the receptor exposed to the Potential Greenway Area and adjacent water bodies (i.e., Upper and Lower Drinkwater Corridors) indicated the following:

- No significant carcinogenic or non-carcinogenic risks associated with exposure to the Potential Greenway Area soils;
- No significant carcinogenic or non-carcinogenic risks associated with exposure to the Upper Drinkwater River Corridor surface water and sediment; and
- No significant carcinogenic or non-carcinogenic risks associated with exposure to the Lower Drinkwater River Corridor surface water and sediment.

8.3.8 Eastern Channel Corridor

8.3.8.1 Trespasser

Section 8.3.1.4 presented the results of the human health risk characterization for the trespasser in the Upper North Area and the potential contributions to risk from exposure to the sediment and surface water in the Eastern Channel Corridor. Benzo(a)pyrene and mercury in the sediments were identified as the primary risk drivers for this receptor in this area due to dermal absorption.

8.3.8.2 Fisherman

The total cumulative ELCR and HI potentially associated with current/future exposure to the fisherman to surface water, sediment, and fish tissue from the Eastern Channel Corridor were calculated to be 1.21×10^{-4} and 7.67 (see Tables A-8-13 and A-8-14). Both the ELCR and the HI estimates are above their MADEP acceptable benchmarks of 1×10^{-5} and 1.0, respectively. Benzo(a)pyrene and dibenzo(a,h)anthracene are the primary contributors to the ELCR via dermal contact with sediment. Mercury, via dermal contact with sediment and ingestion of fish tissue, and methyl mercury via ingestion of fish tissue, are the primary contributors to the HI.

8.3.8.3 Summary

The results for the receptors exposed to the Eastern Channel Corridor indicated the following:

- No significant carcinogenic or non-carcinogenic risks associated with exposure to the Eastern Channel Corridor surface water;
- Significant carcinogenic and non-carcinogenic risks associated with exposure to the Eastern Channel Corridor sediment. Benzo(a)pyrene and mercury are the COCs contributing to the projected carcinogenic and non-carcinogenic risks for the trespasser in the Eastern Channel Corridor relative to projected exposures to sediment through dermal absorption. Benzo(a)pyrene, dibenzo(a,h)anthracene, and mercury are the COCs contributing to the projected carcinogenic and non-carcinogenic risks for the fisherman in the Eastern Channel Corridor relative to projected exposures to sediment through dermal absorption;
- No significant carcinogenic risks associated with exposure to the Eastern Channel Corridor fish tissue; and
- Significant non-carcinogenic risk associated with exposure to the Eastern Channel Corridor fish tissue. Mercury and methyl mercury are the COCs contributing to the projected non-carcinogenic risk for the fisherman in the Eastern Channel Corridor relative to projected exposures to fish tissue through ingestion.

8.3.9 Upper Drinkwater River Corridor

8.3.9.1 Construction Worker

Section 8.3.7.1 presented the results of the human health risk characterization for the construction worker in the Potential Greenway Area and the potential contributions to risk from exposure to the sediment and surface water in the Upper Drinkwater River Corridor. No COCs were indicated to be of concern relative to the construction worker in this area.

8.3.9.2 Trespasser

Section 8.3.1.4 presented the results of the human health risk characterization for the trespasser in the Upper North Area and the potential contributions to risk from exposure to the sediment and surface water in the Upper Drinkwater River Corridor. No COCs were indicated to be of concern relative to the trespasser in this area.

8.3.9.3 Fisherman

The total cumulative ELCR and HI potentially associated with current/future exposure to the fisherman to surface water and sediment from the Upper Drinkwater River Corridor were calculated to be 2.85×10^{-6} and 0.039 (see Tables A-8-13 and A-8-14). Both the ELCR and the HI estimates are below their MADEP acceptable benchmarks of 1×10^{-5} and 1.0, respectively.

8.3.9.4 Summary

The results for the receptors exposed to the Upper Drinkwater River Corridor indicated the following:

- No significant carcinogenic or non-carcinogenic risks associated with exposure to the Upper Drinkwater River Corridor surface water and sediment.

8.3.10 Lower Drinkwater River Corridor

8.3.10.1 Construction Worker

Section 8.3.7.1 presented the results of the human health risk characterization for the construction worker in the Potential Greenway Area and the potential contributions to risk from exposure to the sediment and surface water in the Lower Drinkwater River Corridor. No COCs were indicated to be of concern relative to the construction worker in this area.

8.3.10.2 Trespasser

Section 8.3.2.4 presented the results of the human health risk characterization for the trespasser in the Lower North Area and the potential contributions to risk from exposure to the sediment and surface water in the Lower Drinkwater River Corridor. No COCs were indicated to be of concern relative to the trespasser in this area.

8.3.10.3 Fisherman

The total cumulative ELCR and HI potentially associated with current/future exposure to the fisherman to surface water, sediment, and fish tissue from the Lower Drinkwater River Corridor were calculated to be 1.86×10^{-5} and 3.91 (see Tables A-8-13 and A-8-14). Both the ELCR and the HI estimates are slightly above their MADEP acceptable benchmarks of 1×10^{-5} and 1.0, respectively. Benzo(a)pyrene and vinyl chloride are the primary contributors to the ELCR via dermal contact with sediment. Mercury and methyl mercury, via ingestion of fish tissue, are the primary contributors to the HI.

8.3.10.4 Summary

The results for the receptors exposed to the Lower Drinkwater River Corridor indicated the following:

- No significant carcinogenic or non-carcinogenic risks associated with exposure to the Lower Drinkwater River Corridor surface water;
- No significant non-carcinogenic risks associated with exposure to the Lower Drinkwater River Corridor sediment;
- Significant carcinogenic risk associated with exposure to the Lower Drinkwater River Corridor sediment. Benzo(a)pyrene and vinyl chloride are the COCs contributing to the projected carcinogenic risk for the fisherman in the Lower Drinkwater River Corridor relative to projected exposures to sediment through dermal absorption;
- No significant carcinogenic risks associated with exposure to the Lower Drinkwater River Corridor fish tissue; and
- Significant non-carcinogenic risk associated with exposure to the Lower Drinkwater River Corridor fish tissue. Mercury and methyl mercury are the COCs contributing to the projected non-carcinogenic risk for the fisherman in the Lower Drinkwater River Corridor relative to projected exposures to fish tissue through ingestion.

8.3.11 Lily Pond/Upper Factory Pond

8.3.11.1 Fisherman

The total cumulative ELCR and HI potentially associated with current/future exposure to the fisherman to surface water, sediment, and fish tissue from Lily Pond/Upper Factory Pond were calculated to be 4.72 x 10^{-5} and 3.59 (see Tables A-8-13 and A-8-14). Both the ELCR and the HI estimates are slightly above their MADEP acceptable benchmarks of 1 x 10^{-5} and 1.0, respectively. Benzo(a)pyrene via dermal contact with sediment and arsenic via ingestion of fish tissue, are the primary contributors to the ELCR. It should be noted, however, that the arsenic concentration detected in the Lily Pond/Upper Factory Pond fish tissue sample was below the arsenic concentration detected in the Site background fish tissue sample. Therefore, based on this fish tissue background comparison, arsenic does not represent a site-related risk to human health. Mercury and methyl mercury, via ingestion of fish tissue, are the primary contributors to the HI.

8.3.11.2 Summary

The results for the fisherman exposed to Lily Pond/Upper Factory Pond indicated the following:

- No significant carcinogenic or non-carcinogenic risks associated with exposure to the Lily Pond/Upper Factory Pond surface water;
- No significant non-carcinogenic risks associated with exposure to the Lily Pond/Upper Factory Pond sediment;
- Significant carcinogenic risk associated with exposure to the Lily Pond/Upper Factory Pond sediment. Benzo(a)pyrene is the COC contributing to the projected carcinogenic risk for the fisherman in Lily Pond/Upper Factory Pond relative to projected exposures to sediment through dermal absorption;

- No significant carcinogenic risks associated with exposure to Lily Pond/Upper Factory Pond fish tissue; and
- Significant non-carcinogenic risk associated with exposure to Lily Pond/Upper Factory Pond fish tissue. Mercury and methyl mercury are the COCs contributing to the projected non-carcinogenic risks for the fisherman in Lily Pond/Upper Factory Pond relative to projected exposures to fish tissue through ingestion.

8.3.12 Middle/Lower Factory Pond

8.3.12.1 Fisherman

The total cumulative ELCR and HI potentially associated with current/future exposure to the fisherman to surface water, sediment, and fish tissue from Middle/Lower Factory Pond were calculated to be 4.56 x 10^{-5} and 2.66 (see Tables A-8-13 and A-8-14). Both the ELCR and the HI estimates are slightly above their MADEP acceptable benchmarks of 1 x 10^{-5} and 1.0, respectively. Benzo(a)pyrene via dermal contact with sediment and arsenic via ingestion of fish tissue, are the primary contributors to the ELCR. It should be noted, however, that the maximum benzo(a)pyrene concentration detected in the Middle/Lower Factory Pond sediment samples was below the maximum benzo(a)pyrene concentration detected in the Site background sediment samples. Also, the median benzo(a)pyrene concentration detected in the Middle/Lower Factory Pond sediment was only slightly greater than the benzo(a)pyrene concentration detected in the Site background sediment samples. It should also be noted that the arsenic concentration detected in the Middle/Lower Factory Pond fish tissue sample was below the arsenic concentration detected in the one Site background fish tissue sample. Therefore, based on these sediment and fish tissue background comparisons, benzo(a)pyrene and arsenic in sediment and fish tissue, respectively, do not represent a site-related risk to human health. Mercury and methyl mercury, via ingestion of fish tissue, are the primary contributors to the HI.

8.3.12.2 Summary

The results for the fisherman exposed to Middle/Lower Factory Pond indicated the following:

- No significant carcinogenic or non-carcinogenic risks associated with exposure to the Middle/Lower Factory Pond surface water and sediment;
- No significant carcinogenic risks associated with exposure to Middle/Lower Factory Pond fish tissue; and
- Significant non-carcinogenic risk associated with exposure to Middle/Lower Factory Pond fish tissue. Mercury and methyl mercury are the COCs contributing to the projected non-carcinogenic risks for the fisherman in Middle/Lower Factory Pond relative to projected exposures to fish tissue through ingestion.

8.3.13 Public Use Areas

The adult and child recreational users were assumed to be exposed to accessible (surficial) soil (0-3 feet bgs) in the Southern Conservation Commission Area, Cold Waste Area, Marsh Upland Area, Southern Disposal Area, and the Potential Greenway Area, and to surface water and sediment in the Upper and Lower Drinkwater River Corridors, Lily Pond/Upper Factory Pond, and Middle/Lower Factory Pond. Since, from a practical standpoint, these receptors are not likely to spend all of their time in one particular area or water body (given their limited size or lack of unique features), two different cumulative ELCRs and HIs were calculated. The first set was derived using a "worst case" exposure scenario where the highest projected ELCR or HI from each medium was identified and then these were summed together to reach a total cumulative "worst case" ELCR and HI for the recreational users. The second set was derived using a "weighted" exposure scenario. The accessible (surficial) soil (0-3 feet bgs) exposure weights were established as the ratio of the acreage of a particular Public Use Area to the total acreage of all five Public Use Areas (i.e., a surface area weighted exposure). The surface water and sediment exposure weights were based on contacting each different water body equally (i.e., since there are four surface water areas, each was assigned an exposure weight of 25% and since there are five sediment areas, each was assigned an exposure weight of 20%). Tables A-8-9 and A-8-12 present the exposure weights used for each risk characterization area. The following summarizes the "worst case" and "weighted" cumulative ELCRs and HIs for each recreational user.

8.3.13.1 Adult Recreational User

The "worst case" total cumulative ELCR and HI potentially associated with current/future exposure to the adult recreational user to accessible (surficial) soil (0-3 feet bgs) from the Southern Disposal Area (carcinogenic risk) or the Cold Waste Area (non-carcinogenic risk) and surface water and sediment from Lily Pond/Upper Factory Pond were calculated to be 6.52 x 10^{-5} and 1.62 (see Tables A-8-9 and A-8-10). Both the ELCR and the HI estimates for this "worst case" scenario are slightly above their MADEP acceptable benchmarks of 1 x 10^{-5} and 1.0, respectively. 1,1-Dichloroethene, via the inhalation of soil particulates in the Southern Disposal Area, is the primary contributor to the ELCR. Antimony via incidental ingestion and dermal contact with soil and, to a lesser extent, manganese and arsenic via the inhalation of soil particulates in the Cold Waste Area were the primary contributors to the HI. The results for antimony, manganese, and arsenic are not considered to represent a concern relative to human health exposure and risk. This is because antimony primarily targets the blood and cholesterol, manganese primarily targets the central nervous system, and arsenic primarily targets the skin. As such, these HI contributions should be considered separately. The chemical-specific HIs for antimony, manganese, and arsenic (0.81, 0.28, 0.22, respectively) do not exceed the MADEP acceptable benchmark of 1.0 individually and therefore, they are not indicated to pose a significant human health concern.

The "weighted" total cumulative ELCR and HI potentially associated with current/future exposure to the adult recreational user to accessible (surficial) soil (0-3 feet bgs), surface water, and sediment from the recreational areas stated above were calculated to be 6.60 x 10^{-6} and 0.13 (see Tables A-8-9 and A-8-10). Both the ELCR and the HI estimates for this "weighted" scenario are below their MADEP acceptable benchmarks of 1 x 10^{-5} and 1.0, respectively.

8.3.13.2 Child Recreational User

The "worst case" total cumulative ELCR and HI potentially associated with current/future exposure to the child recreational user to accessible (surficial) soil (0-3 feet bgs) from the Southern Disposal Area (carcinogenic risk) or the Cold Waste Area (non-carcinogenic risk) and surface water and sediment from Lily Pond/Upper Faetory Pond were calculated to be 3.51 x 10^{-5} and 12 (see Tables A-8-11 and A-8-12). Both the ELCR and the HI estimates for this "worst case" scenario are above their MADEP acceptable benchmarks of 1 x 10^{-5} and 1.0, respectively. 1,1-Dichloroethene via the inhalation of soil particulates in the Southern Disposal Area is the primary contributor to the ELCR. Antimony via the incidental ingestion and dermal absorption of soil, lead via the incidental ingestion of soil, and barium via the inhalation of soil particulates in the Cold Waste Area are the primary contributors to the HI. An evaluation of the target organ-specific HIs indicated that the MADEP benchmark of 1.0 was exceeded relative to effects on the central nervous system, fetus, and blood in the soils of the Southern Disposal Area.

The "weighted" total cumulative ELCR and HI potentially associated with current/future exposure to the child recreational user to accessible (surficial) soil (0-3 feet bgs), surface water, and sediment from the recreational areas stated above were calculated to be 4.87 x 10^{-6} and 1.12 (see Tables A-8-11 and A-8-12). This "weighted" ELCR estimate is below the MADEP benchmark of 1 x 10^{-5} while the HI estimate is slightly above the MADEP acceptable benchmark of 1.0. Manganese via the inhalation of soil particulates from the Southern Conservation Commission Area, mercury via the incidental ingestion of soil in the Marsh Upland Area and the incidental ingestion and dermal contact with sediment in Lily Pond/Upper Factory Pond and the Lower Drinkwater River Corridor, and lead via the incidental ingestion of soil in the Southern Disposal Area are the primary contributors to this "weighted" HI. Although all of these COCs target the central nervous system, when their "weighted" HIs are added together, they do not exceed the MADEP benchmark of 1.0. Therefore, these calculated HI results are not indicated to pose a significant human health concern.

8.3.13.3 Adult Fisherman

Sections 8.3.10.3, 8.3.11.1, and 8.3.12.1 presented the results of the human health risk characterization for the adult fisherman from exposure to fish tissue from the Lower Drinkwater River Corridor, Lily Pond/Upper Factory Pond, and Middle/Lower Factory Pond, respectively. Mercury and methyl mercury, via ingestion of fish tissue, were identified as the primary risk drivers for this receptor in all of these areas. As was previously noted, it is possible (but not considered likely) that a recreational user might choose to fish in the impacted water bodies despite the posted fishing ban (in addition to talking part in their other recreational activities). As the ingestion of the locally caught fish at the rate assumed for the adult fisherman was shown all alone to create a risk that exceeded target levels, assuming that any of the recreational receptors also consumed locally caught fish at this same rate would indicate unacceptable total receptor risks for them.

8.3.13.4 Summary

The results for the recreational user receptors exposed to the Public Use Areas in the "worst case" exposure scenario indicated the following:

- Significant carcinogenic and non-carcinogenic risk associated with exposure to the Public Use Area soil. 1,1-Dichloroethene is the COC contributing to the projected carcinogenic risk for the adult and child recreational users in the Southern Disposal Area relative to projected exposures to soil through the inhalation of soil particulates. Since the total ELCR for this area was conservatively calculated with Class C carcinogens and 1,1-dichlorethene is a Class C carcinogen, it will be determined at a later date if it will be focused on in the Phase III investigation. Antimony, via the incidental ingestion and dermal absorption of soil, lead via the incidental ingestion of soil, and barium via the inhalation of soil particulates are the COCs contributing to the projected non-carcinogenic risk for the child recreational user in the Cold Waste Area.
- No significant carcinogenic or non-carcinogenic risks associated with exposure to the aquatic Public Use Areas surface water or sediment.

The results for the recreational user receptors exposed to the Public Use Areas in the "weighted" exposure scenario indicated the following:

- No significant non-carcinogenic or carcinogenic risks associated with exposure to the Public Use Area soils, surface water, or sediment.

The results for the fisherman exposed to the Lower Drinkwater River Corridor, Lily Pond/Upper Factory Pond, and Middle/Lower Factory Pond indicated the following:

- Significant non-carcinogenic risk associated with exposure to Lily Lower Drinkwater River Corridor, Lily Pond/Upper Factory Pond, and Middle/Lower Factory Pond fish tissue. Mercury and methyl mercury are the COCs contributing to the projected non-carcinogenic risks for the fisherman in these areas due to projected exposures to fish tissue through ingestion.

8.3.14 Flood Plain Area

The Flood Plain Area, the land on the western and southern shores of Lily Pond/Upper Factory Pond and Middle/Lower Factory Pond, was not identified as a risk characterization area for purposes of this risk characterization. No former Fireworks facility operations were ever performed in this area, which is now on the edge of some residential properties. Fluctuations in the water level caused by storms and purposeful water level management create the opportunity for sediments to potentially be deposited on the near shore of the pond in these areas. A small number of surficial soil samples were collected near the nominal water line to determine if any upstream sediment contamination appears to have been deposited in this area (see Table A-4-15 for this data summary). A full quantitative evaluation of the potential risks associated with the Flood Plain Area soil was not performed. However, the results for the two samples collected in this area were screened against risk-based MADEP Method 1 standards (i.e., S-1/GW-2, S-1/GW-3, S-2/GW-2, and S-2/GW-3). Given the limited accessibility and overgrown nature of this area, the frequency and duration of exposure to soil in this area would be significantly less than is associated with the residential scenario that forms the basis of the S-1 soil standards or the commercial scenario that forms the basis of the S-2 soil standards. As such, this comparison provides a very conservative screening of the observed constituent levels relative to actual, infrequent, incidental exposure.

All chemicals were below their respective standards except for beryllium. The highest measured beryllium concentration in the Flood Plain Area was 1.30 mg/kg, 54% greater than the most stringent Method 1 Standard (i.e., S-1). Beryllium was chosen as a COC in the soil in other parts of the Site (i.e., Lower North Area, Central Commercial Area, Southern Conservation Commission Area, and the Cold Waste Area), but was not a driver of risk in those areas. Beryllium was also chosen as a COC in the Lily Pond/Upper Factory Pond sediment, which abuts the Flood Plain Area, but was not a driver of risk. Therefore, beryllium in the Flood Plain Area is not indicated to pose a significant harm to human health. Due to the overgrown nature of this area, receptors have limited access and any exposure to these receptors would be low.

8.4 Applicable or Suitably Analogous Standards

MADEP also requires that a characterization of risk of harm to human health include a comparison of the EPCs to applicable or suitably analogous public health standards (MADEP, 1996). These standards include, but are not limited to:

- Massachusetts Drinking Water Quality Standards (310 CMR 22.00)
- Massachusetts Air Quality Standards (310 CMR 6.00)
- Massachusetts Surface Water Quality Standards (314 CMR 4.00)

For this Site, the Massachusetts Drinking Water Quality Standards are not applicable because the groundwater beneath the Site is not categorized as GW-1. The Massachusetts Air Quality Standards, which consist of air standards for sulfur oxides, particulate matter, carbon monoxide, ozone and lead, do not have a bearing on the Risk Characterization. These standards would be considered as part of any future investigation or response activities with the potential to impact the quality of the ambient air (most likely relative to particulate matter). The Massachusetts Surface Water Standards consist of water standards applicable for three inland water classes. The parameters limited by the Surface Water Standards are dissolved oxygen, temperature, pH, fecal coliform bacteria, solids, color and turbidity, oil and grease, and taste and odor. At this Site, the Drinkwater River is classified as Class B. Class B is designated as a habitat for fish, other aquatic life, and wildlife, and for primary and secondary contact recreation and should be suitable for irrigation and other agricultural uses and for compatible industrial cooling and process uses. Also, where designated, Class B water bodies should be suitable as a source of public water supply with appropriate treatment. As such, these standards would be considered as part of any future investigation or response activities with the potential to impact the quality of the surface water. In addition, the Massachusetts Surface Water Quality Standards (which include USEPA Ambient Water Quality Criteria) were used as part of the Stage I Environmental Screening.

8.5 Conclusions

Based on the above cumulative receptor carcinogenic and non-carcinogenic risks and the applicable or suitably analogous standards, a condition of "No Significant Risk" to harm for human health does not exist for all areas of the Site. Table A-8-15 depicts a summary of the human health risk characterization and where the condition of "Significant Risk" exists.

9.0 UNCERTAINTY ANALYSIS

Risk characterizations are subject to a number of uncertainties. As a result, risk estimates derived from the equations and assumptions in this risk characterization should not be interpreted as absolute estimates of the risks of harm to human health posed by potential exposures to COCs detected at the Site. The level of uncertainty associated with the human health risk characterization associated with this Site is relatively lower than typically seen as a result of the planning and coordination activities conducted during the problem formulation and throughout the assessment. The following paragraphs address the primary uncertainties and their implications relative to this risk characterization.

Qualified Data Sets

The analytical data used in this human health risk characterization included estimated concentrations ("J", "E", "Z", "Y", "P", and "B" (organic and inorganic compounds) qualified) and diluted concentrations ("D" qualified). All of these qualified data were used in the calculation of EPCs for all media assessed (MADEP, 1996). The data that were qualified as "J", "E", "Y", "P", "Z", "B" (for organic and inorganic compounds), and "D" do not systematically lead to an over- or under-estimation of risk.

Background

Site-specific background locations were identified and their concentrations used in this risk characterization. Uncertainty in the range of background concentrations in each media is due to the limited amount of background samples collected in each media. This was a result of a lack of additional locations that would represent places that were not impacted by the Site or its neighbors.

Cold Waste Area Data Set

Due to the limited amount of data collected and the high concentrations of COCs in the Cold Waste Area, an over-estimation of risk may exist for the adult and child recreational users in the Cold Waste Area.

Soil Data Collected Deeper than Six Feet Below Ground Surface in Certain Areas

The soils addressed in this assessment were the accessible (surficial) soil (0-3 feet bgs) and upper potentially accessible soil (0-6 feet bgs). In addition, two of the characterization areas (the Lower North Area and the Central Commercial Area) did have three and nine samples, respectively, collected from 6-15 feet bgs. The three VOCs detected in the Lower North Area were all below their respective MCP Method 1 S-2/GW-2 and S-2/GW-3 standards. Three VOCs, 22 SVOCs, and 21 metals were detected in the Central Commercial Area soils from 6-15 feet bgs. All detected chemicals were below their respective MCP Method 1 S-2/GW-2 and S-2/GW-3 standards except for four PAHs. Benzo(a)anthracene (4 mg/kg), Benzo(a)pyrene (3 mg/kg), Benzo(b)fluoranthene (2.9 mg/kg), and Indeno(1,2,3-cd)pyrene (1.4 mg/kg) were only slightly over their respective standards of 1.0, 0.7, 1.0, and 1.0. Given these comparisons, contamination does not exist at the site in the 6-15 foot depth range. Inclusion of the sampling results from these depths into the various EPCs would have diluted the data and resulted in lower, less representative EPCs for the depth ranges of practical importance to the identified receptors. Therefore, the calculations of risk performed for this risk characterization relative to soil is not underestimated and no AUL would be required to prevent excavation into the 6-15 feet bgs depth interval.

EPCs

For this risk characterization, EPCs were calculated based on an average concentration within each exposure point (risk characterization area). The use of the average concentration in these areas was believed to lead to a best estimate of the associated risks.

Exposure Assessment

The risk characterization addressed potential exposures by the identified receptors to OHM originating at the Site under current and reasonably foreseeable future uses. Other potential sources of OHM to other possible receptors that may be exposed to environmental media or natural resources outside these characterization boundaries were not assessed. The exposure assessment focuses on the evaluation of non-carcinogenic and carcinogenic effects for an individual who is maximally exposed to the COC. Generally, conservative exposure assumptions were used for exposure frequency and the duration of exposure. These conservative assumptions can potentially over-estimate and result in compounding conservatism in the estimates of risk.

Intermedia Transfer of Contaminants

The analysis of potential risks due to volatile COCs in the soil (accessible (surficial) and upper potentially accessible soil) considered the potential inhalation of VOCs emitted into the outdoor air as a vapor (characterized by $[OHM]_{air}$) and as part of a soil particulate (characterized by [RP]air). Consideration of both forms of release is appropriate for COCs with any appreciable volatility (i.e., exposure to metals is typically associated only with particulate inhalation). Consideration and inclusion of both possible mechanisms of release for the volatile and semivolatile organic COCs is therefore unlikely to under-estimate EPCs in the outdoor air.

Assessment of the Potential Vapor Intrusion Pathway

This risk characterization included an evaluation of the diffusion and migration of VOC contamination in the groundwater into the indoor area. This quantitative evaluation was performed using conservative assumptions to account for variability in conditions and characteristics of the area. The predicted indoor air concentrations may provide an over-estimation of the projected risk for this pathway.

Dose-Response Assessment

In the dose-response assessment, many factors can lead to the over-estimation or under-estimation of dose-response data for human receptors. These factors include:

- The use of dose-response information from effects observed at high doses to predict the adverse health effects that may occur following exposure to the low levels expected from human contact with the COCs in the environment;
- The use of dose-response information from short-term exposure studies to predict the effects of long-term exposures, and vice-versa;
- The use of dose-response information from animal studies to predict adverse health effects in humans;
- The use of dose-response information from homogeneous animal populations to healthy human populations to predict the adverse health effects likely to be observed in the general population, consisting of individuals with a wide range of sensitivities;

- The use of oral RfDs and oral CSFs as surrogate toxicity values for the dermal route of exposure;
- The use of surrogate values for those compounds without assigned values for RfDs and RfCs (i.e., chromium, mercury, thallium, endrin aldehyde, and endrin ketone);
- The assumption that a COC exerts the same toxic effect regardless of the route of exposure; and
- The application of an RAF of 1 for a COC without an assigned RAF. This assumes that the entire amount of the compound inhaled, ingested, or in contact with the skin is absorbed (i.e., 100 percent absorption) and available to exert its toxic action.

In addition, no dose-response data was found for 4-isopropyltoluene, methyl iodide, 1,2,3-trichlorobenzene, 4-nitrophenol, PETN, or picric acid. These COCs would be expected to contribute to a relatively small under-estimation of risk.

Risk Quantification

Potential health effects caused by simultaneous exposure to multiple on-site COCs were assumed to be additive in nature. Uncertainties associated with summing cancer risks or HIs for multiple substances are of particular concern in the risk characterization step. Assuming dose additivity ignores possible synergism or antagonism among chemicals and assumes similarity in mechanisms of action. These assumptions tend to over-estimate the carcinogenic risk or potential non-carcinogenic health effects at a site.

Also, including the contributions of Class C carcinogens in the carcinogenic risk calculations is not indicated by MADEP (MADEP, 1996). The ELCRs for Class C carcinogens were conservatively calculated in this human health risk characterization and therefore the ELCR calculations may be slightly over-estimated. Since 1,1-dichlorethene is a Class C carcinogen and was determined to drive risks in some risk characterization areas, it will be determined at a later date if it will be focused on in the Phase III investigation.

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Attachment 1
Toxicity Profiles

Acetone[1]

Acetone is a clear, colorless, highly flammable liquid. It is completely miscible in water and soluble in organics such as benzene and ethanol. Acetone is used primarily as a solvent and chemical intermediate, and it is also found in some consumer products such as nail polish remover. Acetone may be released into the environment as stack emissions and/or fugitive emissions and in wastewater effluents from facilities involved in its production and use as a chemical intermediate and solvent. Acetone is also a natural metabolic byproduct found in and released from plants and animals. Much of the acetone released into the environment will volatilize into the atmosphere where it will be subject to photo-oxidation (average half-life is 22 days). Volatilization from surface waters is moderately rapid (estimated half-life about 20 hours from a model river). If released onto the ground, acetone will both volatilize and leach into the soil and relatively little will be adsorbed to soil particles. Acetone has been detected in groundwater and drinking water.

Acetone can be absorbed through the lungs, digestive tract, and the skin. Dermal uptake may occur following prolonged contact with the undiluted liquid. Information on gastrointestinal absorption rates was not found in the available literature. It is rapidly transported throughout the body and is not preferentially stored in any body tissue. The liver is the major organ of acetone metabolism, and excretion occurs mainly through the lungs and in the urine. Acute toxic effects following ingestion of 50 mL or more may include ataxia, sedation, and coma; respiratory depression; gastrointestinal disorders (vomiting and hematemesis); hyperglycemia and ketonemia; acidosis; and hepatic and renal lesions. Typical symptoms of inhalation exposure are central nervous system depression and irritation of the mucous membranes of the eyes, nose, and throat. Central nervous system effects can range from subtle neurobehavioral changes to narcosis depending on the magnitude and length of exposure. The available data indicate that individuals occupationally exposed to acetone may exhibit transient symptoms of toxicity; however, there is little evidence of permanent systemic damage even after many years of exposure.

No evidence is available that suggests acetone is carcinogenic in humans. Acetone is classified by EPA in weight-of-evidence Group D, not classifiable as to human carcinogenicity.

Benzene[1]

Benzene is widely used in the United States; it ranks in the top 20 chemicals for production volume. Benzene is a colorless organic liquid with a sweet odor. It evaporates into the air very quickly and dissolves slightly in water. It is highly flammable and is formed from both natural processes and human activities. Benzene. Benzene is used primarily in the production of other chemicals such as ethylbenzene, cumene, and cyclohexane. Benzene has also been used as a solvent, but this use is declining, coincidental with the replacement of benzene with other organic solvents. Benzene is emitted into the workplace and the environment from industrial and other manmade sources, including gasoline from filling stations, smoking tobacco products, and auto exhaust.

Because of benzene's high vapor pressure, inhalation is the most likely route of exposure to the chemical, particularly in the workplace. Benzene is absorbed via ingestion, inhalation, and skin application. Experimental data indicate that humans can absorb up to 80% of inhaled benzene (after 5 minutes of exposure). Lethal oral doses of benzene are estimated to be 10 mL in humans. Nonlethal oral doses of benzene can impact the nervous, hematological, and immunological systems. Ingested and inhaled benzene produces symptoms of neurotoxicity at acute doses of 2 mL for humans. Inhalation of benzene vapor concentrations of 20,000 ppm for 5-10 minutes can be fatal to humans; death results from central nervous system depression.

Benzene is carcinogenic in humans by inhalation and in animals by the oral route of exposure. Occupational exposure to benzene has been associated mainly with increased incidences of acute myeloblastic or erythroblastic leukemias and chronic myeloid and lymphoid leukemias among workers. Studies in animals have demonstrated an association between oral and inhalation exposure to benzene and the development of a variety of tumors, including lymphoma and carcinomas of the Zymbal gland, oral cavity, mammary gland, ovaries, lung, and skin. Benzene has been placed in the EPA weight-of-evidence classification A, human carcinogen.

Bromoform[1]

Bromoform, also referred to as tribromomethane, is a halogenated aliphatic hydrocarbon. Bromoform is a colorless, heavy liquid with an odor and taste similar to chloroform. It is sparingly soluble in water but is soluble in ethanol, ethyl ether, benzene, solvent naphtha, and fixed and volatile oils. It is produced commercially from chloroform. Bromoform is used as an intermediate in organic synthesis; in gauge fluids; as a solvent for waxes, greases, and oils; as an ingredient in fire-resistant chemicals; and as a heavy-dense liquid in separating mixtures of chemicals. In addition, it has been used formerly in pharmaceuticals as a sedative and antitussive. romoform is formed as a byproduct during water chlorination when chlorine reacts with endogenous organic materials and bromide ions.

In humans, accidental ingestion of bromoform has led to listlessness, headache, and vertigo and at higher doses to central nervous system depression, coma, and death. The estimated lethal dose for a 10- to 20-kg child is 250 to 500 mg/kg. Exposure to bromoform vapor has caused irritation of the respiratory tract, pharynx, and larynx, as well as lacrimation and salivation. In animals, the liver, kidneys, and central nervous system are the primary target organs for bromoform toxicity. The principal cause of death following acute oral exposure is central nervous system depression.

The epidemiological evidence for an association between ingestion of chlorinated drinking water containing bromoform and increased cancer risk is inadequate. One long-term oral study and a lung tumor assay provide evidence of carcinogenicity for bromoform in animals. An increased incidence of intestinal tumors was seen in female rats, and an increased incidence of lung tumors was seen in male mice administered intraperitoneal injections of bromoform. Based on EPA guidelines, bromoform was assigned to weight-of-evidence group B2, probable human carcinogen.

Bromomethane[2]

Bromomethane (also called methyl bromide) is a colorless gas without much smell. The primary use of bromomethane is as a soil or space fumigant for the control of insects, fungi, and rodents. Bromomethane is also used as a methylating agent in various chemical reactions, and as a solvent to extract oils from nuts, seeds, and wool. Bromomethane was also used in fire extinguishers in Europe from the 1920s through the 1940s, but never gained widespread use as a fire extinguishing agent in the United States. Bromomethane is usually stored in sealed containers to keep it from evaporating. If leaking containers of bromomethane are put in a waste site, most of the bromomethane will probably escape into the air. Small amounts might leak into the soil or pass through the soil and dissolve in underground water. Bromomethane breaks down in the environment to other chemicals. In air, it usually takes about 11 months for half the bromomethane that was released to disappear. In underground water, it usually takes about 1 month for half the bromomethane to break down.

Human exposure to bromomethane is most likely to occur by inhalation or dermal contact. Inhalation exposure may cause neurological, respiratory and renal damage. Dermal contact may cause skin lesions while oral exposure leads to digestive tract mucosal membrane irritation.

The carcinogenic potential of bromomethane has not been formally investigated in epidemiological studies of occupationally-exposed workers. The incidence of cancer in a cohort of workers exposed to a wide variety of brominated chemicals noted that two men died of testicular cancer and both had been exposed to bromomethane. However, since there are numerous risk factors for testicular cancer, and since the workers may have been exposed to other chemicals, this observation is not sufficient to indicate that bromomethane is carcinogenic. No evidence of carcinogenic effects was detected in mice or rats exposed to bromomethane. EPA considers that the data currently available are inadequate to evaluate the carcinogenic potential of bromomethane, and has assigned this chemical to Group D (not classifiable as to human carcinogenicity).

2-Butanone[2]

2-Butanone, also known as methyl ethyl ketone (MEK), is a colorless liquid with a sweet, but sharp odor. 2-Butanone exhibits outstanding solvent properties, and combined with its low cost, it is often the choice solvent for various coating systems. Examples of specific applications include its use as a solvent for nitrocellulose, lacquers, rubber cement, printing inks, paint removers, vinyl films, resins, rosins, polystyrene, chlorinated rubber, polyurethane, acrylic coatings, and cleaning solutions. 2-Butanone is used in the production of synthetic leathers, transparent paper, and aluminum foil. It is also used in the degreasing of metals, as an extraction solvent, in dewaxing applications, and as a solvent for the production of smokeless powders. 2-Butanone is also a natural product made by some trees and is found in some fruits and vegetables.

The main health effects that have been seen in humans who breathed higher concentrations of 2-butanone are mild irritation of the nose, throat, eyes, and skin. Serious health effects in animals have been seen only at very high concentrations of 2-butanone. Studies in animals have shown that 2-butanone does not cause serious damage to the nervous system or the liver, but mice that breathed low levels for a short time had temporary behavioral effects. 2-Butanone alone does not have serious effects on the liver or nervous system, but it can cause other chemicals to become more harmful to these systems. Guinea pigs, rats, and mice that breathed high levels of 2-butanone for a short time became unconscious and died. Pregnant rats and mice that breathed air containing high levels of 2-butanone had underdeveloped fetuses. Rats that swallowed very high concentrations of 2-butanone in water also developed signs of nervous system effects such as inactivity, drooping eye lids, and uncoordinated muscle movement. Some rats and mice that swallowed water containing high concentrations of 2-butanone died. Rats that received water containing a lower concentration of 2-butanone had mild kidney damage. Skin irritation developed in rabbits and guinea pigs that had small amounts of 2-butanone dropped on their skin. It is not known whether 2-butanone causes birth defects or affects reproduction in humans. Reproductive effects were not seen in animals exposed to 2-butanone. No information is available relative to 2-butanone causing cancer in humans or animals.

Carbon Disulfide[2]

Pure carbon disulfide is a colorless liquid with a pleasant odor that smells sweet. The impure carbon disulfide that is usually used in most industrial processes, however, is a yellowish liquid with an unpleasant odor like that of rotting radishes. Carbon disulfide evaporates at room temperature, and the vapor is more than twice as heavy as air. It easily explodes in air and also catches fire very easily. Carbon disulfide has been an important industrial chemical since the 1800s because of its many useful properties, including its ability to solubilize fats, rubbers, phosphorus, sulfur, and other elements. Carbon disulfide's fat solvent properties also made it indispensable in preparing fats, lacquers, and camphor; in refining petroleum jelly and paraffin; and in extracting oil from bones, palmstones, olives, and rags. In all of these extraction processes, however, carbon disulfide has been replaced by other solvents.

Its fat, rubber, and metal solvent properties have made carbon disulfide highly suitable for a variety of other continuing industrial applications including the following: vulcanization and manufacture of rubber and rubber accessories; production of resins, xanthates, thiocyanates, plywood adhesives, and flotation agents; solvent and spinning-solution applications primarily in the manufacture of rayon; polymerization inhibition of vinyl chloride; conversion and processing of hydrocarbons; petroleumwell cleaning; brightening of precious metals in electroplating; thin film deposition of nickel; as an agent to increase corrosion and wear-resistance in metals; rust removal from metals; and removal and recovery of metals and other elements from waste water and other media. It has also been used in industry as a development restrainer in photography and lithography and as a solvent to remove printing on recycled plastics. In the food industry, carbon disulfide has been used to protect fresh fruit from insects and fungus during shipping, in adhesives for food packaging, and in the solvent extraction of growth inhibitors. In agriculture, carbon disulfide has been widely used as a fumigant to control insects in stored grain, normally when mixed with carbon tetrachloride to reduce the fire hazard. Use of carbon disulfide as a grain fumigant was voluntarily cancelled after 1985.

The systemic toxicity of carbon disulfide is manifested primarily as cardiovascular, hepatic, and ocular effects in both humans and animals following inhalation exposure. At very high levels (10,000 parts of carbon disulfide per million parts [ppm] of air), carbon disulfide may be life threatening because of its effects on the nervous system. Studies in animals show that high levels of carbon disulfide can damage the heart. Some workers who breathed more than 20 ppm during working hours for at least 6 months had headaches, tiredness, and trouble sleeping. Studies in animals indicate that carbon disulfide can affect the normal functions of the brain, liver, and heart. After pregnant rats breathed 225 ppm carbon disulfide in the air, some of the newborn rats died or had birth defects. There is no information on health effects in people who eat food or drink water contaminated with carbon disulfide. Animals fed food that contained carbon disulfide developed liver and heart disease, and some showed abnormal behavior. These amounts, however, were very much higher than those that occur in drinking water supplies. When pregnant animals received large doses of carbon disulfide in their diet, some of the newborns died or had birth defects. Skin contact with spilt carbon disulfide can lead to burns at the contact site.

There are no definitive data in humans or animals that indicate a carcinogenic potential for carbon disulfide. In the absence of positive genotoxic data, increased cancer risk does not appear to be an effect of exposure to carbon disulfide.

Carbon Tetrachloride[1]

Carbon tetrachloride is a clear liquid with a sweet smell that can be detected at low levels. It is a manufactured organic compound that does not occur naturally; trade names include Benzinoform, Freon 10, Halon 104, Tetraform, or Tetrasol. Carbon tetrachloride is most often found as a colorless gas. It's not flammable and doesn't dissolve in water very easily. It was used in the production of refrigeration fluid and propellants for aerosol cans, as a pesticide, as a cleaning fluid and degreasing agent, in fire extinguishers, and in spot removers. Because of its harmful effects, these uses are now banned and it is only used in some industrial applications. It can form explosive, impact-sensitive mixtures with particulates of metals including aluminum, barium, beryllium, potassium, lithium, sodium and zinc. Carbon tetrachloride also forms explosive mixtures with chlorine trifluoride, calcium hypochlorite, calcium disilicide, triethyldialuminum trichloride, decaborane and dinitrogen tetraoxide. It will react violently with fluorine, boranes, allyl alcohol and other related chemicals.

High exposure to carbon tetrachloride by oral, inhalation, or dermal routes can cause liver, kidney, and central nervous system damage. The liver is especially sensitive to carbon tetrachloride because it swells and cells are damaged or destroyed. Kidneys are also damaged, causing a buildup of wastes in the blood. If exposure is low and then stops, the liver and kidneys can repair the damaged cells and function normally again. If exposure is very high, the nervous system, including the brain, is affected. Humans may feel intoxicated and experience headaches, dizziness, sleepiness, and nausea and vomiting. These effects may subside if exposure is stopped, but in severe cases, coma and even death can occur. Although an inhalation exposure of about 1000 ppm for a few minutes to hours will cause the narcotic effects in 100% of the population, large variations in sensitivity are seen. Alcohol intake greatly increases human sensitivity to carbon tetrachloride; consequently, exposure to 250 ppm for 15 minutes can be life threatening to an alcoholic. Subchronic and chronic exposure to doses as low as 10 ppm can result in liver and kidney damage.

Although data for the carcinogenicity of carbon tetrachloride in humans are inconclusive, there is ample evidence in animals that the chemical can cause liver cancer. Hepatocellular carcinomas have been induced in hamsters, rats and mice after oral carbon tetrachloride treatment for 16 to 76 weeks. Liver tumors have also been demonstrated in rats following inhalation exposure, but the doses were not quantitatively established. The EPA weight-of-evidence classification for both oral and inhalation exposure is B2, probable human carcinogen based on adequate animal evidence.

<u>Chloroethane[2]</u>

Chloroethane, also called ethyl chloride, is a colorless gas at room temperature and pressure, with a characteristically sharp odor. In pressurized containers, chloroethane exists as a liquid. However, the liquid evaporates quickly when exposed to air. It catches fire easily and is very dangerous when exposed to heat or flame. In the past, the largest single use for chloroethane was for the production of tetraethyl lead, which is a gasoline additive. However, production of chloroethane has decreased dramatically as a result of stricter government regulations controlling lead in gasoline. Other applications include use in the production of ethyl cellulose, dyes, medicinal drugs, and other commercial chemicals, and use as a solvent and refrigerant. It is used to numb skin prior to medical procedures such as ear piercing and skin biopsies, and it is used in the treatment of sports injuries.

Brief exposure to high levels of chloroethane vapor can produce temporary feelings of drunkenness, and at still higher levels, lack of muscle coordination and unconsciousness. Adults have felt dizzy and have suffered decreased reaction times as a result of inhaling chloroethane. They have also experienced stomach cramps, nausea, vomiting, and eye irritation after breathing high concentrations of chloroethane for a short time. Long term abuse of high chloroethane concentrations causes the most adverse effects of chloroethane exposure, namely, those to the nervous system. Abusers have had severe symptoms including jerking eye movements, an inability to control muscles in voluntary movements, difficulty in speaking clearly, an inability to perform finger tapping exercises, sluggish lower limb reflexes, seizures, difficulties in walking, disorientation, short-term memory loss, and hallucinations affecting their sight and hearing. Human patients have died after breathing chloroethane concentrations high enough to induce anesthesia. Dogs have suffered irregular heart rhythms, followed by death, when given anesthetic doses of chloroethane. Due to the risk of accidental death, chloroethane is no longer medically used as a general anesthetic during major surgery. Chloroethane can, however, be applied to the skin in the form of chloroethane spray as a numbing agent prior to minor surgery. If this spray is applied for too long, frostbite can result.

It is not known whether chloroethane produces cancer in humans. However, long-term exposure to high levels of chloroethane vapor has been shown to produce cancer in mice. There have been no animal or human studies involving the ability of chloroethane to cause cancer when either eaten or applied to the skin. The International Agency for Research on Cancer (IARC) has reviewed the information available concerning the ability of chloroethane to cause cancer. They concluded that chloroethane is not classifiable as to its carcinogenicity in humans.

Chloromethane[2]

Chloromethane (also known as methyl chloride) is a clear, colorless gas. It has a faint, sweet odor that is noticeable only at levels which may be toxic. It is heavier than air and is extremely flammable. Chloromethane is produced in industry, but it also occurs naturally, and most of the chloromethane that is released to the environment (estimated at up to 99%) comes from natural sources. In the past, chloromethane was widely used as a refrigerant, but refrigerators no longer use chloromethane because of its toxic effects. It was also used as a foam-blowing agent and as a pesticide or fumigant. Today, nearly all commercially produced chloromethane is used to make other substances, mainly silicones (72% of the total chloromethane used). Other products that are made from reactions involving chloromethane include agricultural chemicals, methyl cellulose, quaternary amines, and butyl rubber. Chloromethane is completely used up so that by the end of the process there is no or little chloromethane left to be released, disposed of, or reused. It is, however, found as a pollutant in municipal waste streams from treatment plants and industrial waste streams as a result of formation or incomplete removal. There are also some manufacturing processes for vinyl chloride that result in chloromethane as an impurity in the vinyl chloride end product.

If the levels are high enough (over a million times the natural levels in outside air), even brief exposures to chloromethane can have serious effects on the nervous system, including convulsions, coma, and death. Some people have died from breathing chloromethane that leaked from refrigerators in rooms that had little or no ventilation. Others who were exposed to high levels of chloromethane while they were repairing refrigerators did not die, but they did have toxic effects like staggering, blurred or double vision, dizziness, fatigue, personality changes, confusion, tremors, uncoordinated movements, nausea, or vomiting. These symptoms can last for several months or years. Complete recovery has occurred in some cases, but not in others. Exposure to chloromethane can also harm your liver and kidney, or have an effect on your heart rate and blood pressure. Harmful liver, kidney, and nervous system effects have developed after animals breathed air containing high levels of chloromethane (one million times higher than natural levels). Some of these animals died from exposure to high levels of chloromethane. Similar effects were seen in animals that breathed low levels continuously and animals that breathed high levels for shorter periods with some breaks from exposure. Animals that breathed relatively low test levels of chloromethane (but still one hundred thousand to one million times higher than background levels people are exposed to) over a long period (weeks to months) had slower growth and developed brain damage. Some male animals were less fertile or even sterile or produced sperm that were damaged. Females that became pregnant by the exposed males lost their developing young.

Male mice that breathed air containing chloromethane (one million ppb) for 2 years developed tumors in their kidneys, but female mice and male and female rats did not develop tumors. It is not known whether chloromethane can cause sterility, miscarriages, birth defects, or cancer in humans. The Department of Health and Human Services (DHHS) has not classified chloromethane for carcinogenic effects. IARC calls chloromethane a Group 3 compound, which means it cannot be determined whether or not it is a carcinogen because there is not enough human or animal data. The Environmental Protection Agency (EPA) considers chloromethane possibly carcinogenic to humans (i.e., Group C) based on limited evidence of carcinogenicity in animals

Chloroform[1]

Chloroform is an organic, colorless liquid with a pleasant, nonirritating odor and a slightly sweet taste. It will burn only when it reaches very high temperatures. In the past, chloroform was used as an inhaled anesthetic during surgery, but the Food and Drug Administration banned the use of chloroform as an ingredient in human drug and cosmetic products in July 1976. Today, chloroform is used to make other chemicals and can also be formed in small amounts when chlorine is added to water. Chloroform is widely used as an intermediate in the production of refrigerants, plastics, and pharmaceuticals, and as a general solvent or constituent of solvent mixtures.

Chloroform is rapidly absorbed from the lungs and the digestive tract, and to some extent through the skin. Breathing about 900 parts of chloroform per million parts air (900 ppm) for a short time can cause dizziness, fatigue, and headache. Breathing air, eating food, or drinking water containing high levels of chloroform for long periods of time may damage your liver and kidneys. Large amounts of chloroform can cause sores when chloroform touches your skin. Animal studies have shown that miscarriages occurred in rats and mice that breathed air containing 30 to 300 ppm chloroform during pregnancy and also in rats that ate chloroform during pregnancy. Offspring of rats and mice that breathed chloroform during pregnancy had birth defects. Abnormal sperm were found in mice that breathed air containing 400 ppm chloroform for a few days.

Epidemiological studies indicate a possible relationship between exposure to chloroform present in chlorinated drinking water and cancer of the bladder, large intestine, and rectum. Based on U.S. EPA guidelines, chloroform was assigned to weight-of-evidence Group B2, probable human carcinogen. Rats and mice that ate food or drank water with chloroform developed cancer of the liver and kidneys.

1,1-Dichloroethane[1]

1,1-Dichloroethane is a colorless, oily liquid with a sweet odor that does not occur naturally in the environment. It evaporates easily at room temperature and burns easily. In the past, 1,1-dichloroethane was used as a surgical anesthetic. Today, however, it is used primarily to make other chemicals; to dissolve substances such as paint, varnish, and finish removers; and to remove grease.

Very limited information is available on the effects of 1,1-dichloroethane on human health. The available evidence indicates that 1,1-dichloroethane can be readily absorbed following inhalation and oral exposures. The chemical was discontinued as a surgical anesthetic when effects on the heart, such as irregular heart beats, were reported. Studies in animals have shown that 1,1-dichloroethane can cause kidney disease after long-term exposure to high levels in air.

1,1-Dichloroethane is placed in Group C, possible human carcinogen. There is no human data and limited evidence of carcinogenicity in two animal species (rats and mice) as shown by an increased incidence of mammary gland adenocarcinomas and hemangiosarcomas in female rats and an increased incidence of hepatocellular carcinomas and benign uterine polyps in mice.

cis-1.2-Dichloroethene and trans-1,2-Dichloroethene[1]

1,2-Dichloroethylene, also called 1,2-dichloroethene, is a highly flammable, colorless liquid with a sharp, harsh odor. It is used to produce solvents and in chemical mixtures. Very small amounts of 1,2-dichloroethylene may be smelled in air (about 17 ppm). There are two forms of 1,2-dichloroethylene: cis-1,2-dichloroethylene and trans-1,2-dichloroethylene. Sometimes both forms are present as a mixture. Commercial use is not extensive, but trans-1,2-dichloroethylene and mixtures of cis- and trans-1,2-dichloroethylene have been used as intermediates in the production of other chlorinated solvents and compounds, as well as low temperature extraction solvents for dyes, perfumes, and lacquers. Additionally, cis- and trans -1,2-dichloroethylene react violently with potassium hydroxide, sodium, and sodium hydroxide and form shock-sensitive explosives when combined with dinitrogen tetraoxide.

Humans are exposed to 1,2-dichloroethylene primarily by inhalation, but exposure can also occur by oral and dermal routes. Breathing high levels of 1,2-dichloroethylene can cause nauseous, drowsiness, and tiredness in humans; very high levels can cause death. Breathing high levels of trans-1,2-dichloroethylene caused liver and lung damage in animals, and the effects were more severe with longer exposure times. Animals that breathed very high levels of trans-1,2-dichloroethylene had damaged hearts. Animals that ingested extremely high doses of cis- or trans-1,2-dichloroethylene died. Lower doses of cis-1,2-dichloroethylene caused effects on the blood, such as decreased numbers of red blood cells and also effects on the liver.

No cancer bioassays or epidemiological studies were available to assess the carcinogenicity of 1,2-dichloroethylene. EPA has placed cis-1,2-dichloro-ethene in weight-of-evidence group D, not classifiable as to human carcinogenicity, based on the lack of or negative human or animal cancer data. Trans-1,2-dichloroethylene has not undergone a complete evaluation and determination under US EPA's IRIS program for evidence of human carcinogenic potential.

1,1-Dichloroethene[1]

1,1-Dichloroethylene is an industrial chemical that is not found naturally in the environment. It is a colorless liquid with a mild, sweet smell. Also called 1,1-dichloroethene. 1,1-Dichloroethylene is used primarily in the production of polyvinylidine chloride (PVC) copolymers and as an intermediate for synthesis of organic chemicals. 1,1-Dichloroethylene is also used to make certain plastics, such as flexible films like food wrap; used in packaging materials; used to make flame retardant coatings for fiber and carpet backings; and used in piping, coating for steel pipes, and adhesive applications.

The main effect from breathing high levels (approximately 4000 ppm) of 1,1-dichloroethylene is on the central nervous system. Breathing high levels of the chemical may cause loss of breath and fainting. Breathing lower levels of 1,1-dichloroethylene in air for a long time may damage the nervous system, liver, and lungs. Workers exposed to 1,1-dichloroethylene have reported a loss in liver function, but other chemicals were present. Animals that breathed high levels of 1,1-dichloroethylene had damaged livers, kidneys, and lungs. Animals that ingested high levels of 1,1-dichloroethylene had damaged livers, kidneys, and lungs. Spilling 1,1-dichloroethylene on skin or in eyes can cause irritation.

Studies on workers who breathed 1,1-dichloroethylene have not shown an increase in cancer. These studies, however, are not conclusive because of the small numbers of workers and the short time studied. Animal studies have shown mixed results. Several studies reported an increase in tumors in rats and mice, and other studies reported no such effects. In one inhalation study, statistically significant increases in renal adenocarcinomas were noted in male Swiss mice exposed to 25 ppm for 12 months. Also observed were statistically significant increases in mammary gland carcinomas in females and lung tumors in both sexes. Based on EPA guidelines, 1,1-dichloroethylene was assigned to weight-of-evidence group C, possible human carcinogen.

Ethylbenzene[1]

Ethylbenzene is a colorless, flammable liquid that smells like gasoline. It is found in natural products such as coal tar and petroleum and in manufactured products such as inks, insecticides, and paints. Ethylbenzene is used primarily to make another chemical, styrene. Additionally, it may be used as a solvent, in aviation fuels, and to make other chemicals. The general public can be exposed to ethylbenzene in ambient air as a result of releases from vehicle exhaust and cigarette smoke.

Ethylbenzene can be absorbed through the lungs, digestive tract, and skin. Limited information is available on the health effects of ethylbenzene on humans. The available information shows dizziness, throat and eye irritation, tightening of the chest, and a burning sensation in the eyes of humans exposed to high levels of ethylbenzene in air. Animal studies have shown effects on the nervous system, liver, kidneys, and eyes from breathing ethylbenzene in air. Ingestion of sublethal amounts of ethylbenzene is likely to cause central nervous system (CNS) depression, oro-pharyngeal and gastric discomfort, and vomiting. Animal studies indicate that the primary target organs following chronic oral exposures are likely to be the liver and kidney.

No human studies of oral or inhalation exposure to ethylbenzene have resulted in cancer. Two available animal studies suggest that ethylbenzene may cause tumors. Ethylbenzene is placed by EPA in Group D, not classifiable as to human carcinogenicity, based on a lack of data in humans and animals.

2-Hexanone[2]

2-hexanone, also known as methyl n-butyl ketone or MBK, is a clear, colorless liquid with a somewhat sharp odor. The liquid form can easily evaporate into the air as a vapor. 2-hexanone is not currently manufactured, processed, or used for commercial purposes in the United States. 2-hexanone had been used as a solvent for many materials, primarily in the lacquer industry as a solvent for lacquers and varnish removers. It had also been used as a solvent for ink thinners, resins, oils, fats, and waxes and as an intermediate in the synthesis of organic chemicals. It is also a waste product of wood pulping, coal gasification, and oil shale operations.

The most important health concern for humans from exposure to 2-hexanone is its harmful effects on the nervous system. The major effects are weakness, numbness, and tingling in the skin of the hands and feet. Similar effects were seen in animals that ate or breathed high levels of 2-hexanone; these effects included weakness, clumsiness, and paralysis.

It is not known whether 2-hexanone can cause cancer or birth defects. In one study, when pregnant rats were exposed to 2-hexanone in the air, fewer offspring lived after birth, and those that did survive had low birth weights.

4-Methyl-2-Pentanone[1]

Methyl isobutyl ketone (MIBK), also known as 4-methyl-2-pentanone, is a clear liquid with a characteristic ketone odor. It is widely used as a solvent for synthetic resinous paints; lacquers; varnishes; adhesives; rubber cements; and DDT. As an extractant, it is used in dewaxing mineral oils, refining tall oil, and cleaning metals. MIBK is released to the environment in effluents and emissions from its manufacturing and use facilities, in automotive exhaust gases, and from disposal of consumer products containing MIBK.

MIBK is readily absorbed following inhalation and, by analogy to other ketones, is expected to be absorbed through the skin. Targets for MIBK toxicity appear to be the central nervous system, digestive tract, liver, kidneys, fetus, and mucous membranes. At high concentrations, MIBK is a central nervous system depressant, inducing ataxia, narcosis, and death in experimental animals. Human exposure to lower concentrations has resulted in central nervous system effects such as headache, weakness, vertigo, insomnia, and somnolence. Digestive effects include nausea, vomiting, loss of appetite, heart burn, and intestinal pain.

No studies were available to evaluate the carcinogenicity of MIBK. Furthermore, EPA has not assigned a weight-of-evidence classification for carcinogenicity.

Methylene Chloride[1]

Methylene chloride, also known as also known as dichloromethane, is a colorless organic liquid with a penetrating ether-like odor that does not occur naturally in the environment. Methylene chloride is used as a solvent in paint removers, degreasing agents, and aerosol propellants; as a polyurethane foam-blowing agent; as a process solvent in the pharmaceutical industry; and as an extraction solvent for spice oleoresins, hops, and caffeine.

Methylene chloride is readily absorbed from the lungs, the digestive tract, and to some extent through the skin. Breathing large amounts of methylene chloride may cause unsteadiness, dizziness, nausea, and a tingling or numbness of fingers and toes. Breathing smaller amounts of methylene chloride may decrease attention and accuracy in tasks requiring hand-eye coordination. Skin contact with methylene chloride causes burning and redness of the skin.

The primary adverse health effects associated with methylene chloride exposure are central nervous system (CNS) depression and mild liver effects. Neurological symptoms described in individuals occupationally exposed to methylene chloride included headaches, dizziness, nausea, memory loss, paresthesia, tingling hands and feet, and loss of consciousness. Major effects following acute inhalation exposure include fatigue, irritability, analgesia, narcosis, and death.

It is not known whether methylene chloride causes cancer in humans. Studies of workers exposed to methylene chloride have not recorded a significant increase in cancer cases above the number of cases expected for nonexposed workers; however, an increased cancer risk was seen in mice breathing large amounts of methylene chloride for a long time. Tumors were found in lungs and liver of exposed mice. Rats showed increases of benign mammary tumors. Based on inadequate evidence of carcinogenicity in humans and sufficient evidence in animals, U.S. EPA has placed methylene chloride in weight-of-evidence group B2, probable human carcinogen.

Methyl-t-butyl Ether[2]

MTBE is the common name for a synthetic chemical called methyl tert-butyl ether. It is a flammable liquid made from combinations of chemicals like isobutylene and methanol. It has a distinctive odor that most people find disagreeable. It was first introduced as an additive for unleaded gasolines in the 1980s to enhance octane ratings. MTBE is also used in small quantities as a laboratory reagent to extract semi-volatile organic compounds from such sample types as leachates or solid wastes. MTBE is also a pharmaceutical agent, which can be used as an alternative to surgery in dissolving gallstones when injected intraductally.

Some people who were exposed to MTBE while pumping gasoline, driving their cars, or working as attendants or mechanics at gas stations complained of headaches, nausea, dizziness, irritation of the nose or throat, and feelings of spaciness or confusion. These symptoms were reported when high levels of MTBE were added to gasoline in order to lower the amount of carbon monoxide, a known poison, released from cars. MTBE has a very unpleasant odor that most people can smell before any harmful effects would occur, but some people might feel irritation of the nose or throat before noticing the smell. MTBE caused side effects in some patients who were given MTBE to dissolve gallstones. The MTBE is given to these patients through special tubes that are placed into their gallbladders. If MTBE leaks from the gallbladder into other areas of the body, the patient can have minor liver damage, a lowering of the amount of white blood cells, nausea, vomiting, sleepiness, dizziness, and confusion. MTBE also caused irritation to the noses and throats of animals that breathed MTBE. The most common effect of MTBE in animals is on their nervous systems. Breathing MTBE at high levels can cause animals to act as if they are drunk. For example, some became less active, staggered, fell down, were unable to get up, and had partially closed eyelids. These effects lasted only for about an hour, and then the animals seemed normal again. Some animals that breathed high levels of MTBE for several hours a day for several weeks gained less weight than normal, probably because they ate less food while they were inactive.

When rats breathed high levels of MTBE for several hours every day for two years, some got more serious kidney disease than these rats usually get as they grow old. Some of the male rats developed cancer in the kidney, but whether this has meaning for people is not known. When mice breathed high levels of MTBE for several hours every day for a year and a half, some had larger livers than normal, and some mice developed tumors in the liver. When rats were given high levels of MTBE by mouth for 2 years, some male rats developed cancer in the testes and some female rats developed cancer of the blood (leukemia) and cancer (lymphoma) of some of the tissues that produce blood cells. The DHSS, IARC, and the EPA have not classified MTBE for its ability to cause cancer.

Tetrachloroethene[1]

Tetrachloroethylene is a manufactured organic chemical that is widely used for dry cleaning of fabrics and for metal-degreasing. It is also used to make other chemicals and is used in some consumer products. Other names for tetrachloroethylene include perchloroethylene, PCE, and tetrachloroethene. It is a nonflammable liquid at room temperature that evaporates easily into the air and has a sharp, sweet odor.

Tetrachloroethylene is rapidly absorbed by the lungs and the digestive tract, but not through the skin. High concentrations of tetrachloroethylene in the air can cause dizziness, headache, sleepiness, confusion, nausea, difficulty in speaking and walking, unconsciousness, and death. Acute exposure to high concentrations of the chemical (estimated to be greater than 1500 ppm for a 30-minute exposure) may be fatal to humans. Irritation may result from repeated or extended skin contact with Tetrachloroethylene. These symptoms occur almost entirely in work (or hobby) environments due to accidental exposure to high concentrations or intention use of tetrachloroethylene to get a "high". In industry, most workers are exposed to levels lower than those causing obvious nervous system effects. The health effects of breathing air or drinking water with low levels of tetrachloroethylene are not known. Results from some studies suggest that women who work in dry cleaning industries where exposures to tetrachloroethylene can be quite high may have more menstrual problems and spontaneous abortions than women who are not exposed. It is not known, however, if tetrachloroethylene was responsible for these problems because other possible causes were not considered. Results of animal studies, conducted with amounts much higher than those that most humans are exposed to, show that tetrachloroethylene can cause liver and kidney damage.

Epidemiology studies of dry cleaning and laundry workers have demonstrated excesses in mortality due to various types of cancer, including liver cancer, but the data are regarded as inconclusive because of various confounding factors. The tenuous finding of an excess of liver tumors in humans is strengthened by the results of carcinogenicity bioassays, in which tetrachloroethylene, administered either orally or by inhalation, induced hepatocellular tumors in mice. The chemical also induced mononuclear cell leukemia and renal tubular cell tumors in rats. Although U.S. EPA's Science Advisory Board recommended a weight-of-evidence classification of C-B2 continuum (C = possible human carcinogen; B2 = probable human carcinogen), the agency has not adopted a current position on the weight-of-evidence classification. The Department of Health and Human Services (DHHS) has determined that tetrachloroethylene may reasonably be anticipated to be a carcinogen.

Toluene[1]

Toluene is a colorless organic liquid with a sweet pungent odor. Toluene is isolated by distillation of reformed or pyrolized petroleum and coal tar; however, most of the toluene produced remains as a benzene-toluene-xylene (BTX) mixture for use in gasoline. The primary use of isolated toluene is in the production of benzene and for backblending into gasoline to increase octane ratings. Toluene is also used as raw material in the production of benzyl chloride, benzoic acid, phenol, cresols, vinyl toluene, and TNT; as a solvent for paints and coatings; and in adhesives, inks, and pharmaceuticals.

In humans and animals, the primary effect associated with inhalation exposure to toluene is central nervous system (CNS) depression. Short-term exposure of humans to 100-1500 ppm has elicited CNS effects such as fatigue, confusion, incoordination, and impairments in reaction time, perception, motor control and function. Exposure to concentrations ranging from 10,000-30,000 ppm has resulted in narcosis and deaths. Equivocal evidence shows that exposure to toluene in utero causes an increased risk of CNS abnormalities and developmental delay in humans.

No studies on human exposure to toluene and carcinogenicity are available. An increased incidence of hemolymphoreticular neoplasms was reported in rats exposed to 500 mg/kg of toluene by gavage for 2 years; however, results from two long-term inhalation studies indicate that toluene is not carcinogenic at concentrations up to 1200 ppm. Based on U.S.

Environmental Protection Agency (EPA) guidelines, toluene was assigned to weight-of-evidence group D, not classifiable as to human carcinogenicity.

1,1,1-Trichloroethane[1]

1,1,1-Trichloroethane is a colorless liquid with a sharp, sweet odor that does not occur naturally in the environment. Even though it is usually found as a liquid, it evaporates quickly and becomes a vapor. 1,1,1-Trichloroethane is found in many common products such as glue, paint, industrial degreasers, and aerosol sprays. 1,1,1-trichloroethane will no longer be made in the United States due to its effects on the ozone layer.
Breathing air containing high levels of 1,1,1-trichloroethane for a short time may cause dizziness, light-headedness, and loss of balance. These symptoms disappear if fresh air is inhaled. Breathing much higher levels may cause unconsciousness, low blood pressure, and loss of heartbeat. The effects of breathing 1,1,1-trichloroethane for a long time are not known. In animals, such as rats and dogs, exposure to high levels damages the breathing passages, affects the nervous system, and causes mild effects on the liver. After pregnant rats or rabbits were exposed to 1,1,1-trichloroethane, effects on the offspring, such as delayed development and changes in the setting of the bone structure, were usually only seen at levels that were toxic to the mother. It is not known whether this chemical affects human reproduction or development. There are no human studies to determine whether harmful health effects occur from eating food or drinking water contaminated with 1,1,1-trichloroethane. Placing large amounts in an animal's stomach has caused effects on the nervous system, mild liver damage, unconsciousness, and even death. If skin comes into contact with 1,1,1-trichloroethane, some irritation may occur. Studies in animals have shown that skin contact may affect the liver and very large amounts may cause death.

No information is available to show that 1,1,1-trichloroethane causes cancer. Oral bioassays were inconclusive and inhalation studies were negative. No epidemiological data for 1,1,1-trichloroethane and inadequate carcinogenicity data for animals place the chemical in the United States Environmental Protection Agency's weight-of-evidence group D, not classifiable as to human carcinogenicity.

1,1,2-Trichloroethane[1]

1,1,2-Trichloroethane is a halogenated aliphatic hydrocarbon. 1,1,2-Trichloroethane is a nonflammable liquid with a pleasant odor that is insoluble in water and miscible with alcohol, ether, and many other organic liquids. 1,1,2-Trichloroethane is used in the manufacture of 1,1-dichloroethene; as a solvent for fats, waxes, natural resins, and alkaloids; and in organic synthesis. Small amounts of 1,1,2-trichloroethane are formed during the water chlorination process.

Very limited human data were available to evaluate the toxicity of 1,1,2-trichloroethane. 1,1,2-Trichloroethane is rapidly absorbed by the body. The chemical exerts a narcotic action at "low" concentrations and is irritating to the eyes and mucous membranes of the respiratory tract. When in contact with skin, 1,1,2-trichloroethane may cause cracking and erythema. No information is available on how breathing or swallowing 1,1,2-

trichloroethane may affect human health. Applying 1,1,2-trichloroethane to the skin of a person resulted in stinging and burning of the skin. When animals breathed high levels of 1,1,2-trichloroethane, it affected the liver and kidneys. Nervous system effects, such as excitation and sleepiness, were also seen. When animals swallowed food or water containing 1,1,2-trichloroethane, effects on the stomach, blood, liver, kidneys, and nervous system were seen.

No epidemiologic studies or case reports addressing the carcinogenicity of 1,1,2-trichloroethane in humans were available. In a rodent bioassay, 1,1,2-trichloroethane was administered by gavage to rats and mice. No effects on tumor development were noted in rats. Treated mice had significantly increased incidences of hepatocellular carcinomas. An increased incidence of adrenal pheochromocytomas was also observed in male and female mice. In a cancer initiation/promotion study with rats, 1,1,2-trichloroethane did not exhibit tumor initiating or promoting activity. Based on EPA guidelines, 1,1,2-trichloroethane was assigned to weight-of-evidence group C, possible human carcinogen.

Trichloroethene[1]

Trichloroethene (TCE), also known as trichlorothylene, is a colorless, highly volatile liquid that is miscible with water and a number of organic solvents. TCE is a man-made chemical and is not known to occur naturally. It is mainly used as a solvent in industrial degreasing and cleaning of metals, but it is also used as a solvent for waxes, fats, resins, oils, and in numerous other applications. Prior to 1977, TCE had been used as an anesthetic, grain fumigant, disinfectant, and extractant of spice oleoresins in food and of caffeine in the production of decaffeinated coffee. The evaluation of the toxicity of TCE is complicated by the presence or absence of other chemicals. Industrial grade TCE usually contains stabilizers that are known to be toxic such as triethylamine, triethanolamine, epichlorohydrin, or stearates. In the absence of stabilizers, TCE readily decomposes. These decomposition products are also toxic.

Human and animal data indicate that exposure to TCE can result in toxic effects on a number of organs and systems, including the liver, kidney, blood, skin, immune system, reproductive system, nervous system, and cardiovascular system. Breathing small amounts of TCE may cause headaches, lung irritation, dizziness, poor coordination, and difficulty concentrating. Breathing large amounts of TCE may cause impaired heart function, unconsciousness, and death. Breathing it for long periods may cause nerve, kidney, and liver damage. Drinking large amounts of TCE may cause nausea, liver damage, unconsciousness, impaired heart function, or death. Drinking small amounts of TCE for long periods may cause liver and kidney damage, impaired immune system function, and impaired fetal development in pregnant women, although the extent of some of these effects is not yet clear. Skin contact with TCE for short periods may cause skin rashes.

Epidemiologic studies have been inadequate to determine if a correlation exists between exposure to TCE and increased cancer risk in humans. Some human studies with exposure over long periods to high levels of TCE in drinking water or in workplace air have found evidence of increased cancer; however, these results are inconclusive because the cancer could have been caused by other chemicals. Some studies with mice and rats have suggested that high levels of TCE may cause liver or lung cancer. Although U.S. EPA's Science Advisory Board recommended a weight-of-evidence classification of C-B2 continuum (C = possible human carcinogen; B2 = probable human carcinogen), the agency has not adopted a current position on the weight-of-evidence classification. In an earlier evaluation, TCE was assigned to weight-of-evidence Group B2, probable human carcinogen. The International Agency for Research on Cancer (IARC) has determined that TCE is not classifiable as to human carcinogenicity.

Vinyl Chloride[1]

Vinyl chloride (VC), also known as chloroethene, is a halogenated aliphatic hydrocarbon. It is a colorless gas with a mild sweetish odor that is slightly soluble in water and soluble in hydrocarbons, oil, alcohol, chlorinated solvents, and most common organic liquids. VC is produced by thermal cracking of ethylene chloride and does not occur naturally. It is used primarily as an intermediate in the manufacture of polyvinyl chloride (PVC); limited quantities are used as a refrigerant and as an intermediate in the production of chlorinated compounds. It is a biodegradation product of trichloroethylene, tetrachloroethylene, and 1,1,1-trichloroethane. VC may leach into groundwater from spills, landfills, and industrial sources.

VC is rapidly absorbed from the digestive tract and lungs. Breathing high levels of VC can cause dizziness or sleepiness. Breathing very high levels can cause passing out, and breathing extremely high levels can cause death. Humans exposed to VC in air for long periods of time can develop changes to the structure of their livers. Workers exposed to VC have developed nerve damage and immune reactions. Other workers have developed problems with the blood flow in their hands: the tips of their fingers turn white and hurt when they are in cold temperatures. Sometimes, the bones in the tips of their fingers have broken down. The effects of drinking high levels of VC are unknown. If VC is spilled on skin, numbness, redness, and blisters may occur. Animal studies have shown that long-term (365 days or longer) exposure to VC can damage the sperm and testes. It has not been proven that VC causes birth defects in humans, but animal studies have shown that breathing VC can harm unborn offspring and may also cause increases in early miscarriages.

Studies show that VC causes liver cancer in humans. On the basis of sufficient evidence for carcinogenicity in human epidemiology studies, VC is considered to best fit the weight-of-evidence Category "A," according to current EPA Risk Assessment Guidelines. Agents classified into this category are considered known human carcinogens. This classification is supported by positive evidence for carcinogenicity in animal bioassays including several species and strains, and strong evidence for genotoxicity.

Xylene[1]

Xylene is a colorless, sweet-smelling liquid that catches on fire easily. Xylene is a volatile organic solvent widely used in chemical synthesis, consumer products, and agricultural chemicals. Xylene occurs naturally in petroleum and coal tar and is formed during forest fires; it is found in small amounts in airplane fuel and gasoline. Xylene, which is produced from petroleum, is one of the top 30 chemicals produced in the United States in terms of volume. Xylene is used as a solvent, a cleaning agent, a thinner for paint, in paints and varnishes, and in the printing, rubber, and leather industries.

Human exposure to xylene by either oral or inhalation routes can cause death due to respiratory failure accompanied by pulmonary congestion. High levels from exposure for short periods (14 days or less) or long periods (more than 1 year) can cause headaches, lack of muscle coordination, dizziness, confusion, and changes in balance. Exposure of humans to high levels of xylene for short periods can also cause irritation of the skin, eyes, nose, and throat; difficulty in breathing; problems with the lungs; delayed reaction time; memory difficulties; stomach discomfort; and possibly changes in the liver and kidneys. Studies of unborn animals indicate that high concentrations of xylene may cause increased numbers of deaths and delayed growth and development. In many instances, these same concentrations also cause damage to the mothers. It is not known whether xylene harms the unborn child if the mother is exposed to low levels of xylene during pregnancy.

Human and animal studies have not shown xylene to be carcinogenic, but these studies are lacking in information and are therefore not conclusive. EPA has placed xylene in weight-of-evidence group D, not classifiable as to human carcinogenicity. No significant increase in tumor incidence was observed in rats or mice of both sexes following oral administration of technical grade xylene.

Polycylic Aromatic Hydrocarbons (PAHs)[2]

PAHs are a group of chemicals that are formed during the incomplete burning of coal, oil, gas, wood, garbage, or other organic substances, such as tobacco and charbroiled meat. There are more than 100 different PAHs. PAHs generally occur as complex mixtures (for example, as part of combustion products such as soot), not as single compounds. PAHs usually occur naturally, but they can be manufactured as individual compounds for research purposes; however, not as the mixtures found in combustion products. As pure chemicals, PAHs generally exist as colorless, white, or pale yellow-green solids. They can have a faint, pleasant odor. A few PAHs are used in medicines and to make dyes, plastics, and pesticides. Others are contained in asphalt used in road construction. They can also be found in substances such as crude oil, coal, coal tar pitch, creosote, and roofing tar.

There is no known use for acenaphthylene, benz[a]anthracene, benzo[b]fluoranthene, benzo[k]fluoranthene, benzo[g,h,i]perylene, benzo[a]pyrene, chrysene, dibenz[a,h]anthracene, indeno[1,2,3-c,d]pyrene, or pyrene except as research chemicals.

Anthracene is used as an intermediate in dye production, in the manufacture of synthetic fibers, and as a diluent for wood preservatives. It is also used in smoke screens, as scintillation counter crystals, and in organic semiconductor research. Anthracene is also used to synthesize the chemotherapeutic agent, Amsacrine. Acenaphthene is used as a dye intermediate, in the manufacture of pharmaceuticals and plastics, and as an insecticide and fungicide. Fluorene is used as a chemical intermediate in many chemical processes, in the formation of polyradicals for resins, and in the manufacture of dyestuffs. Phenanthrene is used in the manufacture of dyestuffs and explosives and in biological research. Fluoranthene is used as a lining material to protect the interior of steel and ductile-iron drinking water pipes and storage tanks.

Mice fed high levels of benzo[a]pyrene during pregnancy had difficulty reproducing and so did their offspring. The offspring of pregnant mice fed benzo[a]pyrene also showed other harmful effects, such as birth defects and decreased body weight. Similar effects could occur in people, but we have no information to show that these effects do occur. Studies in animals have also shown that PAHs can cause harmful effects on skin, body fluids, and the body's system for fighting disease after both short- and long-term exposure. These effects have not been reported in people.

Several of the PAHs, including benz[a]anthracene, benzo[a]pyrene, benzo[b]fluoranthene, benzo[k]fluoranthene, chrysene, dibenz[a,h]anthracene, and indeno[1,2,3-c,d]pyrene, have caused tumors in laboratory animals when they breathed these substances in the air, when they ate them, or when they had long periods of skin contact with them. Studies of people show that individuals exposed by breathing or skin contact for long periods to mixtures that contain PAHs and other compounds can also develop cancer. The DHHS has determined that benz[a]anthracene, benzo[b]fluoranthene, benzo[k]fluoranthene, benzo[a]pyrene, dibenz[a,h]anthracene, and indeno[1,2,3-c,d]pyrene are known animal carcinogens. IARC has determined the following: benz[a]anthracene and benzo[a]pyrene are probably carcinogenic to humans; benzo[b]fluoranthene, benzo[k]fluoranthene, and indeno[1,2,3-c,d]pyrene are possibly carcinogenic to humans; and anthracene, benzo[g,h,i]perylene, chrysene, fluoranthene, fluorene, phenanthrene, and pyrene are not classifiable as to their carcinogenicity to humans. EPA has determined that benz[a]anthracene, benzo[a]pyrene, benzo[b]fluoranthene, benzo[k]fluoranthene, chrysene, dibenz[a,h]anthracene, and indeno[1,2,3-c,d]pyrene are probable human carcinogens and that acenaphthylene, anthracene, benzo[g,h,i]perylene, fluoranthene, fluorene, phenanthrene, and pyrene are not classifiable as to human carcinogenicity. Acenaphthene has not been classified for carcinogenic effects by the DHHS, IARC, or EPA.

Bis(2-ethylhexyl)phthalate[2]

DEHP, which is an abbreviation for di(2-ethylhexyl) phthalate, is a manufactured chemical that is commonly added to plastics to make them flexible. Other names for this compound are dioctyl phthalate (DOP) and bis(2-ethylhexyl) phthalate (BEHP). Trade names used for DEHP include Platinol DOP, Octoil, Silicol 150, Bisoflex 81, and Eviplast 80. DEHP is a colorless liquid with almost no odor. It does not evaporate easily, and little will be present in the air even near sources of production. It dissolves more easily in materials such as gasoline, paint removers, and oils than it does in water. It is present in many plastics, especially vinyl materials, which may contain up to 40% DEHP, although lower levels are common. DEHP is present in plastic products such as wall coverings, tablecloths, floor tiles, furniture upholstery, shower curtains, garden hoses, swimming pool liners, rainwear, baby pants, dolls, some toys, shoes, automobile upholstery and tops, packaging film and sheets, sheathing for wire and cable, medical tubing, and blood storage bags.

DEHP, at the levels found in the environment, is not expected to cause adverse health effects in humans. Most of what is known about the health effects of DEHP comes from studies of rats and mice that were given DEHP in their food, or the DEHP was placed in their stomach with the aid of a tube through their mouth. Rats and mice appear to be particularly sensitive to some of the effects of DEHP. Studies of long-term exposures in rats and mice have shown that high oral doses of DEHP caused health effects mainly in the liver and testes. These effects were induced by levels of DEHP that are much higher than those received by humans from environmental exposures. Toxicity of DEHP in other tissues is less well characterized, although effects in the thyroid, ovaries, kidneys, and blood have been reported in a few animal studies. The potential for kidney effects is a particular concern for humans because this organ is exposed to DEHP during dialysis and because structural and functional kidney changes have been observed in some exposed rats.

No studies have evaluated the potential for DEHP to cause cancer in humans. Eating high doses of DEHP for a long time resulted in liver cancer in rats and mice. The DHHS has determined that DEHP may reasonably be anticipated to be a human carcinogen. EPA has determined that DEHP is a probable human carcinogen. These determinations were based entirely on liver cancer in rats and mice. IARC has recently changed its classification for DEHP from "possibly carcinogenic to humans" to "cannot be classified as to its carcinogenicity to humans," because of the differences in how the livers of humans and primates respond to DEHP as compared with the livers of rats and mice.

Dichlorobenzenes[2]

Each of the three types of DCBs (i.e., 1,2-DCB, 1,3-DCB, and 1,4-DCB) contains two chlorine atoms connected to one benzene molecule. 1,2-DCB is a colorless to pale yellow liquid used to make herbicides. 1,3-DCB is a colorless liquid used to make herbicides, insecticides, medicine, and dyes. 1,4-DCB, the most important of the three chemicals, is a colorless to white solid. It smells like mothballs and it is one of two chemicals commonly used to make mothballs. 1,4-DCB also is used to make deodorant blocks used in garbage cans and restrooms, and to help control odors in animal-holding facilities. 1,4-DCB has been used as an insecticide on fruit and as an agent to control mold and mildew growth on tobacco seeds, leather, and some fabrics. Recently, using 1,4-DCB to make resins has become very important.

Most of the information on health effects of DCBs is from studies of 1,2- and 1,4-DCB. Very little is known about the health effects of 1,3-DCB, especially in humans, but they are likely to be similar to those of the other DCBs. Inhaling the vapor or dusts of 1,2-DCB and 1,4-DCB at very high concentrations could be very irritating to eyes and nose and cause burning and tearing of the eyes, coughing, difficult breathing, and an upset stomach. Some people reported health problems, such as dizziness, headaches, and liver problems, from very high levels of 1,4-DCB in the home. However, these people used very high amounts of 1,4-DCB products and continued to use the products for months or even years, even though they felt ill. People who ate 1,4-DCB products regularly for long periods (months to years) because of its sweet taste developed skin blotches and problems with red blood cells, such as anemia (iron-poor blood).

Breathing or eating any of the DCBs caused harmful effects in the liver of laboratory animals. Animal studies also found that 1,2-DCB and 1,4-DCB caused effects in the kidneys and blood, and that 1,3-DCB caused thyroid and pituitary effects. There is no clear evidence that 1,2-DCB and 1,4-DCB impair reproduction or fetal development in animals at levels below those that also cause serious health effects in the mother, although there is an indication that 1,4-DCB can affect development of the nervous system after birth.

Lifetime exposure to 1,4-DCB by breathing or eating induced liver cancer in mice. 1,2-DCB was not carcinogenic in laboratory animals, and 1,3-DCB has not been tested for its potential to cause cancer. The animal studies suggest that 1,4-DCB could play a role in the development of cancer in humans, but that is not definitely known. The DHHS has determined that 1,4-DCB might be a human carcinogen and IARC determined that 1,4-DCB is possibly carcinogenic to humans. Both IARC and the EPA concluded that 1,2-DCB and 1,3-DCB are not classifiable as to human carcinogenicity.

Diethyl Phthalate[2, 3]

Diethyl phthalate is a man-made colorless liquid with a slight aromatic odor and a bitter, disagreeable taste. Trade names include neantine, peilatinol A, and solvanol. Diethyl phthalate is manufactured for many uses. It is commonly used to make plastics more flexible. These plastics are found in products such as toothbrushes, automobile parts, tools, toys, and food packaging. Diethyl phthalate is also used in cosmetics, insecticides, and aspirin.

Diethyl phthalate has caused death in animals given very high doses by mouth, but brief oral exposures to lower doses caused no harmful effects. One effect found in animals that ate high doses of diethyl phthalate for long periods of time was a decrease in weight gain.

Diethyl phthalate is not known to cause cancer in humans or animals. Unlike other phthalates such as di(2-ethylhexyl) phthalate, diethyl phthalate does not appear to affect the ability of male animals to father babies. However, a decrease occurred in the number of live babies born to female animals that were exposed to diethyl phthalate throughout their lives. Some birth defects occurred in newborn rats whose mothers received high doses (approximately 3 g/kg) of diethyl phthalate by injection during pregnancy. EPA classifies diethyl phthalate as Class D, not classifiable as a human carcinogen.

Di-n-butyl phthalate[2,3]

Di-*n*-butyl phthalate is an odorless and colorless or faintly yellow oily liquid that does not occur in nature. It has a slightly ester smell and a strong, bitter taste. It has moderately low solubility in water, but is quite soluble in organic solvents such as alcohol, ether, benzene, and acetone. It is a chemical that is added to hard plastics to make them soft. The plastics that di-*n*-butyl phthalate is used most in are called polyvinyl chloride plastics and nitrocellulose lacquers. These plastics are used to make many products that we use every day such as carpets, paints, glue, insect repellents, hair spray, nail polish, and rocket fuel.

Di-*n*-butyl phthalate appears to have relatively low toxicity, and large amounts are needed to cause injury. Adverse effects on humans from exposure to di-*n*-butyl phthalate have not been reported. In animals, eating large amounts of di-*n*-butyl phthalate can affect their ability to reproduce. In male animals, sperm production can decrease after eating large amounts of di-*n*-butyl phthalate. However, when exposure to di-*n*-butyl phthalate stops, sperm production seems to return to near normal levels. The levels of di-*n*-butyl phthalate that cause toxic effects in animals are about 10,000 times higher than the levels of di-*n*-butyl phthalate found in air, food, or water. Exposure to high levels of di-*n*-butyl phthalate might cause similar effects in humans as in animals, but this is not known. In animals, large amounts of di-*n*-butyl phthalate repeatedly applied to the skin for a long time cause mild irritation.

Although the available data do not indicate that di-*n*-butyl phthalate causes cancer, this needs to be more thoroughly studied. Animal studies have shown that acute- and intermediate-duration oral exposure to di- n-butyl phthalate causes a number of developmental effects, including increases in postimplantation losses, decreases in the number of live fetuses per litter, decreases in fetal/pup body weights, increases in incidences of external, skeletal, and internal malformations, and altered reproductive development in the offspring. EPA classifies diethyl phthalate as Class D, not classifiable as a human carcinogen.

Hexachlorobenzene[2]

Hexachlorobenzene is a white crystalline solid. This compound does not occur naturally. It is formed as a by-product during the manufacture of chemicals used as solvents, other chlorine-containing compounds, and pesticides. Small amounts of hexachlorobenzene can also be produced during combustion processes such as burning of city wastes. It may also be produced as a by-product in waste streams of chlor-alkali and wood- preserving plants. Hexachlorobenzene was widely used as a pesticide until 1965. It was also used to make fireworks, ammunition, and synthetic rubber. Currently, the substance is not used commercially in the United States.

A study of people in Turkey who, over a period of several years, ate grain that was accidentally contaminated with hexachlorobenzene, showed a high death rate in young children of mothers who ate it and in young children who ate it themselves. These peoplealso suffered from liver disease. The main effect of this disease is slowed or stopped formation of heme, the oxygen-carrying part of the hemoglobin molecule found in red blood cells and an important chemical in the body. This disease can cause red-colored urine, skin sores, change in skin color, arthritis, and problems of the liver, nervous system, and stomach.

Studies in animals also suggest that eating this substance for months or years can cause cancer of the liver, kidney, and thyroid, but there is no strong evidence that the substance causes cancer in people. The DHHS has determined that the substance may reasonably be anticipated to be a human carcinogen. IARC has determined that hexachlorobenzene is possibly carcinogenic to humans. EPA has determined that hexachlorobenzene is a probable human carcinogen.

Naphthalene/2-Methylnaphthalene[2]

Naphthalene is a white solid that evaporates easily. Naphthalene has a strong but not an unpleasant smell. It is also called mothballs, moth flakes, white tar, and tar camphor. When mixed with air, naphthalene vapors easily burn. Fossil fuels, such as petroleum and coal, naturally contain naphthalene. Burning tobacco or wood produces naphthalene. The major commercial use of naphthalene is to make other chemicals used in making polyvinyl chloride (PVC) plastics. The major consumer products made from naphthalene are moth repellents, in the form of mothballs or crystals, and toilet deodorant blocks. It is also used for making dyes, resins, leather tanning agents, and the insecticide carbaryl. Another naphthalene-related compound, 2-methylnaphthalene, also called beta methylnaphthalene, is a solid like naphthalene. 1-Methylnaphthalene and 2 - methylnaphthalene are used to make other chemicals such as dyes, and resins. 2-Methylnaphthalene is also used to make vitamin K. All three chemicals are present in cigarette smoke, wood smoke, tar, and asphalt.

Exposure to a large amount of naphthalene may damage or destroy red blood cells. This could cause the body to have too few red blood cells until the body replaces the destroyed cells. This problem is called hemolytic anemia. Some of the symptoms that occur with hemolytic anemia are fatigue, lack of appetite, restlessness, and a pale appearance to your skin. Exposure to a large amount of naphthalene, such as by eating mothballs, may cause nausea, vomiting, diarrhea, blood in the urine, and a yellow color to the skin. Laboratory rabbits, guinea pigs, mice, and rats sometimes develop cataracts (cloudiness) in their eyes after swallowing naphthalene at high dose levels.

When mice or rats breathed in naphthalene vapors daily throughout their lives (2 years), cells in the lining of their noses or lungs were damaged. Some exposed female mice also developed lung and nose tumors. When mice or rats were fed naphthalene in their food for 13 weeks, no tumors or other tissue changes were found. The only effect found was decreased body weight in rats. When mice were fed food containing 1-

methylnaphthalene or 2-methylnaphthalene for most of their lives (81 weeks), the gas-exchange part of the lungs of some mice became filled with an abnormal material. This type of lung injury is called pulmonary alveolar proteinosis. A few mice also had lung tumors, but the numbers of mice with lung tumors were not enough to conclude that 1-methylnaphthalene or 2-methylnaphthalene caused the tumors. Based on these results from animal studies, the DHHS concluded that naphthalene is reasonably anticipated to be a human carcinogen. IARC concluded that naphthalene is possibly carcinogenic to humans, because there is enough evidence that naphthalene causes cancer in animals, but not enough evidence about such an effect in humans. The EPA determined that naphthalene is not classifiable as to its carcinogenicity to humans, but has not yet looked at new studies that found nose tumors in rats that breathed in naphthalene throughout their lives.

Methylphenols (Cresols)[2]

Three types of closely related cresols exist: ortho-cresol (o-cresol), meta-cresol (m-cresol), and para-cresol (p-cresol). Pure cresols are colorless chemicals, but they may be found in brown mixtures such as creosote and cresylic acids (e.g., wood preservatives). Cresols can be either solid or liquid, depending on how pure they are; pure cresols are solid, while mixtures tend to be liquid. Cresols have a medicinal odor. They are natural products that are present in many foods and in animal and human urine. They are also present in wood and tobacco smoke, crude oil, and coal tar. In addition, cresols also are man-made and used as disinfectants and deodorizers, to dissolve substances, and as starting chemicals for making other chemicals.

Oral exposure to very high levels of cresols could cause a burning sensation in the mouth and throat, as well as stomach pains. Skin contact with a substance containing high cresol levels, may cause a rash or severe irritation. In some cases, a severe chemical burn might result. Also, coming in contact with high enough levels of cresols may cause anemia, kidney problems, unconsciousness, or even death. Effects on the nervous system, such as loss of coordination and twitching of muscles, have been produced by low levels of cresols in animals.

Cresols may enhance the ability of carcinogenic chemicals to produce tumors in animals, and they have some ability to interact with mammalian genetic material in the test tube, but they have not been shown to produce cancer in humans or animals. The EPA has determined that cresols are possible human carcinogens (Class C).

Nirtrophenols[2]

2-Nitrophenol is a light yellow solid with a peculiar aromatic smell. 4-Nitrophenol is a colorless to light yellow solid with very little odor. 2-Nitrophenol is slightly soluble in cold water, but 4-nitrophenol is moderately soluble in cold water. Neither chemical evaporates at room temperature. These are man-made chemicals with no evidence of their formation from any natural source. 2-Nitrophenol is used mainly to produce dyes, paint coloring, rubber chemicals, and substances that kill molds (fungicides). 4-

Nitrophenol is used mainly to manufacture drugs, fungicides, and dyes, and to darken leather.

Rats that breathed dusts of 4-nitrophenol for 2 weeks developed a blood disorder which reduces the ability of the blood to carry oxygen to tissues and organs. However, these abnormalities disappeared a few days after exposure stopped. Chemicals like the nitrophenols cause a similar blood disorder in humans, and so humans exposed for weeks or longer to high levels of nitrophenols may develop the same types of blood disorders that animals do. Experimental studies have shown that 4-nitrophenol is more harmful than 2-nitrophenol in animals. Rats and rabbits that had relatively large amounts of 4-nitrophenol applied to their skin for a day or less had skin irritation. Rats that had a small amount of 4-nitrophenol on their skin for a few months also had skin irritation.

Application of 2-nitrophenol or 4-nitrophenol (dissolved in dioxane) to the shaved backs of mice in doses of 47 mg nitrophenol/kg/day for 12 weeks did not induce skin tumors or lesions that could be considered precancerous in nature.

N-Nitrosodiphenylamine[2]

N-Nitrosodiphenylamine is an orange-brown or yellow solid. N-Nitrosodiphenylamine was primarily used as a retardant in the rubber-processing industry. Retardants are chemicals that prevent the premature vulcanization of rubber compounds during certain rubber-processing steps such as mixing and calendaring.

There is not enough information to know how *n*-nitrosodiphenylamine affects human health. Very little is known about the health effects of exposure to n-nitrosodiphenylamine in animals, except that swallowing large doses can cause death. Animals given n-nitrosodiphenylamine in their diets for long periods developed swelling, cancer of the bladder, and changes in body weight. It is also not known if it can affect pregnancy or causebirth defects. EPA considers n-nitrosodiphenylamine to be a possible cancer-causing substance in humans because of the health effects seen in some animals. IARC concluded that there are not enough data to determine whether n-nitrosodiphenylamine causes cancer in humans. IARC also concluded that there is limited evidence indicating that n-nitrosodiphenylamine causes cancer in experimental animals.

Pentachlorophenol[1]

Pentachlorophenol is a manufactured organic chemical not found naturally in the environment. Pure pentachlorophenol occurs as a colorless or white powder with a crystalline structure that has a sharp chemical odor when hot, but very little smell at room temperature. Pentachlorophenol was previously used as a biocide and wood preservative and was one of the most heavily used pesticides in the United States. Now, only certified applicators can purchase and use pentachlorophenol. It is still used in industry as a wood preservative for power line poles, railroad ties, cross arms, and fence posts. It is no longer found in wood preserving solutions or insecticides and herbicides that can be purchased for home and garden use. Commercial pentachlorophenol preparations contain 85 to 99%

pentachlorophenol and various other phenol impurities as well as dioxins and furans. The presence of these impurities makes the assessment of toxicity difficult.

Pentachlorophenol is readily absorbed following oral or inhalation exposure and is widely and rapidly distributed throughout the body. Human fatalities and toxic effects including tachycardia, jaundice, and other hematologic alterations have been reported for acute and subchronic occupational inhalation exposures to pentachlorophenol. Short-term exposures to large amounts of pentachlorophenol or long-term exposure to low levels can harm the liver, kidneys, blood, lungs, nervous system, immune system, and digestive tract. Researchers have seen similar effects in animals. Impurities in commercial pentachlorophenol may cause many, but not all, of its harmful effects. Direct contact with pentachlorophenol can irritate the skin, eyes, and mouth, particularly when it is a hot vapor.

Based upon increased risk of cancer, specifically in the livers and adrenal glands of mice, pentachlorophenol is classified by the EPA as a probable human carcinogen (Weight of Evidence Category B2). There is no good evidence that pentachlorophenol causes cancer in humans.

Phenol[2, 3]

Phenol is a colorless-to-white solid when pure; however, the commercial product, which contains some water, is a liquid. It has a distinct odor that is sickeningly sweet and tarry. Phenol is both a man-made chemical and is produced naturally. It is found in nature in some foods and in human and animal wastes and decomposing organic material. The largest single use of phenol is as an intermediate in the production of phenolic resins. However, it is also used in the production of caprolactam (which is used in the manufacture of nylon 6 and other synthetic fibers) and bisphenol A (which is used in the manufacture of epoxy and other resins). Phenol is also used as a slimicide (a chemical toxic to bacteria and fungi characteristic of aqueous slimes), as a disinfectant, and in medicinal preparations such as over-the-counter treatments for sore throats. It is an antiseptic (kills germs) when applied to the skin in small amounts and may have antiseptic properties when gargled as a mouthwash. It is an anesthetic (relieves pain) and is a component of certain sore-throat lozenges and throat sprays or gargles. Small amounts of phenol in water have been injected into nerve tissue to lessen pain associated with certain nerve disorders. Phenol destroys the outer layers of skin if allowed to remain in contact with skin, and small amounts of concentrated solutions of phenol are sometimes applied to the skin to remove warts and to treat other skin blemishes and disorders.

A number of effects from breathing phenol in air have been reported in humans. Short-term effects reported include respiratory irritation, headaches, and burning eyes. Chronic effects of high exposures included weakness, muscle pain, anorexia, weight loss, and fatigue; effects of chronic low-level exposures included increases in respiratory cancer, heart disease, and effects on the immune system. Repeated exposure to low levels of phenol in drinking water has been associated with diarrhea and mouth sores in humans. Ingestion of very high concentrations of phenol has resulted in death.

Effects reported in humans following dermal exposure to phenol include liver damage, diarrhea, dark urine, and red blood cell destruction. Skin exposure to a relatively small amount of concentrated phenol has resulted in the death of humans.

It is not known if phenol causes cancer in humans. However, cancer has been shown to occur in mice when phenol was applied to the skin several times each week during the whole lifetime of the animal. When it is applied in combination with certain cancer-causing chemicals, a higher rate of cancer occurs than when the carcinogens are applied alone. Phenol did not cause cancer in mice or rats when they drank water containing phenol for 2 years. IARC and consider phenol not classifiable as to its carcinogenicity in humans.

Aluminum[1]

Aluminum is a silver-white flexible metal with a vast number of uses. It makes up about 8% of the earth's crust. The aluminum content of seawater ranges from 3 to 2400 ppb. Aluminum metal is used as a structural material in the construction, automotive, and aircraft industries, in the production of metal alloys, and in the electrical industry in power lines, insulated cables and wiring. Other uses of aluminum metal include cooking utensils, decorations, fencing, highway signs, cans, food packaging, foil, and dental crowns and dentures. Aluminum powder is used in paints and fireworks, and natural aluminum minerals are used in water purification, sugar refining, and in the brewing and paper industries. Aluminum borate is used in the production of glass and ceramics, and aluminum chloride is used to make rubber, lubricants, wood preservatives, and cosmetics. Aluminum chlorohydrate is the active ingredient in antiperspirants and deodorants, while aluminum hydroxide is used as a pharmaceutical to lower plasma phosphorus levels of patients with kidney failure. Until recently, aluminum has existed in forms not available to humans and most other species. However, acid rain has increased the availability of aluminum to biological systems and has resulted in destructive effects on fish and plant species. It is unknown if humans are susceptible to this increased bioavailability. It is poorly absorbed and efficiently eliminated; however, when absorption does occur, aluminum is distributed mainly in bone, liver, testes, kidneys, and brain. Aluminum may be involved in Alzheimer's disease (dialysis dementia) and in Amyotrophic Lateral Sclerosis and Parkinsonism-Dementia Syndromes of Guam. Aluminum content of brain, muscle, and bone increases in Alzheimer's patients. Neurofibrillary tangles are found in patients suffering from aluminum encephalopathy and Alzheimer's disease. Symptoms of "dialysis dementia" include speech disorders, dementia, convulsions, and myoclonus. Neurological effects have also been observed in rats orally exposed to aluminum compounds.

The respiratory system appears to be the primary target following inhalation exposure to aluminum. Alveolar proteinosis has been observed in guinea pigs, rats, and hamsters exposed to aluminum powders. Rats and guinea pigs exposed to aluminum chlorohydrate exhibited an increase in alveolar macrophages, increased relative lung weight, and multifocal granulomatous pneumonia. Male rats exposed to aluminum (as aluminum chloride) via gavage for 6 months exhibited decreased spermatozoa counts and sperm motility, and testicular histological and histochemical changes. Male rats exposed to drinking water containing aluminum (as aluminum potassium sulfate) for a lifetime exhibited increases in unspecified malignant and nonmalignant tumors and similarly exposed female mice exhibited an increased incidence of leukemia. Rats and guinea pigs exposed via inhalation to aluminum chlorohydrate developed lung granulomas while granulomatous foci developed in similarly exposed male hamsters.

Aluminum has been placed in the EPA weight-of-evidence classification D, not classifiable as to human carcinogenicity.

Antimony[1]

Antimony is a naturally occurring silvery-white metal that is found in the earth's crust. Antimony ores are mined and then mixed with other metals to form antimony alloys or combined with oxygen to form antimony oxide. Little antimony is currently mined in the United States. It is brought into this country from other countries for processing. However, there are companies in the United States that produce antimony as a by-product of smelting lead and other metals. Antimony is used in lead storage batteries, solder, sheet and pipe metal, bearings, castings, and pewter. Antimony oxide is added to textiles and plastics to prevent them from catching fire. It is also used in paints, ceramics, and fireworks, and as enamels for plastics, metal, and glass.

Metallic antimony and a few trivalent antimony compounds are the most significant regarding exposure potential and toxicity. Antimony is a common urban air pollutant, occurring at an average concentration of 0.001 $\mu g/m^3$. Exposure to antimony may occur via inhalation and by ingestion of contaminated food.

Acute oral and inhalation exposure of humans and animals to high doses of antimony or antimony-containing compounds (antimonials) may cause gastrointestinal disorders (vomiting, diarrhea), respiratory difficulties, and death at extremely high doses. Subchronic and chronic oral exposure may affect hematologic parameters. Long-term oral exposure to high doses of antimony or antimonials has been shown to adversely affect longevity in animals. Long-term occupational exposure of humans has resulted in electrocardiac disorders, respiratory disorders, and possibly increased mortality. Antimony levels for these occupational exposure evaluations ranged from 2.2 to 11.98 mg Sb/m^3. Based on limited data, occupational exposure of women to metallic antimony and several antimonials has reportedly caused alterations in the menstrual cycle and an increased incidence of spontaneous abortions.

The Department of Health and Human Services, the International Agency for Research on Cancer, and the Environmental Protection Agency (EPA) have not classified antimony as to its human carcinogenicity.

Arsenic[1]

Arsenic is a naturally occurring element widely distributed in the earth's crust. In the environment, arsenic is combined with oxygen, chlorine, and sulfur to form inorganic arsenic compounds. Arsenic in animals and plants combines with carbon and hydrogen to form organic arsenic compounds. Inorganic arsenic compounds are mainly used to preserve wood. Organic arsenic compounds are used as pesticides, primarily on cotton plants. Arsenic cannot be destroyed in the environment. It can only change its form. Arsenic in air will settle to the ground or is washed out of the air by rain. Many arsenic compounds can dissolve in water. Fish and shellfish can accumulate arsenic, but the arsenic in fish is mostly in a form that is not harmful. The toxicity of inorganic arsenic depends on its valence state and also on the physical and chemical properties of the compound in which it occurs.

Water soluble inorganic arsenic compounds are absorbed through the gastrointestinal tract and lungs; distributed primarily to the liver, kidney, lung, spleen, aorta, and skin; and excreted mainly in the urine at rates as high as 80%. Symptoms of acute inorganic arsenic poisoning in humans are nausea, anorexia, vomiting, epigastric and abdominal pain, and diarrhea. Dermatitis (exfoliative erythroderma), muscle cramps, cardiac abnormalities, hepatotoxicity, bone marrow suppression and hematologic abnormalities (anemia), vascular lesions, and peripheral neuropathy (motor dysfunction, paresthesia) have also been reported. Oral doses as low as 20-60 g/kg/day have been reported to cause toxic effects in some individuals. Severe exposures can result in acute encephalopathy, congestive heart failure, stupor, convulsions, paralysis, coma, and death. The acute lethal dose to humans has been estimated to be about 0.6 mg/kg/day.

General symptoms of chronic arsenic poisoning in humans are weakness, general debility and lassitude, loss of appetite and energy, loss of hair, hoarseness of voice, loss of weight, and mental disorders. Primary target organs are the skin (hyperpigmentation and hyperkeratosis), nervous system (peripheral neuropathy), and vascular system. Anemia, leukopenia, hepatomegaly, and portal hypertension have also been reported. In addition, possible reproductive effects include a high male to female birth ratio.

Epidemiological studies have revealed an association between arsenic concentrations in drinking water and increased incidences of skin cancers, as well as cancers of the liver, bladder, respiratory and gastrointestinal tracts. Occupational exposure studies have shown a clear correlation between exposure to arsenic and lung cancer mortality. Several studies have shown that inorganic arsenic can increase the risk of lung cancer, skin cancer, bladder cancer, liver cancer, kidney cancer, and prostate cancer. The World Health Organization (WHO), the Department of Health and Human Services (DHHS), and the EPA have determined that inorganic arsenic is a human carcinogen and is classified: A; human carcinogen.

Barium[1]

Barium is a divalent alkaline-earth metal found only in combination with other elements in nature. The most important of these combinations are the peroxide, chloride, sulfate, carbonate, nitrate, and chlorate. The pure metal oxidizes readily and reacts with water emitting hydrogen. The most likely source of barium in the atmosphere is from industrial emissions. Barium compounds are used by the oil and gas industries to make drilling muds. Drilling muds make it easier to drill through rock by keeping the drill bit lubricated. They are also used to make paint, bricks, tiles, glass, and rubber. A barium compound (barium sulfate) is sometimes used by doctors to perform medical tests and to take barium-rays of the stomach. Since it is usually present as a particulate form, it can be removed from the atmosphere by wet precipitation and deposition. Due to the element's tendency to form salts with limited solubility in soil and water, it is expected to have a residence time of hundreds of years and is not expected to be very mobile. Trace amounts of barium were found in more than 99% of the surface waters and finished drinking water samples across the United States.

The soluble salts of barium are toxic in mammalian systems. They are absorbed rapidly from the gastrointestinal tract and are deposited in the muscles, lungs, and bone. Inhalation exposure of human populations to barium-containing dust can result in a benign pneumoconiosis called "baritosis." At low doses, barium acts as a muscle stimulant and at higher doses affects the nervous system eventually leading to paralysis. Acute and subchronic oral doses of barium cause vomiting and diarrhea, followed by decreased heart rate and elevated blood pressure. Higher doses result in cardiac irregularities, weakness, tremors, anxiety, and dyspnea. A drop in serum potassium may account for some of the symptoms. Death can occur from cardiac and respiratory failure. Acute doses around 0.8 grams can be fatal to humans.

The Department of Health and Human Services, the International Agency for Research on Cancer, and the Environmental Protection Agency (EPA) have not classified barium as to its human carcinogenicity.

Beryllium[1]

Beryllium is a metallic element. Pure beryllium is a hard, grayish metal. In nature, beryllium can be found in compounds in mineral rocks, coal, soil, and volcanic dust. Beryllium compounds have no particular smell. Beryllium occurs naturally in the earth's crust at concentrations ranging from 2-10 ppm. It is also released into the atmosphere from coal combustion at concentrations of ~0.01-0.1 ng/m^3, most likely as beryllium oxide. Beryllium occurs in house dust, surface water, food, and soil. The general population is exposed to beryllium every day. Cigarette smokers can be exposed to nearly twice the amount of beryllium as nonsmokers. Beryllium compounds are commercially mined, and the beryllium purified for use in electrical parts, machine parts, ceramics, aircraft parts, nuclear weapons, and mirrors. Currently, beryllium has many industrial uses (e.g., in brake systems of airplanes, for neutron monochromatization, as window material for x-ray tubes, and in radiation detectors). The commercially important compound, beryllium oxide, is used in the electronics industry as a substrate for transistors and silicon chips, coil cores, and laser tubes.

Limited data indicate that the oral toxicity of beryllium is low in humans. No adverse effects were noted in mice given 5 ppm beryllium in the drinking water in a lifetime bioassay. In contrast, the toxicity of inhaled beryllium is well-documented. Humans inhaling "massive" doses of beryllium compounds may develop acute berylliosis. ATSDR estimated that, based on existing data, the disease could develop at levels ranging from approximately 2-1000 µg Be/m^3. This disease usually develops shortly after exposure and is characterized by rhinitis, pharyngitis, and/or tracheobronchitis, and may progress to severe pulmonary symptoms. The severity of acute beryllium toxicity correlates with exposure levels, and the disease is now rarely observed in the United States because of improved industrial hygiene. Humans inhaling beryllium may also develop chronic berylliosis which, in contrast to acute berylliosis, is highly variable in onset, is more likely to be fatal, and can develop a few months to >=20 years after exposure.

Epidemiologic studies have suggested that beryllium and its compounds could be human carcinogens. Studies in workers exposed to beryllium, mostly via inhalation, have shown significant increases in observed over expected lung cancer incidences. The U.S. EPA, in evaluating the total database for the association of lung cancer with occupational exposure to beryllium, noted several limitations, but concluded that the results must be considered to be at least suggestive of a carcinogenic risk to humans. In laboratory studies, beryllium sulfate caused increased incidences of pulmonary tumors in rats and rhesus monkeys.

Based on sufficient evidence for animals and inadequate evidence for humans, beryllium has been placed in the EPA weight-of-evidence classification B2, probable human carcinogen.

Cadmium[1]

Cadmium is a natural element in the earth's crust. It is usually found as a mineral combined with other elements such as oxygen (cadmium oxide), chlorine (cadmium chloride), or sulfur (cadmium sulfate, cadmium sulfide). These cadmium compounds have varying degrees of solubility ranging from very soluble to nearly insoluble. The solubility affects their absorption and toxicity. All soils and rocks, including coal and mineral fertilizers, contain some cadmium. Most cadmium used in the United States is extracted during the production of other metals like zinc, lead, and copper. Cadmium does not corrode easily and has many uses, including batteries, pigments, metal coatings, and plastics. Cadmium compounds have varying degrees of solubility ranging from very soluble to nearly insoluble. The solubility affects their absorption and toxicity. Environmental exposure can occur via the diet and drinking water.

Breathing high levels of cadmium severely damages the lungs and can cause death. The 1-minute and 10-minute lethal concentration of cadmium for humans has been estimated to be about 2,500 and 250 mg/m^3, respectively. Eating food or drinking water with very high levels severely irritates the stomach, leading to vomiting and diarrhea. Acute oral exposure to 20-30 g have caused fatalities in humans. Cadmium is absorbed more efficiently by the lungs (30 to 60%) than by the gastrointestinal tract. Long-term exposure to lower levels of cadmium in air, food, or water leads to a buildup of cadmium in the kidneys and possible kidney disease. Other long-term effects are lung damage and fragile bones. Animals given cadmium in food or water had high blood pressure, iron-poor blood, liver disease, and nerve or brain damage.

There is limited evidence from epidemiologic studies for cadmium-related respiratory tract cancer. Based on limited evidence from multiple occupational exposure studies and adequate animal data, cadmium is placed in weight-of-evidence group B1 - probable human carcinogen.

Chromium[1]

Elemental chromium does not occur in nature, but it is present in ores, primarily chromite. Chromium can be found in rocks, animals, plants, soil, and in volcanic dust and gases. Chromium is present in the environment in several different forms (oxidation states). The most common forms are chromium(0), chromium(III), and chromium(VI). No taste or odor is associated with chromium compounds. Chromium(III) occurs naturally in the environment and is an essential nutrient that helps the body use sugar, protein, and fat.. Chromium(VI) and chromium(0) are generally produced by industrial processes. The metal chromium, chromium(0), is used for making steel. Chromium(VI) and chromium(III) are used for chrome plating, dyes and pigments, leather tanning, and wood preserving.

Chromium enters the body through the lungs, digestive tract and, to a lesser extent, the skin. Inhalation is the most important route for occupational exposure. Non-occupational exposure occurs via ingestion of chromium-containing food and water. Breathing high levels of chromium(VI) can cause irritation to the nose, such as runny nose, nosebleeds, and ulcers and holes in the nasal septum. Ingesting large amounts of chromium(VI) can cause stomach upsets and ulcers, convulsions, kidney and liver damage, and even death. Skin contact with certain chromium(VI) compounds can cause skin ulcers. Some people are extremely sensitive to chromium(VI) or chromium(III). Allergic reactions consisting of severe redness and swelling of the skin have been noted.

Several studies have shown that chromium(VI) compounds can increase the risk of lung cancer when inhaled. Animal studies have also shown an increased risk of cancer. There is also evidence for an increased risk of developing nasal, pharyngeal, and gastrointestinal carcinomas. Based on sufficient evidence for humans and animals, Chromium(VI) has been placed in the EPA weight-of-evidence classification A, human carcinogen. Chromium(III) is most appropriately designated a Group D -- Not classified as to its human carcinogenicity; however, the classification of chromium(VI) as a known human carcinogen raises a concern for the carcinogenic potential of trivalent chromium.

Cobalt[2]

Cobalt is a naturally-occurring element that has properties similar to those of iron and nickel. Small amounts of cobalt are naturally found in most rocks, soil, water, plants, and animals, typically in small amounts. Cobalt is also found in meteorites. Elemental cobalt is a hard, silvery gray metal. A biochemically important cobalt compound is vitamin B_{12}. Vitamin B_{12} is essential for good health in animals and humans. Cobalt metal is usually mixed with other metals to form alloys, which are harder or more resistant to wear and corrosion. These alloys are used in a number of military and industrial applications such as aircraft engines, magnets, and grinding and cutting tools. They are also used in artificial hip and knee joints. Cobalt compounds are used as colorants in glass, ceramics, and paints, as catalysts, and as paint driers. Cobalt colorants have a characteristic blue color; however, not all cobalt compounds are blue. Cobalt compounds are also used as trace element additives in agriculture and medicine. Cobalt can also exist in radioactive forms. ^{60}Co is used as a source of gamma rays for sterilizing medical equipment and consumer products, radiation therapy for treating cancer patients, and for manufacturing plastics. ^{60}Co has also been used for food irradiation; depending on the radiation dose, this process may be used to sterilize food, destroy pathogens, extend the shelf-life of food, disinfest fruits and grain, delay ripening, and retard sprouting (e.g., potatoes and onions). ^{57}Co is used in medical and scientific research.

Cobalt has both beneficial and harmful effects on human health. Cobalt is beneficial for humans because it is part of vitamin B_{12}, which is essential to maintain human health. Cobalt (0.16-1.0 mg cobalt/kg of body weight) has also been used as a treatment for anemia, including in pregnant women, because it causes red blood cells to be produced. Cobalt also increases red blood cell production in healthy people, but only at very high exposure levels. Cobalt is also essential for the health of various animals, such as cattle and sheep. When too much cobalt is taken into the body, however, harmful health effects can occur. Serious effects on the lungs, including asthma, pneumonia, and wheezing, have been found in people exposed to 0.005 mg cobalt/m^3 while working with hard metal, a cobalt-tungsten carbide alloy. People exposed to 0.007 mg cobalt/m^3 at work have also developed allergies to cobalt that resulted in asthma and skin rashes. Effects on the thyroid were found in people exposed to 0.5 mg cobalt/kg for a few weeks.

Being exposed to radioactive cobalt may be very dangerous to human health. Being near radioactive cobalt may result in cells in the body becoming damaged from gamma rays that can penetrate the entire body, even if the radioactive cobalt is not touched. If exposed to enough radiation, a reduction in the number of white blood cells may occur, which could lower resistance to infections. The skin might blister or burn and hair loss could occur from the exposed areas. Cells in the reproductive system could become damaged and cause temporary sterility. Exposure to lower levels of radiation might cause nausea, and higher levels can cause vomiting, diarrhea, bleeding, coma, and even death. Exposure to radiation can also cause changes in the genetic materials within cells and may result in the development of some types of cancer.

Non-radioactive cobalt has not been found to cause cancer in humans or in animals following exposure in the food or water. Cancer has been shown, however, in animals who breathed cobalt or when cobalt was placed directly into the muscle or under the skin.

Manganese[1]

Manganese is a silver-colored, naturally occurring metal that is found in many types of rocks and makes up about 0.10% of the earth's crust. Manganese is not found alone but combines with other substances such as oxygen, sulfur, or chlorine. Manganese can also be combined with carbon to make organic manganese compounds, including pesticides (e.g., maneb or mancozeb) and methylcyclopentadienyl manganese tricarbonyl (MMT), a fuel additive in some gasolines. Manganese is an essential trace element and is necessary for good health. Normal nutritional requirements of manganese are satisfied through the diet, which is the normal source of the element, with minor contributions from water and air. The National Research Council recommends a dietary allowance of 2-5 mg/day for a safe and adequate intake of manganese for an adult human. Manganese can be found in several food items, including grains, cereals, and tea.

Manganese can elicit a variety of serious toxic responses upon prolonged exposure to elevated concentrations, either orally or by inhalation. The central nervous system is the primary target. Initial symptoms are headache, insomnia, disorientation, anxiety, lethargy, and memory loss. These symptoms progress with continued exposure and eventually include motor disturbances, tremors, and difficulty in walking, symptoms similar to those seen with Parkinsonism. These motor difficulties are often irreversible. Some individuals exposed to very high levels of manganese for long periods of time at work developed mental and emotional disturbances and slow and clumsy body movements. This combination of symptoms is a disease called "manganism."

There are no human cancer data available for manganese. Some conflicting data exist on possible carcinogenesis following injections of manganese chloride and manganese sulfate in mice. However, the EPA weight-of-evidence classification is D, not classifiable as to human carcinogenicity, based on no evidence in humans and inadequate evidence in animals.

Mercury[1]

Mercury is a naturally occurring metal which has several forms. The metallic mercury is a shiny, silver-white, odorless liquid; if heated, it is a colorless, odorless gas. Mercury combines with other elements, such as chlorine, sulfur, or oxygen, to form inorganic mercury compounds or "salts," which are usually white powders or crystals. Mercury also combines with carbon to make organic mercury compounds; methylmercury is the most common organic mercury compound and is produced mainly by microscopic organisms in the water and soil. More mercury in the environment can increase the amounts of methylmercury that these small organisms make. Metallic mercury is used to produce chlorine gas and caustic soda and is also used in thermometers, dental fillings, electrical switches, and batteries. Mercury salts are sometimes used in skin lightening creams and as antiseptic creams and ointments.

The nervous system is very sensitive to all forms of mercury. Methylmercury and metallic mercury vapors are more harmful than other forms, because more mercury reaches the brain in these forms. Exposure to high levels of metallic, inorganic, or organic mercury can permanently damage the brain, kidneys, and developing fetus. Effects on brain functioning may result in irritability, shyness, tremors, changes in vision or hearing, and memory problems. Short-term exposure to high levels of metallic mercury vapors may cause lung damage, nausea, vomiting, diarrhea, increases in blood pressure or heart rate, skin rashes, and eye irritation.

No data were available regarding the carcinogenicity of mercury in humans or animals. EPA has placed inorganic mercury in weight-of-evidence classification D, not classifiable as to human carcinogenicity. Other forms of mercury are possible human carcinogens.

Nickel[1]

Nickel is a very abundant element in the environment. It is found primarily combined with oxygen (oxides) or sulfur (sulfides), found in all soils, and is emitted from volcanos. Pure nickel is a hard, silvery-white metal that is combined with other metals to form mixtures called alloys. Some of the metals that nickel can be alloyed with are iron, copper, chromium, and zinc. These alloys are used to make metal coins and jewelry and in industry. Nickel compounds are also used for nickel plating, to color ceramics, to make some batteries, and as substances known as catalysts that increase the rate of chemical reactions. Nickel and its compounds have no characteristic odor or taste. Nickel forms included in this profile are: Nickel carbonyl, CAS number 13463-39-3; Nickel refinery dust, no CAS number; Nickel subsulfide, CAS number 12035-72-2; and Nickel soluble salts, no CAS number.

Nickel is required to maintain health in animals. A small amount of nickel is probably essential for humans, although a lack of nickel has not been found to affect the health of humans. The absorption of nickel is dependent on its physicochemical form, with water soluble forms being more readily absorbed. The most common adverse health effect of nickel in humans is an allergic reaction. Humans can become sensitive to nickel when jewelry or other nickel-containing items are in direct contact with the skin. Once a person is sensitized to nickel, further contact will produce a reaction; the most common reaction is a skin rash at the site of contact. Less frequently, some humans who are sensitive to nickel have asthma attacks or other reactions following exposure to nickel in food, water, or dust. Lung effects, including chronic bronchitis and reduced lung function, have been observed in workers who breathed large amounts of nickel. Current levels of nickel in workplace air are much lower than in the past, and today few workers show symptoms of nickel exposure. Humans who are not sensitive to it must eat very large amounts of nickel to show adverse health effects. In large doses (>0.5 g), some forms of nickel may be acutely toxic to humans when taken orally. Workers who accidentally drank water containing very high levels of nickel (100,000 times more than in normal drinking water) had stomachaches and effects on their blood and kidneys.

Epidemiologic studies have shown that occupational inhalation exposure to nickel dust (primarily nickel subsulfide) at refineries has resulted in increased incidences of pulmonary and nasal cancer. Inhalation studies using rats have also shown nickel

Exposure to high levels of thallium can result in harmful health effects. A study on workers exposed on the job over several years reported nervous system effects, such as numbness of fingers and toes, from breathing thallium. Humans who ingested large amounts of thallium over a short time have reported vomiting, diarrhea, temporary hair loss, and effects on the nervous system, lungs, heart, liver, and kidneys as well as death. It is not known what the effects are from ingesting low levels of thallium over a long time. Birth defects were not reported in the children of mothers exposed to low levels from eating vegetables and fruits contaminated with thallium. Studies in rats, however, exposed to high levels of thallium, showed adverse developmental effects.

Data suitable for evaluating the carcinogenicity of thallium to humans or animals by ingestion, inhalation, or other routes of exposure were not found. Thallium sulfate, selenite, nitrate, chloride, carbonate, acetate, and thallic oxide have been placed in EPA's weight-of evidence Group D, not classifiable as to human carcinogenicity based on inadequate human and animal data. The Department of Health and Human Services and the International Agency for Research on Cancer, have not classified pure thallium as to its human carcinogenicity. No studies are available in humans or animals on the carcinogenic effects of breathing, ingesting, or touching thallium.

Vanadium[1]

Vanadium is a compound that occurs in nature as a white-to-gray metal and is often found as crystals. Pure vanadium has no smell and usually combines with other elements such as oxygen, sodium, sulfur, or chloride, which greatly alter toxicity. Vanadium and vanadium compounds can be found in the earth's crust and in rocks, some iron ores, and crude petroleum deposits. Vanadium is mostly combined with other metals to make special metal mixtures called alloys. Most of the vanadium used in the United States, vanadium oxide, is used to make steel for automobile parts, springs, and ball bearings. Vanadium oxide is a yellow-orange powder, dark-gray flakes, or yellow crystals. Vanadium is also mixed with iron to make important parts for aircraft engines. Small amounts of vanadium are used in making rubber, plastics, ceramics, and other chemicals.

Exposure to high levels of vanadium can cause harmful health effects. Vanadium compounds are poorly absorbed through the digestive system (0.5-2% of dietary amount), but slightly more readily absorbed through the lungs (20-25%). The major effects from breathing high levels of vanadium are on the lungs, throat, and eyes. Workers who breathed it for short and long periods sometimes had lung irritation, coughing, wheezing, chest pain, runny nose, and a sore throat. These effects stopped soon when removed from the contaminated air. Similar effects have been observed in animal studies. No other significant health effects of vanadium have been found in humans. The health effects in humans of ingesting vanadium are not known. Animals that ingested very large doses have died. Lower, but still high levels of vanadium in the water of pregnant animals resulted in minor birth defects. Some animals that breathed or ingested vanadium over a long term had minor kidney and liver changes.

There is no evidence that any vanadium compound is carcinogenic; however, very few adequate studies are available for evaluation. No increase in tumors was noted in a long-term animal study where the animals were exposed to vanadium in the drinking water. The Department of Health and Human Services, the International Agency for Research on Cancer, and the Environmental Protection Agency (EPA) have not classified vanadium as to its human carcinogenicity.

Zinc[1]

Pure zinc is a bluish-white shiny metal. Zinc is one of the most common elements in the earth's crust and is found in air, soil, and water, and is present in all foods. Zinc has many commercial uses as coatings to prevent rust, in dry cell batteries, and mixed with other metals to make alloys like brass and bronze. A zinc and copper alloy is used to make pennies in the United States. Zinc combines with other elements to form zinc compounds; common zinc compounds found at hazardous waste sites include zinc chloride, zinc oxide, zinc sulfate, zinc phosphide, zinc cyanide, and zinc sulfide. Zinc compounds are widely used in industry to make paint, rubber, dye, wood preservatives, and ointments.

Zinc is an essential element with recommended daily allowances (RDS) ranging from 5 mg for infants to 15 mg for adult males. Too little zinc can cause health problems, but too much zinc is also harmful.

The digestive tract absorbs 20% to 80 % of ingested zinc based on the chemical compound ingested. Harmful health effects generally begin at levels in the 100 to 250 mg/day range. Eating large amounts of zinc, even for a short time, can cause stomach cramps, nausea, and vomiting. Taken longer, it can cause anemia, pancreas damage, and lower levels of high-density lipoprotein cholesterol (the good form of cholesterol). Breathing large amounts of zinc (as dust or fumes) can cause a specific short-term disease called metal fume fever. This is believed to be an immune response affecting the lungs and body temperature. The long-term effects of breathing high levels of zinc or the effects on human reproduction are not known. Rats that were fed large amounts of zinc became infertile or had smaller babies. Irritation was also observed on the skin of rabbits, guinea pigs, and mice when exposed to some zinc compounds. Skin irritation will probably occur in humans.

No case studies or epidemiologic evidence has been presented to suggest that zinc is carcinogenic in humans by the oral or inhalation route. In animal studies, zinc sulfate in drinking water or zinc oleate in the diet of mice for a period of one year did not result in a statistically significant increase in tumors; however, in a 3-year, 5-generation study on tumor-resistant and tumor-susceptible strains of mice, exposure to zinc in drinking water resulted in increased frequencies of tumors. Zinc is placed in weight-of-evidence Group D, not classifiable as to human carcinogenicity due to inadequate evidence in humans and animals.

Aroclor 1254[1]

Aroclor® 1254 is a is a viscous, light yellow liquid polychlorinated biphenyl (PCB) mixture containing approximately 21% $C_{12}H_6Cl_4$, 48% $C_{12}H_5Cl_5$, 23% $C_{12}H_4Cl_6$, and 6% $C_{12}H_3Cl_7$ with an average chlorine content of54%. PCBs are inert, thermally and physically stable, and have dielectric properties. In the environment, the behavior of PCB mixtures is directly correlated to the degree of chlorination. They have been used in closed systems such as heat transfer liquids, hydraulic fluids and lubricants, and in open systems such as plasticizers, surface coatings, inks, adhesives, pesticide extenders, and for microencapsulation of dyes for carbonless duplicating papers. Aroclor® is strongly sorbed to soil and remains immobile when leached with water; however, the mixture is highly mobile in the presence of organic solvents. PCBs are resistant to chemical degradation by oxidation or hydrolysis. PCBs have high bioconcentration factors and tend to accumulate in the fat of fish, birds, mammals, and humans.

PCBs are absorbed after oral, inhalation, or dermal exposure and are stored in adipose tissue. The major route of PCB excretion is in the urine and feces; however, more important is the elimination in human milk. Accidental human poisonings and data from occupational exposure to PCBs suggest initial dermal and mucosal disturbances followed by systemic effects that may manifest themselves several years post-exposure. Initial effects are enlargement and hypersecretion of the Meibomian gland of the eye, swelling of the eyelids, pigmentation of the fingernails and mucous membranes, fatigue, and nausea. These effects were followed by hyperkeratosis, darkening of the skin, acneform eruptions, edema of the arms and legs, neurological symptoms, such as headache and limb numbness, and liver disturbance.

Data are suggestive but not conclusive concerning the carcinogenicity of PCBs in humans. However, hepatocellular carcinomas in three strains of rats and two strains of mice have led the EPA to classify PCBs as group B2, probable human carcinogen.

Aroclor 1260[1]

Aroclor® 1260 is a colorless, liquid polychlorinated biphenyl (PCB) mixture containing approximately 38% $C_{12}H_4Cl_6$, 41% $C_{12}H_3Cl_7$, 8% $C_{12}H_2Cl_8$, and 12% $C_{12}H_5Cl_5$ with an average chlorine content of 60%. PCBs are inert, thermally and physically stable, and have dielectric properties. They have been used in closed systems such as heat transfer liquids, hydraulic fluids and lubricants, and in open systems such as plasticizers, surface coatings, inks, adhesives, pesticide extenders, and for microencapsulation of dyes for carbonless duplicating papers. In the environment, the behavior of PCB mixtures is directly correlated to the degree of chlorination. Aroclor® is strongly sorbed to soil and remains immobile when leached with water; however, the mixture is highly mobile in the presence of organic solvents. PCBs are resistant to chemical degradation by oxidation or hydrolysis. PCBs have high bioconcentration factors, and tend to accumulate in the fat of fish, birds, mammals, and humans. In humans, relatively greater amounts of PCBs have also been identified in skin, liver, and breast milk.

PCBs are absorbed after oral, inhalation, or dermal exposure and are stored in adipose tissue. Accidental human poisonings and data from occupational exposure to PCBs suggest initial dermal and mucosal disturbances followed by systemic effects that may manifest themselves several years post-exposure. Initial effects are enlargement and hypersecretion of the Meibomian gland of the eye, swelling of the eyelids, pigmentation of the fingernails and mucous membranes, fatigue, and nausea. These effects were followed by hyperkeratosis, darkening of the skin, acneform eruptions, edema of the arms and legs, neurological symptoms, such as headache and limb numbness, and liver disturbance. Hepatotoxicity is a prominent effect of PCBs, including Aroclor® 1260, that has been well characterized. Effects include hepatic microsomal enzyme induction, increased serum levels of liver-related enzymes (indicative of hepatocellular damage), liver enlargement, lipid deposition, fibrosis, and necrosis.

Data are suggestive but not conclusive concerning the carcinogenicity of PCBs in humans. However, hepatocellular carcinomas in three strains of rats and two strains of mice have led the EPA to classify PCBs as group B2, probable human carcinogen.

Hexachlorocyclohexane (BHC)[2]

Hexachlorocyclohexane (HCH), also known as benzene hexachloride (BHC), is a synthetic chemical that exists in eight chemical forms called isomers. One of these forms, gamma-HCH (or γ-HCH, commonly called lindane), is produced and used as an insecticide on fruit, vegetables, and forest crops. It is also used in the United States and in many other countries as a topical treatment for head and body lice and scabies, a contagious skin disease caused by mites. It is a white solid whose vapor may evaporate into the air. The vapor is colorless and has a slight musty odor. Technical-grade HCH, a mixture of several chemical forms of HCH, was also once used as an insecticide in the United States and typically contained about 10–15% γ-HCH as well as the alpha (α), beta (β), delta (δ), and epsilon (ε) forms of HCH. Virtually all of the insecticidal properties reside in the gamma isomer. Technical-grade HCH has not been produced in the United States since 1983.

In humans, the effects of breathing toxic amounts of γ-HCH and/or α-, β-, and δ-HCH can result in blood disorders, dizziness, headaches, and possible changes in the levels of sex hormones in the blood. These effects have occurred in workers exposed to HCH vapors during pesticide manufacturing. People who have swallowed large amounts have had seizures and some have died. A few people, who have used very large amounts of γ-HCH or used it frequently on their skin, have developed blood disorders or seizures. However, no cause-and-effect relationship between exposure to γ-HCH and blood disorders in humans has been established. Animals that have been fed γ- and α-HCH have had convulsions, and animals fed β-HCH have become comatose. All isomers can produce liver and kidney effects. Reduced ability to fight infection was reported in animals fed γ-HCH, and injury to the ovaries and testes was reported in animals given γ-HCH or β-HCH. HCH isomers are changed by the body into other chemical products, some of which may be responsible for the harmful effects. Long-term oral administration of α-HCH, β-HCH, γ-HCH, or technical-grade HCH to laboratory rodents has been reported to result in liver cancer. The DHHS has determined that HCH may reasonably be anticipated to cause cancer in humans.

DDD, DDE, DDT[2]

DDT (1,1,1-trichloro-2,2-bis(*p*-chlorophenyl)ethane) is a pesticide that was once widely used to control insects on agricultural crops and insects that carry diseases like malaria and typhus, but is now used in only a few countries to control malaria. Technical-grade DDT is a mixture of three forms, *p,p'*-DDT (85%), *o,p'*-DDT (15%), and *o,o'*-DDT (trace amounts). All of these are white, crystalline, tasteless, and almost odorless solids. Technical grade DDT may also contain DDE (1,1-dichloro-2,2-bis(*p*-chlorophenyl)ethylene) and DDD (1,1-dichloro-2,2-bis(*p*-chlorophenyl)ethane) as contaminants. Both DDE and DDD are breakdown products of DDT. DDD was also used to kill pests, but to a far lesser extent than DDT. One form of DDD (*o,p'*-DDD) has been used medically to treat cancer of the adrenal gland and benign Cushing's disease. After 1972, the use of DDT was no longer permitted in the United States except in cases of a public health emergency. It is, however, still used in some other areas of the world, most notably for controlling malaria. The use of DDD to kill pests has also been banned in the United States.

Effects of DDT on the nervous system have been observed in both humans and animals and can vary from mild altered sensations to tremors and convulsions. Humans have been reported to tolerate doses as high as 285 mg/kg without fatal result, although because vomiting occurred, the absorbed dose is not known. There are no documented unequivocal reports of a fatal human poisoning occurring exclusively from ingestion of pure DDT, but deaths have been reported following ingestion of commercial preparations containing also other substances. Death in animals following high exposure to DDT is usually caused by respiratory arrest.

In addition to being a neurotoxicant, DDT is capable of inducing marked alterations on reproduction and development in animals. This is attributed to hormone-altering actions of DDT isomers and/or metabolites. Of all the DDT-related compounds, the *o,p'*-DDT isomer has the strongest estrogenlike properties, although it is still several orders of magnitude less potent than the natural hormone, 17β-estradiol. *p,p'*-DDE, a metabolite of DDT and a persistent environmental pollutant, has antiandrogenic properties and has been shown to alter the development of reproductive organs when administered perinatally to rats. There have been studies in humans suggesting that high DDT/DDE burdens may be associated with alterations in end points that are controlled by hormonal function such as duration of lactation, maintenance of pregnancy, and fertility. High blood levels of DDE during pregnancy have also been associated with increased odds of having pre-term infants and small-forgestational-age infants and height abnormalities in children.

Studies in animals have shown that oral exposure to DDT can cause liver cancer. Studies of DDT-exposed workers did not show increases in deaths or cancers. The possible association between exposure to DDT and various types of cancers in humans has been studied extensively, particularly breast cancer. Thus far, there is no conclusive evidence linking DDT and related compounds to cancer in humans. Based on all of the evidence available, DHHS has determined that DDT is reasonably anticipated to be a human carcinogen. Similarly, IARC has determined that DDT is possibly carcinogenic to humans. EPA has determined that DDT, DDE, and DDD are probable human carcinogens.

Endrin (aldehyde/ketone)[2]

Endrin is a solid, white, almost odorless substance that was used as a pesticide to control insects, rodents, and birds. Endrin has not been produced or sold for general use in the United States since 1986. Little is known about the properties of endrin aldehyde, an impurity and breakdown product of endrin, or endrin ketone, which is a product of endrin when it is exposed to light.

Exposure to endrin can cause various harmful effects including death and severe central nervous system (brain and spinal cord) injury. Swallowing large amounts of endrin (more than 0.2 mg/kg of body weight) may cause convulsions and kill you in a few minutes or hours. Symptoms that may result from endrin poisoning are headache, dizziness, nervousness, confusion, nausea, vomiting, and convulsions. Some of these symptoms may continue for weeks after exposure to high doses of endrin. No long-term health effects have been noted in workers, either in factories or during field applications, who have been exposed to endrin by breathing or touching it.

Studies in animals confirm that endrin's main target is the nervous system, probably because the brain and other parts of the nervous system contain much fatty tissue, and endrin tends to stay in those tissues. Birth defects, especially abnormal bone formation, have been seen in some animal studies. While there are no human data on birth defects, evidence in rodents suggests that exposure to high doses of endrin during pregnancy could be a health risk to developing fetuses.

In studies using rats, mice, and dogs, endrin did not produce cancer. However, most of these studies did not accurately evaluate the ability of endrin to cause cancer. No significant excess of cancer has been found in exposed factory workers, although endrin metabolites have been detected in their urine. One study in rodents suggests that exposure to endrin aldehyde or endrin ketone may cause liver disease. The EPA has determined that endrin is not classifiable as to its human carcinogenicity because there is not enough information to allow classification. Endrin has also not been classified for carcinogenic effects by the DHHS or IARC.

Heptachlor Epoxide[1]

Heptachlor epoxide is a manufactured chemical that does not occur naturally. Pure heptachlor epoxide is a crystalline white powder that is a break down product of heptachlor and chlordane. The epoxide is more likely to be found in the environment than heptachlor because Heptachlor epoxide degrades slower and, as a result, is more persistent than heptachlor. Heptachlor epoxide is not produced commercially in the United States.

Heptachlor and heptachlor epoxide are clearly toxic to humans and animals and can damage the nervous system. No studies were available regarding the specific toxic effects in humans after exposure to heptachlor epoxide alone. In laboratory animals, the liver and central nervous system are the primary target organs for heptachlor epoxide toxicity. Oral doses in animals produced hypoactivity, ruffled fur, increased mortality, muscle spasms, and convulsive seizures.

No epidemiological studies or case reports addressing the carcinogenicity of heptachlor epoxide in humans were available. Studies with laboratory animals demonstrated that heptachlor epoxide causes liver cancer in mice and rats. Based on EPA guidelines, heptachlor epoxide was assigned to weight-of-evidence group B2, probable human carcinogen.

2,4-Dinitrotoluene[1]

2,4-Dinitrotoluene is a pale yellow crystalline solid that does not occur naturally. It is one of six possible chemical forms of dinitrotoluene (DNT) that is produced by dinitration of toluene with nitric acid in the presence of sulfuric acid. 2,4-DNT is primarily used as a chemical intermediate in the manufacture of polyurethanes. It is also used as a component of military and commercial explosives, as an intermediate in dye processes, and as a propellant additive.

The DNTs are absorbed primarily through inhalation but also through ingestion and dermal contact in most species. The initial acute toxic effects of 2,4-DNT in humans include ischemic heart disease; hematological effects characterized by cyanosis, anemia, and leukocytosis; and neurological effects such as dizziness, insomnia, nausea, and tingling pains in extremities. Subchronic and chronic oral toxicity studies with experimental animals indicate that the blood, liver, nervous system, and reproductive system are targets affected by 2,4-DNT.

This substance/agent has not undergone a complete evaluation and determination under US EPA's IRIS program for evidence of human carcinogenic potential. There are no human studies with 2,4-DNT; however, 2,4-DNT caused liver cancer in rats . Although EPA has not evaluated pure 2,4-DNT for evidence of human carcinogenic potential, the dinitrotoluene mixture (containing 2,4-DNT and 2,6-DNT) was classified as a B2 chemical carcinogen, probable human carcinogen. The International Agency for Research on Cancer (IARC) has determined that 2,4-DNT is a possible human carcinogen.

2,6-Dinitrotoluene[1]

2,6-Dinitrotoluene (2,6-DNT) is a pale yellow crystalline solid that does not occur naturally. 2,6-DNT is one of six possible chemical forms of dinitrotoluene (DNT) that is produced by dinitration of toluene with nitric acid in the presence of sulfuric acid. DNT is primarily used as a chemical intermediate in the manufacture of polyurethanes. It is also used as a component of military and commercial explosives, as an intermediate in dye processes, and as a propellant additive. DNT isomers are formed as by-products during the manufacture of trinitrotoluene (TNT).

The DNTs are absorbed through inhalation, ingestion, and dermal contact in most species. Human data regarding potential health effects of 2,6-DNT are very limited. A significant increase in the death rate due to ischemic heart disease has been associated with occupational exposure to DNT. The evidence for potential reproductive effects (reduction of sperm counts) in male workers exposed to a mixture of DNT isomers is equivocal. Oral subchronic toxicity studies with rats, mice, and dogs indicate that the blood, liver, and reproductive system are targets affected by 2,6-DNT in all three species.

This substance has not undergone a complete evaluation and determination under US EPA's IRIS program for evidence of human carcinogenic potential. There are no human studies with 2,6-DNT; however 2,6-DNT caused liver cancer in rats. Although EPA has not evaluated pure 2,6-DNT for evidence of human carcinogenic potential, the dinitrotoluene mixture (containing 2,4-DNT and 2,6-DNT) was classified as a B2 chemical carcinogen, probable human carcinogen. The International Agency for Research on Cancer (IARC) has determined that 2,6-DNT is a possible human carcinogen.

RDX[2, 3]

RDX stands for Royal Demolition eXplosive. It is also known as cyclonite or hexogen. The chemical name for RDX is 1,3,5-trinitro-1,3,5-triazine. It is a white powder and is very explosive. It is used as an explosive and also combined with other ingredients in plastic explosives. Its odor and taste are unknown. RDX creates fumes when it is burned with other substances.

RDX can cause seizures (a problem of the nervous system) in humans and animals when large amounts are inhaled or eaten. The effects of long-term, low-level exposure on the nervous system is not known. No other significant health effects have been seen in humans. Rats and mice have had decreased body weights and slight liver and kidney damage from eating RDX for 3 months or more. It is not known if RDX causes cancer in people, but it did cause liver tumors in mice. It is also not known whether RDX causes birth defects in humans; it did not cause birth defects in rabbits, but it did result in smaller offspring in rats. EPA has classified RDX as Class C, a possible human carcinogen.

Nitrobenzene[1]

Nitrobenzene is an oily yellow liquid with an almond-like odor. It is an industrial chemical mostly produced (98%) in the United States to manufacture a chemical called aniline. The major use of aniline is in the manufacture of polyurethanes. Nitrobenzene is also used to produce lubricating oils such as those used in motors and machinery. A small amount of nitrobenzene is used in the manufacture of dyes, drugs, pesticides, and synthetic rubber.

Nitrobenzene is absorbed by humans through oral, inhalation, or dermal exposure. A small amount of nitrobenzene may cause mild irritation if it contacts the skin or eyes directly. Repeated exposures to a high concentration of nitrobenzene can result in methemoglobinemia, a condition in which the blood's ability to carry oxygen is reduced. This condition may turn the skin a bluish color and may cause nausea, vomiting, and shortness of breath. Effects such as headache, irritability, dizziness, weakness, and drowsiness may also occur. There is also some evidence that breathing high concentrations of nitrobenzene may damage the liver. Animal studies have reported effects on the blood and liver from exposure to nitrobenzene.

No suitable cancer bioassays or epidemiological studies are available to assess the carcinogenicity of nitrobenzene. Therefore, U.S. EPA has placed nitrobenzene in weight-of-evidence group D, not classifiable as to human carcinogenicity. However, the International Agency for Research on Cancer has determined that nitrobenzene is possibly carcinogenic to humans based on animal studies. In animals, breathing nitrobenzene resulted in an increase in liver, thyroid, and kidney tumors.

HMX[2]

HMX, an acronym for High Melting eXplosive, is also known as octogen and cyclotetramethylene-tetranitramine. It is a colorless solid that dissolves slightly in water. Only a very small amount of HMX will evaporate into the air; however, it can occur in air attached to suspended particles or dust. The taste and smell of HMX are not known. HMX is a manmade chemical and does not occur naturally in the environment. It is made from other chemicals known as hexamine, ammonium nitrate, nitric acid, and acetic acid. HMX explodes violently at high temperatures (534°F and above). Because of this property, HMX is used in nuclear devices, plastic explosives, rocket fuels, and burster chargers. A small amount of HMX is also formed in making cyclotrimethylene-trinitramine (RDX), another explosive similar in structure to HMX.

Studies in rats, mice, and rabbits indicate that HMX may be harmful to the liver and central nervous system if it is swallowed or comes in contact with skin. The lowest dose producing any effects in animals was 100 milligrams per kilogram of body weight per day (mg/kg/day) orally and 165 mg/kg/day on the skin. Limited evidence suggests that even a single exposure to these dose levels harmed rabbits. The mechanism by which HMX causes adverse effects on the liver and nervous system is not understood.

The reproductive and developmental effects of HMX have not been well studied in humans or animals. At present, the information needed to determine if HMX causes cancer is insufficient. Due to the lack of information, EPA has determined that HMX is not classifiable as to its human carcinogenicity.

Tetryl[1]

Trinitrophenylmethylnitramine is also known by the synonyms picrylmethylnitramine, tetralite, nitramine, N,2,4,5-tetranitro-N-methylaniline, 2,4,6-trinitrophenyl-Nmethylnitramine, and tetryl. Tetryl is a Class A explosive that is used as an intermediary detonating agent for less sensitive high explosives and as a booster charge in certain military munitions. Tetryl was produced mostly during World Wars I and II; it is no longer manufactured or used in the United States. Stocks of tetryl are found in storage at military installations and are being destroyed by the Department of Defense. Tetryl is an odorless, synthetic, yellow crystal-like solid that is not found naturally in the environment. A powerful oxidant and a dangerous fire hazard sensitive to shock and friction, tetryl explodes at 187C and on contact with trioxygen difluoride. Tetryl will ignite when exposed to hydrazine and emit toxic fumes of nitrous and nitric oxide when heated to decomposition.

Workers at military facilities during World Wars I and II who breathed tetryl-laden dust complained of coughs, fatigue, headaches, eye irritation, lack of appetite, nosebleeds, nausea, and vomiting. Workers who routinely handled tetryl developed a distinct yellow staining of the hands, neck, and hair. Many workers who had skin contact with tetryl developed skin rashes. Some also developed allergies with asthma-like reactions (severe coughing and wheezing) after breathing tetryl. Rabbits fed high doses of tetryl every day for 6–9 months, developed effects on the kidneys and liver. Decreased blood-clotting capability and changes in the spleen were also noted. It is not known if these effects would occur in humans exposed to similar doses of tetryl, if tetryl causes birth defects, or if it affects reproduction in humans or animals.

No suitable cancer bioassays or epidemiological studies are available to assess the carcinogenicity of tetryl. The International Agency for Research on Cancer, the Department of Health and Human Services, and the EPA have not reviewed tetryl to determine whether it is likely to cause cancer.

2,4,6-Trinitrotoluene[1]

2,4,6-Trinitrotoluene (TNT) is a manmade, yellow crystalline solid used as a high explosive in military armaments and as a chemical intermediate in the manufacture of dyestuffs and photographic chemicals. TNT production in the United States occurs solely at military arsenals.

TNT is absorbed through the digestive tract, skin, and lungs. Workers involved in the production of explosives that were exposed to high concentrations of TNT in air experienced several harmful health effects, including anemia and abnormal liver function. Similar blood and liver effects, as well as spleen enlargement and other harmful effects on the immune system, have been observed in animals that ate or breathed TNT. Other effects in humans include skin irritation after prolonged skin contact and cataract development after long-term (365 days or longer) exposure. It is not known whether TNT can cause birth defects in humans. However, male animals treated with high doses of TNT have developed serious reproductive system effects.

No epidemiological evidence is available showing an association between chronic TNT exposure and tumorigenicity in humans. In animal carcinogenicity studies, a significant increase in urinary bladder papillomas and carcinomas was seen in rats. TNT is classified in weight-of-evidence Group C, possible human carcinogen.

References:

1 RAIS, 2005. Toxicity Profiles. Risk Assessment Information System. http://risk.lsd.ornl.gov/tox/rap_toxp.shtml

2 ATSDR, 2005. Toxicological Profiles. Agency for Toxic Substance and Disease Registry. http://www.atsdr.cdc.gov/toxprofiles/

3 USEPA, 2005. Integrated Risk Information System. Online. http://www.iris.gov

Attachment 2
Carcinogenic Risk Calculation Spreadsheets

See Electronic Files on Enclosed CD

Attachment 3
Non-Carcinogenic Risk Calculation Spreadsheets

See Electronic Files on Enclosed CD

Attachment 4
Technical Memorandum: Evaluation of Indoor Air Exposure to a Hypothetical Conservation Commission Worker in the Southern Conservation Commission Area and the Southern Disposal Area

TETRA TECH EC, INC.

To: Boyd Allen

From: Melanie Weed

CC: Ron Marnicio

Re: Evaluation of Indoor Air Exposure to a Hypothetical Conservation Commission Worker in the Southern Conservation Commission Area and the Southern Disposal Area
Fireworks Site

Date: August 3, 2005

As stated in the Fireworks Site Phase II Comprehensive Site Assessment's (CSA) Human Health Risk Characterization (HHRC), the GW-2 groundwater classification was not assumed to apply to the Southern Conservation Commission Area or the Southern Disposal Area since there are no current or planned buildings or structures in these areas. However, in MADEP comments on the Draft HHRC (dated June 29, 2005), it was stated that if it is possible that a building could be on these areas in the future and results in the potential for vapor intrusion and infiltration into indoor air, an Activity and Use Limitation (AUL) would need to be applied unless it is demonstrated that a level of significant risk does not exist for this scenario (MADEP, 2005). Therefore, the possible diffusion and migration of VOC contamination originating from groundwater beneath these areas was modeled to indoor air using the Johnson and Ettinger Model (JEM) for Subsurface Vapor Intrusion into Buildings (USEPA, 2003) for a hypothetical Conservation Commission Worker in these areas. This modeling is consistent with the modeling of potential vapor intrusion that was performed previously for the Upper North Area and the Lower North Area described in the HHRC.

The potential indoor air concentrations of the volatile COCs identified for the groundwater were estimated using the infinite source attenuation coefficient parameter calculated by the JEM. This attenuation coefficient, when multiplied by the dissolved groundwater concentration of the volatile COC (with the required unit conversions), provides an estimate of the indoor air concentration within the hypothetical future building. This indoor air volatile COC concentration was then combined with inhalation intake parameters to calculate an inhalation dose and risk. The exposure parameters used to estimate this dose for the hypothetical Conservation Commission Worker potentially working indoors were conservatively assumed as the same parameters used for the commercial worker, and are shown on Table A-6-2 in Appendix A of the Comprehensive Site Assessment (CSA). It should be noted that this hypothetical future receptor would not likely be in the assumed building for 250 days/year, like the Commercial Worker evaluated in the Upper North Area and Lower North Area. The estimation of the infinite source attenuation coefficient was performed separately for each identified volatile groundwater COC in the Southern Conservation Commission Area and the Southern Disposal Area since the parameter is dependent on a set of site- and location-specific parameters. This pathway evaluation was limited to only those constituents that are considered "volatile" according to the criteria that the constituent's vapor pressure is greater than 0.01 Torr (0.01 mm Hg) (the MADEP definition in the MCP – 310 CMR 40.0000). Location-specific depths to groundwater, soil type, stratigraphy, a reasonable building size, and chemical-specific properties were used in the estimation of the attenuation coefficient for each volatile COC in each of these two risk characterization areas.

Non-carcinogenic and carcinogenic risks were calculated for a future hypothetical Conservation Commission Worker in the Southern Conservation Commission Area and the Southern Disposal Area relative to exposure to volatiles in the indoor air from the upper overburden groundwater. The total cumulative Excess Lifetime Cancer Risk (ELCR) and Hazard Index (HI) for the Southern Conservation Commission Area were calculated to be 0 and 0.000002 (see Tables A4-1 and A4-2). The total cumulative ELCR and HI for the Southern Disposal Area were calculated to be 8.04×10^{-6} and 0.75 (see Tables A4-3 and A4-4). The ELCR and the HI estimates are below their acceptable MADEP benchmarks of 1×10^{-5} and 1.0, respectively. Based on these result, no AUL relative to potential vapor intrusion into the indoor air of a possible future building is necessary.

If you have any questions or concerns, please contact me at (617) 457-8255.

Reference:

MADEP, 2005. Email Correspondence with Laura Stanley of MADEP. Comments on the Fireworks Human Health Risk Characterization. June 29, 2005.

TABLES

Table:	A4-1
Risk Calculations for Carcinogenic Oil or Hazardous Materials	
Receptor Population:	Conservation Commission Worker
Receptor Age:	Adult
Scenario Timeframe:	Future
Medium:	Groundwater
Exposure Medium:	Upper Overburden Groundwater
Exposure Point:	Southern Conservation Commission Area
Exposure Route:	Inhalation
Site:	Fireworks Site

Lifetime Average Daily Dose$_{inh}$ [mg/kg-day] = OHM Concentration in Groundwater X Henry's Law Constant X Infinite Source Attenuation Coefficient X Conversion Factor X Ventilation Rate X Exposure Frequency X Exposure Duration X Exposure Period X 1/Body Weight X 1/Averaging Period - Carcinogen

RISK = LADD$_{inh}$ X Cancer Slope Factor

	[OHM]gw	H	A_∞	CI	VR	EF	ED	EP	BW	AP-C	SFi
Variable Symbols =	[OHM]gw	H	A_∞	CI	VR	EF	ED	EP	BW	AP-C	SFi
Parameter Values =	Site-Specific	Chemical-Specific	Calculated	1.000	1.20	1	8	9,125	57.1	27,375	Chemical Specific
Parameter Units =	[mg/L]	[unitless]	[unitless]	[L/m3]	[m3/hour]	[events/day]	[hours/event]	[days]	[kg]	[days]	[1/mg/kg-day]

Chemical Group	Oil or Hazardous Material	CAS Number	OHM Concentration in Groundwater [mg/L]	Henry's Law Constant [unitless]	Infinite Source Attenuation Coefficient [unitless]	Conversion Factor [L/m3]	Ventilation Rate [m3/hour]	Exposure Frequency [events/day]	Exposure Duration [hours/event]	Exposure Period [days]	Body Weight [kg]	Averaging Period - Carcinogen [days]	LADD$_{inh}$ [mg/kg-day]	Cancer Slope Factor (inhalation) [1/mg/kg-day]	Risk [unitless]
VOC	Acetone	67641	2.45E-03	8.47E-04	1.32E-03	1.000	1.20	1	8	9,125	57.1	27,375	1.54E-07	ND	-
MET	Aluminum	7429905	6.32E-02	-	-	1.000	1.20	1	8	9,125	57.1	27,375	-	ND	-
MET	Barium	7440393	1.70E-02	-	-	1.000	1.20	1	8	9,125	57.1	27,375	-	ND	-
MET	Calcium	7440702	3.61E+00	-	-	1.000	1.20	1	8	9,125	57.1	27,375	-	-	-
MET	Chromium (total)	7440473	1.18E-03	-	-	1.000	1.20	1	8	9,125	57.1	27,375	-	4.20E+01	-
MET	Cobalt	7440484	5.79E-03	-	-	1.000	1.20	1	8	9,125	57.1	27,375	-	9.80E+00	-
MET	Iron	7439896	3.79E+00	-	-	1.000	1.20	1	8	9,125	57.1	27,375	-	-	-
MET	Magnesium	7439954	1.65E+00	-	-	1.000	1.20	1	8	9,125	57.1	27,375	-	-	-
MET	Manganese	7439965	1.06E-01	-	-	1.000	1.20	1	8	9,125	57.1	27,375	-	ND	-
MET	Mercury	7439976	2.20E-04	-	-	1.000	1.20	1	8	9,125	57.1	27,375	-	ND	-
MET	Nickel	7440020	4.38E-01	-	-	1.000	1.20	1	8	9,125	57.1	27,375	-	8.40E-01	-
MET	Potassium	7440097	9.88E-01	-	-	1.000	1.20	1	8	9,125	57.1	27,375	-	-	-
MET	Selenium	7782492	1.25E-03	-	-	1.000	1.20	1	8	9,125	57.1	27,375	-	ND	-
MET	Silver	7440224	1.16E-03	-	-	1.000	1.20	1	8	9,125	57.1	27,375	-	ND	-
MET	Sodium	7440235	3.72E+00	-	-	1.000	1.20	1	8	9,125	57.1	27,375	-	-	-
MET	Vanadium	7440622	2.26E-03	-	-	1.000	1.20	1	8	9,125	57.1	27,375	-	-	-
MET	Zinc	7440666	5.68E-03	-	-	1.000	1.20	1	8	9,125	57.1	27,375	-	ND	-
EXP	Nitroglycerin	55630	4.88E-03	-	-	1.000	1.20	1	8	9,125	57.1	27,375	-	1.40E-02	-

Exposure Route-Specific Excess Lifetime Cancer Risk = -

Notes:
ND No Data Available; - Not Applicable
VOC = Volatile Organic Compound; MET = Metal; EXP = Explosive Compound

Table:	A4-1
Risk Calculations for Carcinogens, Oil or Hazardous Materials	
Receptor Population:	Conservation Commission Worker
Receptor Age:	Adult
Scenario Timeframe:	Future
Medium:	Groundwater
Exposure Medium:	Upper Overburden Groundwater
Exposure Point:	Southern Disposal Area
Exposure Route:	Inhalation
Site:	Fireworks Site

Lifetime Average Daily Dose = [mg/kg-day] = OHM Concentration in Groundwater X Henry's Law Constant X Infinite Source Attenuation Coefficient X Conversion Factor X Ventilation Rate X Exposure Frequency X Exposure Duration X Exposure Period X 1/Body Weight X 1/Averaging Period - Carcinogen

RISK = LADD$_{inh}$ X Cancer Slope Factor

	OHM Concentration	Henry's Law Constant	Attenuation Coefficient	Conversion Factor	Ventilation Rate	Exposure Frequency	Exposure Duration	Exposure Period	Body Weight	Averaging Period - Carcinogen	Cancer Slope Factor
Variable Symbols =	[OHM]gw	H	A_g	CF	VR	EF	ED	EP	BW	AP-C	SFi
Parameter Values =	Site-Specific	Chemical-Specific	Calculated	1,000	1.20	1	8	9,125	57.1	27,375	Chemical Specific
Parameter Units =	[mg/L]	[unitless]	[unitless]	[L/m3]	[m3/hour]	[events/day]	[hours/event]	[days]	[kg]	[days]	[1/mg/kg-day]

Chemical Group	Oil or Hazardous Material	CAS Number	OHM Concentration in Groundwater [mg/L]	Henry's Law Constant [unitless]	Infinite Source Attenuation Coefficient [unitless]	Conversion Factor [L/m3]	Ventilation Rate [m3/hour]	Exposure Frequency [events/day]	Exposure Duration [hours/event]	Exposure Period [days]	Body Weight [kg]	Averaging Period - Carcinogen [days]	LADD$_{inh}$ [mg/kg-day]	Cancer Slope Factor (inhalation) [1/mg/kg-day]	Risk [unitless]
VOC	Acetone	67641	5.81E-02	8.47E-04	1.59E-03	1,000	1.20	1	8	9,125	57.1	27,375	4.40E-06	ND	-
VOC	Benzene	71432	5.66E-02	1.15E-01	8.06E-04	1,000	1.20	1	8	9,125	57.1	27,375	2.95E-04	2.73E-02	8.04E-06
VOC	1,2-Dichloroethene (total)	540590	5.77E-03	9.77E-02	2.04E-04	1,000	1.20	1	8	9,125	57.1	27,375	2.00E-04	ND	-
VOC	cis-1,2-Dichloroethene	156592	5.76E-03	8.77E-02	2.04E-04	1,000	1.20	1	8	9,125	57.1	27,375	1.99E-04	ND	-
VOC	Freon TF	76131	3.67E+00	1.11E+01	7.27E-04	1,000	1.20	1	8	9,125	57.1	27,375	1.66E+00	ND	-
VOC	Toluene	108883	5.64E-03	1.26E-01	7.98E-04	1,000	1.20	1	8	9,125	57.1	27,375	3.17E-04	ND	-
MET	Aluminum	7429905	6.47E-01	-	-	1,000	1.20	1	8	9,125	57.1	27,375	-	ND	-
MET	Arsenic	7440382	1.20E-03	-	-	1,000	1.20	1	8	9,125	57.1	27,375	-	1.51E+01	-
MET	Barium	7440393	3.47E-02	-	-	1,000	1.20	1	8	9,125	57.1	27,375	-	ND	-
MET	Cadmium	7440439	1.43E-04	-	-	1,000	1.20	1	8	9,125	57.1	27,375	-	6.30E+00	-
MET	Calcium	7440702	6.78E+00	-	-	1,000	1.20	1	8	9,125	57.1	27,375	-	-	-
MET	Chromium (total)	7440473	3.47E-03	-	-	1,000	1.20	1	8	9,125	57.1	27,375	-	4.20E+01	-
MET	Cobalt	7440484	3.41E-02	-	-	1,000	1.20	1	8	9,125	57.1	27,375	-	9.80E+00	-
MET	Iron	7439896	1.40E+01	-	-	1,000	1.20	1	8	9,125	57.1	27,375	-	-	-
MET	Lead	7439921	3.65E-01	-	-	1,000	1.20	1	8	9,125	57.1	27,375	-	4.20E-02	-
MET	Magnesium	7439954	4.33E+00	-	-	1,000	1.20	1	8	9,125	57.1	27,375	-	-	-
MET	Manganese	7439965	1.26E+00	-	-	1,000	1.20	1	8	9,125	57.1	27,375	-	ND	-
MET	Nickel	7440020	7.71E-01	-	-	1,000	1.20	1	8	9,125	57.1	27,375	-	8.00E-01	-
MET	Potassium	7440097	3.90E+00	-	-	1,000	1.20	1	8	9,125	57.1	27,375	-	-	-
MET	Selenium	7782492	9.00E-04	-	-	1,000	1.20	1	8	9,125	57.1	27,375	-	ND	-
MET	Sodium	7440235	1.64E+01	-	-	1,000	1.20	1	8	9,125	57.1	27,375	-	-	-
MET	Thallium	7440280	2.79E-03	-	-	1,000	1.20	1	8	9,125	57.1	27,375	-	ND	-
MET	Vanadium	7440622	3.63E-03	-	-	1,000	1.20	1	8	9,125	57.1	27,375	-	-	-
MET	Zinc	7440666	1.19E-02	-	-	1,000	1.20	1	8	9,125	57.1	27,375	-	ND	-
EXP	HMX	2691410	6.95E-04	-	-	1,000	1.20	1	8	9,125	57.1	27,375	-	ND	-
EXP	RDX	121824	6.17E-04	-	-	1,000	1.20	1	8	9,125	57.1	27,375	-	1.10E-01	-
TPH	Motor Oil	-	6.29E-01	-	-	1,000	1.20	1	8	9,125	57.1	27,375	-	-	-

Exposure Route-Specific Excess Lifetime Cancer Risk = 8.04E-06

Notes:
ND No Data Available; - Not Applicable
VOC = Volatile Organic Compound, SVOC = Semi-Volatile Organic Compound; MET = Metal, EXP = Explosive Compound

Table:	A4-3
Risk Calculations for Noncarcinogenic Oil or Hazardous Materials	
Receptor Population:	Conservation Commission Worker
Receptor Age:	Adult
Scenario Timeframe:	Future
Medium:	Groundwater
Exposure Medium:	Upper Overburden Groundwater
Exposure Point:	Southern Conservation Commission Area
Exposure Route:	Inhalation
Site:	Fireworks Site

Average Daily Dose [mg/kg-day] = OHM Concentration in Groundwater x Henry's Law Constant x Infinite Source Attenuation Coefficient x Conversion Factor x Ventilation Rate x Exposure Frequency x Exposure Duration x Exposure Period x 1 / Body Weight x 1 / Averaging Period- Non Carcinogen

HAZARD QUOTIENT = ADD$_{nc}$ / Reference Dose

	OHM Concentration	Henry's Law Constant	Attenuation Coefficient	Conversion Factor	Ventilation Rate	Exposure Frequency	Exposure Duration	Exposure Period	Body Weight	Averaging Period	Reference Dose
Variable Symbols =	[OHM]gw	H	$\alpha_{s\infty}$	CI	VR	EF	ED	EP	BW	AP-N	RfD (inhalation)
Parameter Values =	Site-Specific	Chemical Specific	Calculated	1,000	1.20	1	8	9,125	57.1	9,125	Chemical Specific
Parameter Units =	[mg/L]	[unitless]	[unitless]	[L/m3]	[m3/hour]	[events/day]	[hours/event]	[days]	[kg]	[days]	[mg/kg-day]

Chemical Group	Oil or Hazardous Material	CAS Number	OHM Concentration in Groundwater, [mg/L]	Henry's Law Constant [unitless]	Infinite Source Attenuation Coefficient [unitless]	Conversion Factor [L/m3]	Ventilation Rate [m3/hour]	Exposure Frequency [events/day]	Exposure Duration [hours/event]	Exposure Period [days]	Body Weight [kg]	Averaging Period- Non Carcinogen [days]	ADD$_{nc}$ [mg/kg-day]	Chronic Reference Dose (inhalation) [mg/kg-day]	HAZARD QUOTIENT [unitless]
VOC	Acetone	67641	2.45E-03	8.47E-04	1.32E-03	1,000	1.20	1	8	9,125	57.1	9,125	4.61E-07	2.29E-01	2.02E-06
MET	Aluminum	7429905	6.32E-02	-	-	1,000	1.20	1	8	9,125	57.1	9,125	-	1.40E-03	-
MET	Barium	7440393	1.70E-02	-	-	1,000	1.20	1	8	9,125	57.1	9,125	-	1.43E-04	-
MET	Calcium	7440702	2.61E+01	-	-	1,000	1.20	1	8	9,125	57.1	9,125	-	-	-
MET	Chromium (total)	7440473	1.19E-03	-	-	1,000	1.20	1	8	9,125	57.1	9,125	-	2.86E-05	-
MET	Cobalt	7440484	5.79E-03	-	-	1,000	1.20	1	8	9,125	57.1	9,125	-	2.86E-05	-
MET	Iron	7439896	1.79E+00	-	-	1,000	1.20	1	8	9,125	57.1	9,125	-	-	-
MET	Magnesium	7439954	1.65E+00	-	-	1,000	1.20	1	8	9,125	57.1	9,125	-	-	-
MET	Manganese	7439965	1.06E-01	-	-	1,000	1.20	1	8	9,125	57.1	9,125	-	1.43E-05	-
MET	Mercury	7439976	2.20E-04	-	-	1,000	1.20	1	8	9,125	57.1	9,125	-	8.57E-05	-
MET	Nickel	7440020	4.38E-01	-	-	1,000	1.20	1	8	9,125	57.1	9,125	-	2.86E-04	-
MET	Potassium	7440097	9.85E-01	-	-	1,000	1.20	1	8	9,125	57.1	9,125	-	-	-
MET	Selenium	7782492	1.25E-03	-	-	1,000	1.20	1	8	9,125	57.1	9,125	-	8.57E-04	-
MET	Silver	7440224	1.16E-03	-	-	1,000	1.20	1	8	9,125	57.1	9,125	-	4.00E-05	-
MET	Sodium	7440235	3.72E+00	-	-	1,000	1.20	1	8	9,125	57.1	9,125	-	-	-
MET	Vanadium	7440622	2.26E-03	-	-	1,000	1.20	1	8	9,125	57.1	9,125	-	-	-
MET	Zinc	7440666	3.65E-03	-	-	1,000	1.20	1	8	9,125	57.1	9,125	-	3.00E-04	-
EXP	Nitroglycerin	55630	4.88E-03	-	-	1,000	1.20	1	8	9,125	57.1	9,125	-	-	-

Exposure Route Specific Hazard Index = 2.02E-06

Notes:
ND: No Data Available; - Not Applicable
VOC = Volatile Organic Compound, MET = Metal, EXP = Explosive Compound

Table:	A4-4
Risk Calculations for Noncarcinogenic Oil or Hazardous Materials	
Receptor/Population:	Conservation Commission Worker
Receptor Age:	Adult
Scenario Timeframe:	Future
Medium:	Groundwater
Exposure Medium:	Upper Overburden Groundwater
Exposure Point:	Southern Disposal Area
Exposure Route:	Inhalation
Site:	Fireworks Site

Average Daily Dose = OHM Concentration in Groundwater X Henry's Law Constant X Infinite Source Attenuation Coefficient X Conversion Factor X Ventilation Rate X Exposure Frequency X Exposure Duration X Exposure Period X 1/Body Weight X 1/Averaging Period- Non Carcinogen

HAZARD QUOTIENT = ADD_{ns} / Reference Dose

	Average Daily Dose [mg/kg-day]	OHM Concentration in Groundwater	Henry's Law Constant	Infinite Source Attenuation Coefficient	Conversion Factor	Ventilation Rate	Exposure Frequency	Exposure Duration	Exposure Period	Body Weight	Averaging Period- Non Carcinogen	Reference Dose
Variable Symbols =		[OHM]gw	H	a_{is}	CF	VR	EF	ED	EP	BW	AP-N	RfD (inhalation)
Parameter Values =		Site-Specific	Chemical-Specific	Calculated	1,000	1.20	1	8	9,125	57.1	9,125	Chemical Specific
Parameter Units =		[mg/L]	[unitless]	[unitless]	[L/m3]	[m3/hour]	[events/day]	[hours/event]	[days]	[kg]	[days]	[mg/kg-day]

Chemical Group	Oil or Hazardous Material	CAS Number	OHM Concentration in Groundwater [mg/L]	Henry's Law Constant [unitless]	Infinite Source Attenuation Coefficient [unitless]	Conversion Factor [L/m3]	Ventilation Rate [m3/hour]	Exposure Frequency [events/day]	Exposure Duration [hours/event]	Exposure Period [days]	Body Weight [kg]	Averaging Period- Non-Carcinogen [days]	ADD_{ns} [mg/kg-day]	Chronic Reference Dose (inhalation) [mg/kg-day]	HAZARD QUOTIENT [unitless]
VOC	Acetone	67641	5.81E-02	8.47E-04	1.59E-03	1,000	1.20	1	8	9,125	57.1	9,125.0	3.32E-05	2.29E-01	5.77E-05
VOC	Benzene	71432	5.66E-02	1.15E-01	8.06E-04	1,000	1.20	1	8	9,125	57.1	9,125.0	8.84E-04	8.57E-03	1.03E-01
VOC	1,2-Dichloroethene (total)	540590	5.77E-02	8.77E-02	7.04E-04	1,000	1.20	1	8	9,125	57.1	9,125.0	5.99E-04	3.14E-01	1.90E-03
VOC	cis-1,2-Dichloroethene	156592	5.76E-02	8.77E-02	7.04E-04	1,000	1.20	1	8	9,125	57.1	9,125.0	5.98E-04	1.00E-02	5.98E-02
VOC	Freon TF	76131	3.67E+00	1.11E+01	7.27E-04	1,000	1.20	1	8	9,125	57.1	9,125.0	4.97E+00	8.57E+00	5.80E-01
VOC	Toluene	108883	5.64E-02	1.26E-01	7.99E-04	1,000	1.20	1	8	9,125	57.1	9,125.0	9.42E-04	1.14E-01	8.33E-03
MET	Aluminum	7429905	6.47E-03	-	-	1,000	1.20	1	8	9,125	57.1	9,125.0	-	1.40E-03	-
MET	Arsenic	7440382	3.20E-03	-	-	1,000	1.20	1	8	9,125	57.1	9,125.0	-	7.14E-07	-
MET	Barium	7440393	3.47E-02	-	-	1,000	1.20	1	8	9,125	57.1	9,125.0	-	1.43E-04	-
MET	Cadmium	7440439	3.43E-04	-	-	1,000	1.20	1	8	9,125	57.1	9,125.0	-	5.71E-06	-
MET	Calcium	7440702	6.78E+00	-	-	1,000	1.20	1	8	9,125	57.1	9,125.0	-	-	-
MET	Chromium (total)	7440473	3.47E-03	-	-	1,000	1.20	1	8	9,125	57.1	9,125.0	-	2.86E-05	-
MET	Cobalt	7440484	1.41E-02	-	-	1,000	1.20	1	8	9,125	57.1	9,125.0	-	2.86E-05	-
MET	Iron	7439896	1.40E+01	-	-	1,000	1.20	1	8	9,125	57.1	9,125.0	-	-	-
MET	Lead	7439921	3.65E-01	-	-	1,000	1.20	1	8	9,125	57.1	9,125.0	-	2.86E-04	-
MET	Magnesium	7439954	1.33E+00	-	-	1,000	1.20	1	8	9,125	57.1	9,125.0	-	-	-
MET	Manganese	7439965	1.16E+00	-	-	1,000	1.20	1	8	9,125	57.1	9,125.0	-	1.43E-05	-
MET	Nickel	7440020	7.71E-01	-	-	1,000	1.20	1	8	9,125	57.1	9,125.0	-	2.86E-04	-
MET	Potassium	7440097	1.80E+00	-	-	1,000	1.20	1	8	9,125	57.1	9,125.0	-	-	-
MET	Selenium	7782492	9.00E-04	-	-	1,000	1.20	1	8	9,125	57.1	9,125.0	-	8.57E-04	-
MET	Sodium	7440235	1.64E+01	-	-	1,000	1.20	1	8	9,125	57.1	9,125.0	-	-	-
MET	Thallium	7440280	2.00E-03	-	-	1,000	1.20	1	8	9,125	57.1	9,125.0	-	4.00E-06	-
MET	Vanadium	7440622	3.63E-03	-	-	1,000	1.20	1	8	9,125	57.1	9,125.0	-	-	-
MET	Zinc	7440666	1.19E-02	-	-	1,000	1.20	1	8	9,125	57.1	9,125.0	-	4.00E-04	-
EXP	HMX	2691410	6.93E-04	-	-	1,000	1.20	1	8	9,125	57.1	9,125.0	-	5.14E-02	-
EXP	RDX	121824	6.17E-04	-	-	1,000	1.20	1	8	9,125	57.1	9,125.0	-	3.14E-03	-
TPH	Motor Oil	-	6.29E-01	-	-	1,000	1.20	1	8	9,125	57.1	9,125.0	-	-	-

Exposure Route Specific Hazard Index = 7.53E-01

Notes
ND: No Data Available; - Not Applicable
VOC = Volatile Organic Compound; SVOC = Semi Volatile Organic Compound; MET = Metal; EXP = Explosive Compound

Appendix B
Final Environmental Risk Characterization Report

TETRA TECH EC, INC.

APPENDIX B

FINAL
COMPREHENSIVE SITE ASSESSMENT
ENVIRONMENTAL RISK CHARACTERIZATION REPORT

FIREWORKS I
(FORMER FIREWORKS FACILITY)
HANOVER, MASSACHUSETTS
TIER IA PERMIT #100223
RTN: 4-0090

November 2005

Prepared for

The Fireworks Site Joint Defense Group

Prepared by

Tetra Tech EC, Inc.
133 Federal Street 6th Floor
Boston, Massachusetts 02110

SGS ISO14001

TETRA TECH EC, INC.

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ISO 9001 SGS

Revision	Date	Prepared By	Approved By	Pages Affected
1	11/09/05	J. Schaffer	B. Allen	All

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LIST OF ATTACHMENTS

ABBREVIATIONS AND ACRONYMS

°C	degrees Celsius
°F	degrees Fahrenheit
ANOVA	analysis of variance
ASTM	American Society of Testing Materials
AWQC	Ambient Water Quality Criteria
BAF	bioaccumulation factor
BCF	bioconcentration factor
bgs	below ground surface
CCA	Central Commercial Area
CLI	Community Loss Index
cm	centimeter
COPEC	chemical of potential environmental concern
CPUE	catch per unit effort
CSA	Phase II Comprehensive Site Assessment
CSM	Conceptual Site Model
CTrSI	community trophic similarity index
CTSI	community taxa similarity index
DI	deionized
DO	dissolved oxygen
DPW	Department of Public Works
dry wt.	dry weight
ECC	Eastern Channel Corridor
EPUS	encounters per unit search
ERC	Environmental Risk Characterization
FEMA	Federal Emergency Management Administration
FP	Forge Pond
FPA	Floodplain Area
ft	feet or foot
FWENC	Foster Wheeler Environmental Corporation
Ha	hectares
HHRC	Human Health Risk Characterization
HQ	hazard quotient
HSDB	Hazardous Substances Database
IRIS	Integrated Risk Information System
km	kilometers
lb	pound
LCV	lowest chronic value
LDS	Lower Drinkwater River Corridor
LEL	lowest effects level
LNA	Lower North Area
LOAEL	lowest observable adverse effects level
LOEC	lowest observable effect concentration
LUFP	Lily Pond/Upper Factory Pond
MADEP	Massachusetts Department of Environmental Protection
MADFW	Massachusetts Division of Fisheries and Wildlife
MCP	Massachusetts Contingency Plan
mg/Kg	milligrams per kilogram
mg/L O_2	milligram per liter of oxygen
MLFP	Middle/Lower Factory Pond
mS/cm	millisiemen per centimeter

MS/MSD	matrix spike/matrix spike duplicates
msl	mean sea level
MUA	Marsh Upland Area
mV	millivolt
NDR	Northern Drinkwater River
NFESC	Naval Facilities Engineering Service Center
NFMR	normalized free living metabolic rate
ng/g	nannogram per gram
NHESP	Natural Heritage and Endangered Species Program
NOAEL	no observable adverse effect level
NOEC	no observable effects concentration
NTU	nephelometric turbidity unit
NWI	National Wetland Inventory
OHM	oil or hazardous material
ORNL	Oak Ridge National Laboratory
ORP	oxidation-reduction potential
PAHs	polycyclic aromatic hydrocarbons
PCBs	polychlorinated biphenyls
PEC	probable effect concentration
PGA	Potential Greenway Area
PVC	polyvinyl chloride
QA	quality assurance
QAP	Quality Assurance Plan
QC	quality control
RPD	relative percent difference
SCCA	Southern Conservation Commission Area
SDA	Southern Disposal Area
SEL	severe effect level
SEM/AVS	simultaneous extractable metals/acid volatile sulfides
SOW	Scope of Work
SVOCs	semivolatile organic compounds
SWDI	Shannon-Weiner Diversity Index
TAL	Target Analyte List
TEC	threshold effect concentration
TEL	threshold effect level
TOC	total organic carbon
TRV	Toxicity Reference Value
TSI	taxa similarity index
TtEC	Tetra Tech EC Inc.
TtFW	Tetra Tech FW, Inc.
UDC	Upper Drinkwater River Corridor
ug/Kg	micrograms per kilogram
ug/L	micrograms per liter
umol/g_{oc}	micromoles per gram of organic carbon
UNA	Upper North Area
USCS	Unified Soil Classification System
USEPA	U.S. Environmental Protection Agency
UXO	unexploded ordnance
VOCs	volatile organic compounds
WBK	wetland background area
wet wt.	wet weight
WTV	weighted tolerance value

1.0 INTRODUCTION

Tetra Tech EC, Inc. (TtEC) performed a Stage II Environmental Risk Characterization (ERC) for the Fireworks Site (the Site) in Hanover, Massachusetts. The ERC was conducted in accordance with the Massachusetts Contingency Plan (MCP) as administered by the Massachusetts Department of Environmental Protection (MADEP) (MADEP, 1996) as part of the Phase II Comprehensive Site Assessment.

1.1 Problem Statement and Summary of the Stage I Screening Assessment

The Site is located within the towns of Hanover and Hanson, Massachusetts and is divided into three general areas (Northern Area, Central Area and Southern Area) based on the different historic uses and habitats observed. All aquatic habitats are classified as ponds and/or impoundments (i.e., lentic habitats) or streams and rivers (i.e., lotic habitats). Wetlands exist on the Site and are classified by the National Wetland Inventory classification system.

Sources of data for the ERC included the following documents:

- Phase I Site Investigation Report: Fireworks I (Former Fireworks Facility) Hanover, MA (FWENC, 1997)
- Phase IIB Site Investigation Draft Data Report: Fireworks I (Former Fireworks Facility) Hanover, MA, Tier IA Permit #100233 (FWENC, 2000)
- Scope of Work for Phase IIC Investigation: Fireworks I (Former Fireworks Facility) Hanover, MA, Tier IA Permit #100233 (FWENC, 2001)
- Data Report for Phase IIC Investigation: Fireworks I (Former Fireworks Facility) Hanover, MA, Tier IA Permit #100233 (FWENC, 2002)
- Data Report for Phase IID Investigation: Fireworks I (Former Fireworks Facility) Hanover, MA, Tier IA Permit #100233 (TtFW, 2004)

Conservative screening level benchmarks protective of a broad base group of species at the community level were used to screen concentrations of contaminants in surface soils, surface water, freshwater sediments and groundwater. The initial benchmark screening evaluation revealed maximum concentrations of preliminary contaminants of potential ecological concern (COPECs) exceeded the corresponding benchmarks. The following summary presents the findings of the screening level evaluation by environmental media:

1.1.1 Surface Soil

- The Central and Southern Areas of the Site contain terrestrial habitats capable of supporting native vegetation covertypes and wildlife.
- Oil or Hazardous Material (OHM) has been detected in surface soils in the three areas evaluated within the project boundary where exposure to terrestrial biological receptors (including plants, soil invertebrates, mammals, birds, amphibians, and reptiles) may occur.
- Exposure pathways for terrestrial receptors were identified and found to be complete with regard to potential exposure to Site-related OHM.
- The eastern box turtle (*Terrapene carolina*), a species of special concern in Massachusetts, has been identified in the vicinity of the Site based upon the Massachusetts Division of

Fisheries and Wildlife (MADFW) Natural Heritage and Endangered Species Program (NHESP) (2002). The eastern box turtle utilizes both terrestrial and wetland habitats and may be utilizing the wetland and terrestrial habitats surrounding Factory and Lily Ponds.

- No Areas of Critical Environmental Concern or Vernal Ponds have been identified on the Site based upon the MADFW NHESP database (2002).
- Maximum concentrations of select metals, volatile organic compounds (VOCs) and semivolatile organic compounds (SVOCs) in soils exceed terrestrial screening level benchmarks in all three general areas.
- Mercury was identified as having the highest associated exposure quotient of the OHM evaluated.

1.1.2 Surface Water and Sediments

- The Site contains aquatic habitats capable of supporting terrestrial, semi-aquatic, and aquatic fish and wildlife including semi-aquatic birds and mammals, reptiles and amphibians, fish, and aquatic invertebrates.
- OHM has been detected in sediment and surface water in areas supporting aquatic wildlife.
- Exposure pathways for ecological receptors were identified and found to be complete with regard to potential exposure to Site-related OHM.
- The spotted turtle (*Clemmys guttata*), a species of special concern in Massachusetts has been identified in the vicinity of the Site based upon the MADFW NHESP database (2002).
- No Areas of Critical Environmental Concern or Vernal Ponds have been identified on the Site based upon the MADFW NHESP database.
- Maximum concentrations of select metals, select VOCs and SVOCs from soil on the Site exceeded screening level benchmarks.
- Mercury was identified as having the greatest concentration gradient associated within the sediment. The highest concentrations of mercury were found in the lotic environments of the Eastern Channel Corridor of the Drinkwater River.

1.1.3 Groundwater

- OHM has been detected in groundwater in all areas evaluated and has the potential to discharge to surface water bodies.
- Exposure pathways for ecological receptors were identified and found to be complete with regard to potential exposure to Site-related OHM via groundwater discharge to surface water.
- Maximum concentrations of metals in groundwater exceed surface water screening level benchmarks in the Southern Area.

The above findings resulted in the decision to continue the MCP process through use of Site-specific studies in a Stage II ERC. The Stage II ERC will reduce uncertainties in the initial assessment through the use of Site-specific studies and support the risk management phase for the Site. This process is consistent with the tiered approach of the MCP for performing environmental risk characterizations (MADEP, 1996).

1.2 Natural Resources

As described in the Phase I report (FWENC, 1997), a database search of natural resources on the Site yielded the following results:

- No public water supplies, Zone II areas, Interim Well Head Protection Areas or private wells were identified.
- The majority of the on-Site area is considered a medium yield, potentially productive aquifer which is classified as a Non-Potential Drinking Water Source Area.
- No Sole Source Aquifers were identified.
- No vernal pools were identified.
- No habitats of special concern were identified.
- There is a Fish Consumption Advisory for Factory Pond fish as recommended by the Massachusetts Department of Public Health.

Based on field work performed in the Phase IID investigation (TtFW, 2004):

- One endangered species (eastern black ratsnake, *Elaphe obsolete obsolete*), one threatened species (eastern spadefoot toad, *Scaphiopus holbrooki holbrooki*), and one species of special concern (eastern pond mussel, *Ligumia nasuta*) were present on the Site.
- There is a corridor of protected open space on-Site along both sides of the Drinkwater River and Factory Pond that includes land owned by the Hanover Conservation Commission.

The total land area of the Fireworks Site is approximately 250 acres. A Site reconnaissance was conducted as part of a preliminary ecological inspection for the Site. This reconnaissance allowed for a general overview of the Site and the ecological communities currently present. For purposes of discussion, the Site will be discussed as three separate areas: Northern Area, Central Area and Southern Area.

1.3 Vegetation Covertypes and Land Use

1.3.1 Northern Area

The Northern Area of the Site represents the most developed of the three areas and includes historically active and currently active properties. This area is defined by the extreme northern property line located to the south of Torrey Brook, a tributary of the Drinkwater River. This portion of the Site historically supported the manufacture and production of pyrotechnics and munitions. Facilities formerly located in this area included laboratories for formulation and testing; production facilities for mines, primers and detonators; explosives loading facilities; and research and development laboratories. Throughout this area was evidence of dumping of construction debris and trespassing as evidenced by tire tracks and shotgun shells. Current active parcels of the Northern Area include the Town of Hanover's Department of Public Works (DPW) garage, a car repair shop and a lumber mill/yard. Abandoned portions from the former Fireworks operation are overgrown with structures that are in various stages of deterioration. Additionally, the area is criss-crossed by deteriorated asphalt and dirt roads along the buildings. Vegetation was dominated by secondary growth broad-leaved deciduous trees with scattered clusters of conifers. Dominant deciduous tree species included oaks, birches, aspens and maples. Conifers identified included white pine, red pine and red cedar. Areas where deteriorated structures were present typically supported younger stands of aspen, alder and a denser scrub-shrub layer than areas that appeared to be indicative of less disturbance, which supported a denser primary canopy of trees. Scrub-shrub species in the secondary canopy included multiflora rose, spice bush, witch hazel, and saplings of aspen and alder.

The existing channel of the Drinkwater River parallels the eastern property boundary in the Northern Area. The Drinkwater River channel in this portion of the Site is well defined with dense, woody vegetation dominating riparian areas. Water velocity at the time of observation was sluggish with the channel showing little tendency to meander along its course. Bottom sediments based upon qualitative observations varied widely between areas of pebble and gravel to areas of softer, finer grained sands/silt with a dense leaf pack. Flow within the river channel is diverted in the Northern Area by means of a manmade channel which continues to the east before turning south and discharging back into the main channel of the Drinkwater River. Flow within this diversion channel appeared minimal though evidence of deposited flotsam suggested that storm events likely increase water passage in the diversion channel. Torrey Brook is a tributary that originates off of the Site to the east. The Torrey Brook channel transects the Site and discharges into the Drinkwater River north of the Lily Pond impoundment portion of the river.

1.3.2 Central Area

The Central Area of the Site functioned as the primary magazine area for the storage of manufactured munitions and pyrotechnics during facility operation. The degree of development within this area is greatly diminished and is limited to widely scattered, deteriorated bunkers formerly used to house munitions. In addition, there are scattered structures that functioned as storage facilities and temporary lay down areas for equipment. All access roads in this area were unimproved dirt roads. Evidence of recent dumping of construction debris and tires was observed along the roadways. Vegetation within this area contrasted to that observed in the Northern Area. The area remained forested with the primary tree canopy dominated by white pine and red pine with a more limited representation by deciduous species. Canopy coverage within this area remains largely continuous with pine tree diameter and height appearing very similar across the area. This continuous, consistent vegetation cover type suggested that little disturbance to the area had occurred during historical Site activities. Understory vegetation remained sparse with slightly greater density occurring along the dirt access roads. In these areas, understory shrubs included pine saplings, multiflora rose, and oak, birch and alder saplings. The Drinkwater River enters its first impounded area, Lily Pond, in the Central Area. Water velocity slows at the inlet and the surface area of the channel expands to form the basin of Lily Pond. The Drinkwater River channel is reformed as the outlet from Lily Pond for a short distance before forming the inlet to Factory Pond. No bathymetric profiles are available for Lily Pond; however, it is expected to remain shallow throughout. Bottom substrates along the shoreline were largely fine grained with leaf packs. Emergent vegetation included rushes, burreeds, and cattails. Arrowhead and duckweed were the dominant floating aquatic plants observed.

1.3.3 Southern Area

The Southern Area of the Site was historically used for disposal of Site-related wastes and testing of munitions and pyrotechnics. The area is also evidenced by extensive recent dumping activities by trespassers including building debris, tires, household refuse and spent shotgun shells. The Southern Area is crossed by dirt roads that connect various disposal and source areas. These areas include the Waste Burn Pit, Factory Pond Drum Area, the Former Test Range Area, the Demolition Pit Area and the Cold Waste Area. In addition to the above areas, a perched scrub-shrub, emergent upland marsh is located down slope from the Demolition Pit Area. Additionally, the former Cold Waste Area was where scrap metal was deposited adjacent to the shoreline areas of Factory Pond. The former disposal and testing areas there still have exposed soils and are clear of vegetation to some degree with some secondary re-growth beginning to infringe along the periphery of these areas. The individual waste disposal areas remained separated by more mature, continuous stands of secondary growth, deciduous forest with scattered conifer stands similar in composition to those described in the Northern Area. A detectable current from the Drinkwater River is not apparent in Factory Pond and the impoundment basin remains fully within the Site boundary. Factory Pond is divided into two sub-basins by a constriction in the shore that formerly supported a wooden bridge structure to the south of the Cold Waste Area. The areas surrounding the Waste Burn Pit, Factory Pond Drum Area and Cold Waste Area appear to be draining into the upper Factory Pond basin. Surface water runoff from the Demolition Pit Area drains into the marsh uplands adjacent to the lower basin of Factory Pond. The basin is characterized by a diverse assemblage of riparian vegetation covertypes including emergent wetland plants, scrub-shrub species and areas of palustrine wetlands composed of cedar, aspen and sycamore saplings. Water coloration within the Factory Pond basin was tea colored suggesting a high humic acid content. Drainages from surrounding swamps form an unnamed tributary which discharges along the eastern shoreline of Factory Pond. The upper basin shoreline remains very complex with regard to riparian and wetland vegetation types.

1.3.4 Aquatic Environments

Aquatic habitats present within the Site boundary or that traverse the property include the Drinkwater River, a diversion channel of the river on the Site property (Eastern Channel Corridor), and a smaller tributary of the river known as Torrey Brook. The Drinkwater River forms a riverine corridor that parallels the western perimeter of the Site. The Drinkwater River traverses the northern boundary of the Site and the main riverine channel is diverted in part into the eastern channel that directs flow around the Northern Area of the Site. This eastern channel is estimated to be 0.8 linear miles in total length and meanders in an easterly direction before turning south-southwest and discharging back into the main channel of the Drinkwater River.

Surface water flow and the hydrology of the Drinkwater River are influenced by Factory Pond Dam, an earthen and concrete dam located southeast of the Site. Additionally, the shoreline of the impoundment behind the dam is highly erratic in nature with wide variations in shoreline constriction causing the formation of several continuous sub-basins identified as Lily Pond, Upper Factory Pond and Lower Factory Pond. The river channel below the Factory Pond Dam becomes the Indian Head River and continues downstream into several small impoundments including Luddam's Ford.

The Drinkwater River, its tributaries and impoundments are classified as Class B waters by the MADEP. Class B waters are designated to be a suitable habitat for fish and other aquatic life, a suitable habitat for wildlife, and suitable for primary and secondary contact recreation. Class B waters are also designated to be a suitable source of water supply with appropriate treatment, a suitable source for irrigation and other agricultural uses, a suitable source for compatible industrial cooling and process uses, and should have consistently good aesthetic value. MADFW also collectively classifies the Drinkwater River, its tributaries and its impoundments as supporting warm water fisheries. Warm water fisheries are defined as waters in which the maximum mean monthly temperature generally exceeds 68°F (20°C) during the summer months and are not capable of sustaining a year-round population of coldwater, stenothermal aquatic life. Water temperatures of sampled habitats were measured during August (summertime) and exceeded 20°C (Table B-1-1). The fish community sampled was representative of warm water environments.

Aquatic sampling station locations can be found on Plate 1 in the CSA. The riverine reference station (NDRTRA10) was located in the Upper Drinkwater River just before the inlet to Forge Pond. The Upper Drinkwater River study area above Forge Pond has 1.69 kilometers (km) (5,545 ft) of shoreline and an area of 12.85 acres (5.2 hectares [Ha] Table B-1-2). The pond reference station (FPTRA10) was located in the southern section of Forge Pond just off the Site. Forge Pond has 5,545 ft (1.69 km) of shoreline and an area of 21.79 acres (8.82 Ha). The Eastern Channel Corridor has 9,121 ft (2.78 km) of shoreline and an estimated area of 2.37 acres (0.96 Ha). The Phase IID sampling stations located in the Eastern Channel Corridor from north to south were ECCTRA12, ECCTRA11, and ECCTRA10. Sampling station UDCTRA10 was located in the central part of the Upper Drinkwater Corridor. The Lower Drinkwater River has two sampling stations, 6,857 ft (2.09 km) of shoreline and an area of 2.74 acres (1.11 Ha). The sampling stations in the Lower Drinkwater River from north to south were LDCTRA11 and LDCTRA10. Lily/Upper Factory Pond has 6,857 ft (2.09 km) of shoreline and an area of 26.49 acres (10.72 Ha). Two sampling stations were located in Lily/Upper Factory Pond; LUFPTRA11 to the north and LUFPTRA10 to the south. Three sampling stations were located in Middle/Lower Factory Pond; from north to south these stations were MLFPTRA12, MLFPTRA11, and MLFPTRA10. Middle/Lower Factory Pond has 9,711 ft (2.96 km) of shoreline and an area of 26.39 acres (10.68 Ha). The average depth of the ponds was about 4 feet at the time of the fish and benthic sampling in August of 2003. The maximum depth of the ponds was located near the dam in Lower Factory Pond with an estimated depth of 9 feet.

Water quality measurements taken during the fish and benthic sampling events were averaged in Table B-1-1. Measurements of pH were comparable to respective reference stations in all aquatic habitats. Measurements of pH were comparable in the riverine and pond habitats with means ranging from 6.30 to 6.68. Conductivity measurements on-Site were comparable to those of the reference station in the riverine and pond habitats with means ranging from 0.26 to 0.39 mS/cm. Turbidity measurements were comparable to reference station measurements in the riverine and pond habitats with means ranging from 50.58 to 91.89 NTU. Dissolved oxygen (DO) measurements were comparable to those of the reference station in the riverine and pond habitats with means ranging from 9.91 to 12.04 mg/L. All riverine and pond habitats had oxygen saturation of over 100% and were comparable to the reference stations with means ranging from 120% to 150%. Temperature measurements were comparable to those of the reference station in the riverine and pond habitats with means ranging from 21.4 to 25.3°C. Oxidation-reduction potential (ORP) measurements were comparable to reference station measurements in the riverine habitat with means ranging from 68.2 to 93.0 mV. Mean ORP measurements were higher in the pond habitat than in the riverine habitat but were comparable to reference station measurements with means ranging from 103.78 to 124.57 mV. All ORP measurements were positive except for the measurement taken at station ECCTRA12. Positive ORP measurements are indicative of an oxidative environment. A negative ORP at station ECCTRA12 (-18 mV) indicates a reducing environment. All water quality parameters were within an order of magnitude of the reference station for all aquatic habitats.

Sediments in aquatic habitats were mainly in the Unified Soil Classification System (USCS) class SM (>50% coarse-grained, clayey sand, >12% clay) or ML (>50% fine-grained, silt) (Table B-1-3). All sediments in aquatic habitats were saturated. Reference station NDTRA10 had ML very soft silt with no staining and no odor. Sediments were dark brown to black and had high organic content and organic litter. Station ECCTRA12 had ML fine-grained organic silt with low plasticity, no staining, and brown to dark brown coloring. Station ECCTRA11 had very soft, fine-grained, SM loose sand with silt. Sediment coloring was light to dark brown with a silvery sheen and no odor containing 15% to 20% organic litter. Station ECCTRA10 had very soft, loose, SM fine to coarse-grained silty sand. Sediment was light brown to black with a silvery sheen and 20% organic litter. Station LDCTRA11 had very soft, ML silt with fine grained trace sand and true gravel. Sediment had low plasticity and 20% organic litter. Station LDCTRA11 had very soft ML silt with low plasticity and a distinct hydrogen sulfide odor. Sediments at this location also had a high organic content and 20% organic litter content. A dark green algal mat was present on the surface of the sediments of the river bottom.

In the pond habitat sediments were in USCS class ML. Reference station FPTRA10 had very soft ML silt with low plasticity and no staining. Sediment was brown-black with 5% organic material and no odor. Station LUFPTRA11 had very soft ML silt with low plasticity and no staining. Sediment was dark brown to black with 5% to 10% organic litter. Station LUFPTRA10 had very soft ML silt with low plasticity and no staining. Sediment was dark brown to black with trace organic litter and an organic odor. Station MLFPTRA12 had loose silty sand with no staining and no odor. Sediment was dark brown with trace organic material. Stations MLFPTRA11 and MLFPTRA10 had very soft fine sand and silt with no odor. Sediment was black/brown with mottling and no coarse organic matter.

1.3.5 Wetland Habitats

A number of continuous and isolated wetlands have been identified within the project boundary from the National Wetland Inventory (NWI) maps for the towns of Hanover and Hanson. A large, continuous corridor of emergent, herbaceous and palustrine scrub-shrub wetland environments are associated with the riparian environment of the lower Drinkwater River and Factory Pond shorelines. A Site reconnaissance of these environments revealed a diverse assemblage of emergent wetland species including arrowhead (*Solidago* sp.), pickerelweed (*Pontederia* sp.), rush (*Juncus* sp.), buttonbush (*Cephalanthus occidentalis*), willow (*Salix* sp.) and wild iris (*Iris versicolor*). Submergent species include water milfoil, (*Myriophyllum spicatum*) and pondweed species (*Potamogeton* sp.). Approximately 120 acres of land associated with these wetland environments are conservation areas owned by the Town of Hanover.

Several smaller isolated wetland areas were identified from the NWI maps in the Northern and Southern Areas. Two of these isolated wetlands are located in the Northern Area of the Site and represent < 1 acre in size individually. Both wetlands are classified as scrub-shrub wetlands on the NWI maps. A small, pocketed upland wetland adjacent to the former demolition area has been identified as a potential area of concern for disposal of OHM. This scrub-shrub wetland may have received OHM from the Demolition Pit in the form of runoff. This area has been referred to as the Marsh Upland Area.

The wetland reference station (WBK01) was located off of the Site to the north of the Eastern Channel Corridor. The marsh upland station (MUA21) was located near the northern edge of Factory Pond (Plate 1 of the CSA).

Water quality measurements collected during benthic sampling are presented in Table B-1-1. Measurements of pH for the on-Site station MUA21 (7.04) were slightly lower than measurements for the reference station (7.26). Specific conductivity at MUA21 (0.07 mS/cm) was considerably lower than in the riverine and pond habitats and reference WBK01 (0.45 mS/cm). Turbidity was somewhat higher in reference station WBK01 (133.0 NTU) than in the riverine and pond habitats. Turbidity in wetland station MUA21 read at 999 NTU, indicating an inaccurate reading possibly caused by bottom sediments disturbed by the probe. Dissolved oxygen in wetland station MUA21 (6.80 mg/L) was lower than in the riverine and pond habitats and reference station WBK01 (13.10 mg/L). Oxygen saturation at MUA21 (74%) was lower than in the riverine and pond habitats and reference station WBK01 (148%). Temperature was lower in the on-Site wetland station MUA21 (18.2°C) than in the reference station WBK01 (16.0°C). This temperature difference may be related to groundwater. ORP measured in the wetland habitat was lower than that of the riverine and pond habitats. ORP was lower in wetland station MUA21 (13.0 mV) than in the reference station WBK01 (62.0 mV).

All sediments sampled in the wetland locations were saturated and in the USCS class ML (>50% fine-grained, sand and silt) (Table B-1-3). Reference station WBK01 had very soft ML silt with low plasticity and an organic odor. Sediments had a silvery sheen, high organic content, and a high volume of litter. Station MUA21 had very soft silt with no staining and an organic odor. Sediment was dark brown with more than 50% organic content.

1.4 Ecology Setting and Fish and Wildlife Resources

1.4.1 Fish

Sampling of the fish community at the Site was conducted by electrofishing in the Drinkwater River (Reach 1 – River Reference), Forge Pond (Reach 1A – Pond Reference), the Eastern Channel Corridor (Reach 2), the Upper Drinkwater River Corridor (Reach 3), the Lower Drinkwater River Corridor (Reach 3A), Lily Pond/Upper Factory Pond (Reach 4), and Middle/Lower Factory Pond (Reach 5). A total of 182 fish of 11 taxa (Table B-1-4) were collected from all of the sampled reaches. Visual examinations for external condition included fin condition, missing scales, fungus, parasites, gill coloration and condition, etc., which could signal stress induced by Site contaminants. Fish not retained for tissue analysis were released unharmed after the data had been collected. Species found during sampling included *Anguilla rostrata* (American Eel), *Lepomis macrochirus* (Bluegill Sunfish), *Ictalurus nebulosus* (Brown Bullhead), *Esox niger* (Chain Pickerel), *Notemigonus crysoleucas* (Golden Shiner), *Micropterus salmoides* (Largemouth Bass), *Lepomis gibbosus* (Pumpkinseed), and *Perca flavescens* (Yellow Perch). Largemouth bass, bluegill sunfish, and pumpkinseed were common to all reaches sampled.

1.4.2 Birds

Birds represented the largest number of wildlife species observed on the Site. Surveys for birds were conducted by random visual encounter and line transect methods to determine species composition, richness (total number), and diversity in August 2003. In total, 44 species were observed throughout the Site (Tables B-1-5 and B-1-6). Transects used in surveys were located to cover major habitat types present in the tree study areas. Along each transect any observations of bird species, auditory or visual, were recorded. Visual identifications of bird species were confirmed using field guides (Peterson, 1980; Veit and Petersen, 1993) and auditory observations were identified to species by a professional ornithologist experienced in the identification of species by songs or calls. A qualitative survey of nocturnal bird species was conducted during night road counts and during the frog and toad breeding call surveys.

1.4.3 Mammals

Methods to characterize the on-Site mammalian community were limited to qualitative surveys and random visual encounters during systematic surveys (Tables B-1-7 and B-1-8). Direct observations of mammals or their signs (i.e., tracks, scat, den trees, burrows, and vocalizations) and other evidence were documented during the belt transects and systematic surveys for birds and herptiles. Visual identification was confirmed using Burt and Grossenheider (1964) and indirect observations using tracks, middens, and scat were confirmed. Eight mammalian species and evidence of the occurrence of several small mammals (i.e., voles, shrews, and mice) were noted at the Site. Species observed included *Odocoileus virginianus* (white-tailed deer), *Procyon lotor* (raccoon), *Vulpes fulva* (red fox), *Mustela vision* (mink), *Marmota monax* (woodchuck), *Sciurus carolinensis* (gray squirrel), *Tamias striatus* (eastern chipmunk), *Peromyscus leucopus* (white-footed mouse), and other rodent species (such as voles, shrews, mice, etc.).

1.4.4 Amphibians

Direct and indirect observations of amphibian species were recorded during transect surveys as well as through incidental observation during other field activities (Table B-1-9). Amphibian species observed included *Plethodon cinercus cinurcus* (red-backed salamander), *Rana clamitans melanota* (green frog), *Rana catebeiana* (bullfrog), *Rana sylvatica* (wood frog), *Rana pipiens* (northern tree frog), *Bufo americanus* (American toad), and *Scaphiopus holbrooki holbrooki* (eastern spadefoot toad) (Tables B-1-10 and B-1-11).

1.4.5 Reptiles

Direct and indirect observations of reptile species were recorded during transect surveys as well as through incidental observation during other field activities. Observations were made when conducting transect surveys (Table B-1-12) as well as basking and funnel trap surveys (Tables B-1-13 and B-1-14). Observations of reptilian species included *Thamnophis sirtalis sirtalis* (eastern garter snake), *Diadophis punctatus edwardsi* (northern ringneck snake), *Natrix sipedon sipedon* (northern water snake), *Elaphe obsolete obsolete* (black rat snake), *Chrysemys picta picta* (eastern painted turtle), and *Chelydra serpentina* (common snapping turtle). Two trapping methods were used to target freshwater turtles. Basking traps are designed to capture smaller turtles such as the eastern painted turtle whereas funnel traps are designed to capture large turtles such as the common snapping turtle (Table B-1-15). Capture in this manner allowed for measurements such as size and weight to be taken (Tables B-1-16 and B-1-17) and observations regarding health to be recorded (Table B-1-18).

A search of the MADFW NHESP database (MADFW, 2002) revealed a number of rare species to be documented from the towns of Hanover and Hanson. These included two reptiles of special concern (eastern box turtle, *Terrapene carolina* and spotted turtle, *Clemmys guttata*), one amphibian of special concern (four-toed salamander *Hemidactylium scutatum*), two aquatic invertebrates (eastern pond mussel, *Ligumia nasuta* and New England blue dragonfly, *Enallagma laterale*), three plant species of special concern (Plymouth gentian, *Sabatia kenndyana*; river arrowhead, *Sagittaria subulatta* var. *subulatta*; and estuary pipewort, *Eriocaulon parkeri*) and one endangered plant species (estuary beggar-ticks, *Bidens hyperborea* var. *colpophila*) and one fish species of special concern (bridle shiner, *Notropis bifrenatus*).

Site-specific surveys for reptiles, amphibians and pond invertebrates in August of 2004 found the presence of three rare species. These observations were submitted to the MADFW NHESP and included: one endangered species (eastern black ratsnake, *Elaphe obsoleta obsoleta);* one threatened species (eastern spadefoot, *Scaphiopus holbrooki holbrooki*); and one species of special concern (eastern pond mussel, *Ligumia nasuta*).

2.0 REFINEMENT OF PRELIMINARY CONTAMINANTS OF POTENTIAL ECOLOGICAL CONCERN

Representative ecological receptors associated with terrestrial, aquatic, and wetland habitats were determined to be potentially exposed to contaminants of potential ecological concern (COPECs) associated with the Site. The environmental media of concern included surface soils, surface water, surface sediment, and groundwater (which may discharge to surface water in lentic, lotic, and wetland environments).

For higher trophic level receptors, bioaccumulation of certain COPECs, such as mercury, will likely result in exposure via transfer within the local food chain. Aquatic communities (i.e., fish, plankton, benthic macroinvertebrates) are potentially at risk from direct exposure to COPECs present in the surface water column. For trophic level receptors, the pathways of exposure to Site-related contaminants will be through direct contact, the consumption of contaminated prey (i.e., soil invertebrates, small fish, or aquatic invertebrates), and incidental exposure to environmental media.

2.1 Exposure Pathways

A conceptual site and pathways analysis model was developed for evaluating the exposure of Site-related contaminants to ecological receptors present on the Site (Figure B-3-1). The primary pathways of exposure to Site-related contaminants for ecological receptors include:

- Direct contact with contaminated environmental media
- Dietary ingestion of contaminated prey items
- Incidental ingestion of contaminated abiotic media during feeding

The environmental media of concern for the terrestrial receptors are surface soils. The exposure pathways of concern for the freshwater ponds/wetlands are exposure through the direct contact of aquatic life with COPECs in surface water and sediments, and exposure of higher vertebrate species through the ingestion of water and incidental ingestion of soils or sediments. Contact with groundwater will be evaluated through the surface water pathway. Incidental ingestion of sediments and surface soils will be evaluated for higher trophic level receptors.

Risks to ecological receptors has been evaluated consistent with MCP guidance. Terms used to describe a determination of risk include:

- **No Significant Risk of Harm** – only if the MCP criteria at 310 CMR 40.0995 are met.
- **No Substantial Hazard** – only if the MCP criteria at 310 CMR 40.0956(2) are met.
- **Evidence of Biologically Significant Harm** – to describe an observed adverse effect at any level of biological organization, including organism, population, community and ecosystem level effects. "Evidence of harm" can be obtained from measurement methods such as field studies that directly measure population parameters and community metrics, as well as readily apparent stressed biota. Such observations include studies of the benthic invertebrate populations, zooplankton populations, fish populations and observations on wildlife.
- **Indications of Potential for Biologically Significant Harm** – to describe effects as predicted from measurements or models. Many measurement methods used to evaluate assessment endpoints indicate "potential for ecological harm," but do not provide "evidence of harm."

2.2 Toxicological Characteristics of COPECs

Attachment B1 provides environmental toxicological profiles for COPECs identified during the initial screening. They are not meant to represent an exhaustive review of all environmental and toxicological characteristics, but a general summary of their potential effects and fate in the environment.

3.0 ASSESSMENT ENDPOINTS AND RISK HYPOTHESES FOR STAGE II ENVIRONMENTAL RISK CHARACTERIZATION

3.1 Assessment Endpoint Identification

Assessment endpoints are defined as "explicit expressions of an environmental value that is to be protected." Assessment endpoints represent discrete natural resource values or functions deemed important to local ecology or natural communities. Based upon the results of the preliminary evaluation and consultation with the MADEP, the following assessment endpoints were developed for the Fireworks Site Stage II ERC:

1. Protection and sustainability of benthic community structure in Factory and Lily Ponds, Drinkwater River areas, and Marsh Upland Area wetland to serve as a prey base.
2. Protection and sustainability of freshwater plankton in Factory and Lily Ponds, and Drinkwater River to serve as a prey base.
3. Protection and sustainability of forage and predatory fish community structure in Factory and Lily Ponds and Drinkwater River comparable to similar warm water environments.
4. Protection and sustainability of piscivorous avian populations utilizing Factory and Lily Ponds, Drinkwater River, and Marsh Upland Area wetland habitats.
5. Protection and sustainability of omnivorous waterfowl populations utilizing Factory and Lily Ponds, Drinkwater River, and Marsh Upland Area wetland habitats.
6. Protection and sustainability of insectivorous avian populations utilizing the terrestrial habitats of the Northern, Central and Southern Areas.
7. Protection and sustainability of carnivorous raptor populations feeding in terrestrial habitat of the Northern, Central and Southern Areas, Factory and Lily Ponds, and the Marsh Upland Area wetland habitats.
8. Protection and sustainability of herbivorous waterfowl populations occupying Factory and Lily Ponds, Drinkwater River, and Marsh Upland Area wetland habitats of the Site.
9. Protection and sustainability of piscivorous mammal populations occupying the habitats of Factory and Lily Ponds, Drinkwater River, and Marsh Upland Area wetland habitats.
10. Protection and sustainability of resident omnivorous mammal populations residing near Factory and Lily Ponds, Drinkwater River, and Marsh Upland Area wetland habitats.
11. Protection and sustainability of insectivorous mammal populations utilizing the terrestrial habitats of the Northern, Central and Southern Areas.
12. Protection and sustainability of resident herbivorous mammal populations residing near Factory and Lily Ponds, Drinkwater River, and Marsh Upland Area wetland habitats.
13. Protection and sustainability of reptilian populations and communities in terrestrial habitats and Factory and Lily Ponds, Drinkwater River, and Marsh Upland Area wetland habitat of the Site.
14. Protection and sustainability of the amphibian populations and communities in Factory and Lily Ponds and Drinkwater River as well as the Marsh Upland Area wetland environments.
15. Protection and sustainability of terrestrial plants, soil invertebrates and soil microbial processes in the surface soils present on the Site.

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

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

Figure B-3-2 presents the conceptual food chain model and representative species identified for the Site ERC.

Risks to candidate ecological receptor species were assessed to determine if the identified COPECs pose a risk to lower and/or higher trophic level receptors. Candidate species are selected using the following criteria:

- Observation of their presence or expected occurrence.
- Representativeness of a trophic level and feeding guild in relation to the habitats present.
- Availability of life history information for developing or identifying key exposure parameters.
- Potential sensitivity to bioaccumulating compounds.

Ecological receptors include representative terrestrial/aquatic plants, benthic macroinvertebrates, soil invertebrates, avian, mammalian, reptilian, amphibian, and fish species. Each species was chosen based on its diet, suitability of the habitats found on the Site, and the bioaccumulating characteristics of mercury, a COPEC of primary concern found in all media on-Site. The following is a list of receptors or communities selected for evaluation in the Site ERC.

Freshwater Benthic Macroinvertebrates:

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

Freshwater Fish and Plankton:

- Freshwater fish represent the most diverse group of vertebrates present in the aquatic food chain. Multiple trophic guilds comprising insectivorous, omnivorous and carnivorous species are represented in typical warm water fish communities.

- Plankton forms the basis of the pelagic food chain and represents an important link between primary consumers and upper trophic levels.

Avian Species:

- Belted kingfisher (*Megaceryle alcyon)* – A representative piscivorous species that lives and feeds in most freshwater bodies and feeds primarily on small fish. Other aquatic prey such as amphibians, crustaceans, and other aquatic animals may also be consumed.
- Mallard duck (*Anas platyrhynchos)* – A representative omnivorous waterfowl species that resides in wetlands and ponds and feeds on benthic macroinvertebrates and aquatic plants.
- American woodcock (*Scolopax minor*) – A representative insectivorous species living in woodlands and marshes and primarily eats terrestrial and wetland soil arthropods, and worms.
- Red-tailed Hawk (*Buteo jamaicensis*) – A representative carnivorous raptor species found in terrestrial upland habitats similar to those present and can tolerate a moderate degree of human encroachment. Its diet consists of small mammals and to a lesser degree small birds, large insects and carrion.
- Mute Swan (*Cygnus olor*) – A representative herbivorous species found in ponds, lakes and marshes. Swans primarily forage on aquatic vegetation. Occasionally, they will feed on aquatic mollusks, and insects.

Mammal Species:

- Mink (*Mustela vison*) – A representative piscivorous mammalian species found in riparian habitats near water. Mink feed on fish, crayfish and small vertebrates such as frogs and snakes.
- Raccoon (*Procyon lotor)* – A representative omnivorous mammal that exploits a variety of potential dietary components in and around aquatic environments and woodlands. Raccoons feed on crayfish and other larger aquatic invertebrates, small fish and occasionally seeds and berries.
- Short-tailed Shrew (*Blarina brevicauda*) – A representative insectivorous mammal species found in areas of abundant vegetative cover. Terrestrial soil invertebrates such as insects, earthworms, slugs and snails make up the bulk of this species' diet.
- Muskrat (*Ondatra zibethicus*) – A representative herbivorous mammal associated with wetland and aquatic environments. This species has a diet consisting of aquatic and wetland vegetation, though limited animal matter may also be consumed.

Reptile Species:

- Snapping turtle (*Chelydra sepentina*) – A representative carnivorous reptile species expected to occur in the ponds and rivers present on-Site. The MADFW NHESP database (MADFW, 2002) identified the potential presence of spotted turtles, a threatened species to be present near the Site. However, this species was not documented in the habitats on-Site. The snapping turtle will be used as the representative reptile species for the ERC.

Amphibian Species:

- Bullfrog (*Rana catesbeiana)* – The bullfrog was chosen as the representative amphibian species due to its widespread occurrence in the area and the large array of literature and ecotoxicity information available for this species or related species.

Terrestrial Plants, Soil Invertebrates, and Microbial Decomposition Processes:

- Terrestrial plants form the basis of the terrestrial food chain. This receptor group was evaluated at the community level using community level benchmarks.
- Soil invertebrates, such as earthworms, and microbial decomposition processes are important receptors responsible for nutrient recycling and decomposition of organic matter within the detrital food web. This group of receptors was evaluated at the community level using community level benchmarks.

A toxicity quotient approach or population level biota surveys will be used to assess risks to the above receptors. Exposure parameters for each of the avian and mammalian terrestrial and semi-aquatic species are presented in Table B-3-1. Other receptors such as benthic communities, fish communities, amphibians, and reptiles were evaluated with Site-specific studies using toxicological testing and population level investigations.

3.1.1 Definition of Risk Hypotheses and Measurement Endpoints

Risk hypotheses are defined as testable statements for evaluating whether an assessment endpoint is perceived to be at risk from Site-related stressors (MADEP, 1996). Risk hypotheses are evaluated through the use of measurement endpoints which represent discrete, direct, or indirect measures of effect related to the assessment endpoint. The following risk hypotheses are presented in corresponding order to the assessment endpoints.

Hypothesis #1: Do COPECs associated with the Factory and Lily Ponds, Drinkwater River, and the Marsh Upland Area wetland sediments pose a significant risk to benthic community structure?

Hypothesis #2: Do COPECs detected in Factory and Lily Ponds and the Drinkwater River pose a significant risk to freshwater plankton in these freshwater systems?

Hypothesis #3: Do COPECs in environmental media pose a significant risk to forage fish or predatory fish species present in the aquatic habitats present?

Hypothesis #4: Do COPECs in environmental media in the aquatic habitats pose a significant risk to piscivorous avian species on the Site?

Hypothesis #5: Do COPECs in environmental media in the aquatic habitats pose a significant risk to omnivorous waterfowl on the Site?

Hypothesis #6 Do COPECs in environmental media pose a significant risk to insectivorous birds in the terrestrial habitats of the Site?

Hypothesis #7 Do COPECs in environmental media pose a significant risk to carnivorous raptors in the terrestrial habitats of the Site?

Hypothesis #8: Do COPECs in environmental media pose a significant risk to herbivorous waterfowl in the aquatic habitats of the Site?

Hypothesis #9	Do COPECs in environmental media pose a significant risk to piscivorous mammals in the aquatic habitats of the Site?
Hypothesis #10	Do COPECs in environmental media pose a significant risk to omnivorous mammals in aquatic habitats of the Site?
Hypothesis #11	Do COPECs in environmental media pose a significant risk to herbivorous mammals in the aquatic habitats of the Site?
Hypothesis #12	Do COPECs in environmental media pose a significant risk to herbivorous terrestrial mammals of the Site?
Hypothesis #13	Do COPECs in environmental media pose a significant risk to reptilian communities present on the Site?
Hypothesis #14	Do COPECs in environmental media pose a significant risk to amphibian communities present on the Site?
Hypothesis #15	Do COPECs in surface soils pose a significant risk to soil invertebrate populations, terrestrial plants or microbial processes in surface soils present on the Site?

3.1.2 Measurement Endpoints

Measurement endpoints are "measurable responses that are related to the assessment endpoint" (MADEP, 1996). The following measurement endpoints were identified as lines of evidence to evaluate the risk hypotheses developed for the ERC assessment endpoints.

3.1.2.1 Measurement Endpoints to be Used as Lines of Evidence for Assessment Endpoint #1

1. Comparison of COPEC concentrations in the sediments of the Factory and Lily Ponds, Drinkwater River, and Marsh Upland Area wetland to sediment benchmarks in MacDonald et al. (2000).
2. Assess bioavailability and toxic potential of metals based on acid volatile sulfide and soluble extractable metals.
3. Evaluate toxicity and bioaccumulation potential of COPECs in sediments to benthic organisms using whole sediment toxicity and bioaccumulation testing using *Lumbriculus variegatus*, *Hyalella azteca* and *Chironomus tentans*.
4. Evaluate potential risks of COPECs in sediments to benthic organisms through direct sampling of the indigenous benthic community and comparison to reference populations.

3.1.2.2 Measurement Endpoints to be Used as Lines of Evidence for Assessment Endpoint #2

1. Compare surface water quality data for toxicity reference values (TRVs) for freshwater zooplankton and phytoplankton survival.

3.1.2.3 Measurement Endpoints to be Used as Lines of Evidence for Assessment Endpoint #3

1. Comparison of surface water data for COPECs to TRVs for fish survival.

2. Sampling of endemic fish populations for community structure and comparison to a reference population.

3. Performance of a fish health assessment in on-Site populations. External examination of endemic fish for evidence of stressor related effects and comparison to a reference population.

4. Comparison of concentrations of COPECs in fish tissues to TRVs related to effects based tissue concentrations.

3.1.2.4 Measurement Endpoints to be Used as Lines of Evidence for Assessment Endpoints #4, 5, 6, 7, 8, 9, 10, 11 and 12

1. Evaluation of exposure for avian and mammalian species based on modeling of exposure pathways and routes to COPECs present in on-Site environmental media.

2. Comparison of exposure dosages of the wildlife receptors evaluated to no observable adverse effects levels (NOAELs) and lowest observable adverse effect levels (LOAELs).

3.1.2.5 Measurement Endpoints to be Used as Lines of Evidence for Assessment Endpoints #13 and #14

1. Compare surface water data for COPECs to TRVs (where available) for amphibian survival.

2. Comparison of qualitative populations/community structure data to population data from a reference area of similar habitat.

3.1.2.6 Measurement Endpoints to be Used as Lines of Evidence for Assessment Endpoint #15

1. Comparison of COPEC concentrations in the soils of the terrestrial habitats present on-Site to ecological benchmarks presented in Efroymson et al. (1997).

2. Qualitatively describe vegetation covertypes and record any observation of stressed vegetation present in areas of known historical disposal activity.

3.1.3 Weight of Evidence Approach

Each line of evidence must be carefully considered and weighed objectively to assess the risk and overall effect of uncertainty on the assessment endpoint evaluated. Supporting lines of evidence defined by the MCP (MADEP, 1996) include chemical analysis, benchmark comparison, toxicity quotient methodologies, field studies, and toxicity tests.

3.1.3.1 Chemical Analyses

Analytical sampling was performed to further delineate the nature and extent of contaminants in Factory and Lily Ponds, Drinkwater River, and the Marsh Upland Area wetland. Analytical sampling coincided with the benthic and toxicological evaluations to assess if a causal link between COPEC concentrations and community level data was present.

3.1.3.2 Benchmark Comparisons

Data collected in support of the Phase IIB, IIC, and IID investigations were used to compare concentrations of COPECs to applicable screening level values. This comparison was used as one line of evidence in assessing risks to community level receptors in the habitats present on the Site.

3.1.3.3 Toxicity Quotient Method

A hazard quotient approach was used to assess the exposure and risk to higher trophic level receptors (i.e., fish, amphibians, birds, and mammals) to COPECs in environmental media. This method relied upon the use of literature-based life history information (i.e., diet, habitat preference, home range, body mass, etc.) for individual species and allometric equations for deriving ingestion rates for food ingestion, drinking water ingestion, and incidental ingestion of abiotic media. Exposure estimates are summed into a daily exposure dosage for each COPEC and are then compared to NOAELs and LOAELs for assessing risk for a specific toxicological endpoint. This approach will be applied as a line of evidence for assessment endpoints #4, 5, 6, 7, 8, 9, 10, 11, and 12.

3.1.3.4 Field Studies

Field studies employed sampling of indigenous populations as models of exposure and/or effect. Direct causation between field-based effects data and analytical chemistry can only be inferred through suggested links between observed events or effects and contaminant distributions in the natural environment. Benthic community analyses and contaminant data are an example of causal effect field studies being employed as a line of evidence for assessment endpoint #1. Fish samples were collected and analyzed as a line of evidence for assessment endpoint #3. A Site evaluation of wildlife and their habitats was conducted by a wildlife biologist to observe community and population level studies for reptilian and amphibian species. This analysis will be used as a line of evidence for assessment endpoints #13 and 14.

3.1.3.5 Toxicity Tests

Toxicity tests are typically laboratory-controlled evaluations in which the largest number of variables may be maintained at a near consistent basis for evaluating contaminant effects as a product of concentration on a discrete toxicological endpoint. Such tests are performed under strict laboratory conditions and rarely reflect a natural state of exposure. Typically, such evaluations result in estimates of exposure and effect in excess of those anticipated in the natural environment. As such, these evaluations are often considered conservative measures of effects. Examples of such evaluations are the 10-day toxicity tests being performed with *Hyalella azteca* and *Chironomus tentans.* This approach is applied as a line of evidence in support of assessment endpoint #1.

3.1.3.6 Bioaccumulation Studies

Bioaccumulation studies were performed to act as lines of evidence for assessment endpoints #1 and 3, undertaken by two separate investigations:

- Collection of fish fillet and offal samples and macroinvertebrate samples from Lily Pond, Factory Pond and the Drinkwater River.
- Collection of bulk sediments for use in laboratory-based bioaccumulation tests for development of a Site-specific, biota-sediment accumulation factor.

A forage and carnivorous fish species and a macroinvertebrate species were collected from Factory and Lily Ponds and the Drinkwater River. Samples of fillet and offal of a large freshwater fish species were analyzed for total mercury and methyl mercury. Crayfish were collected as a representative macroinvertebrate species for body burden analysis. Fish species targeted for collection were species that represented an intermediate omnivorous species (trophic level 2) and higher trophic level, piscivorous fish species (trophic level 3). Based upon previous electrofishing studies (MADEP, 1996), representative species by trophic level included:

- Trophic Level 1: Black tail golden crayfish (*Orconectes limosus*)
- Trophic Level 2: Bluegill sunfish (*Lepomis macrochirus*)
- Trophic Level 3: Largemouth bass (*Micropterus salmoides*)

Whole body samples of crayfish (trophic level 1) and omnivorous (trophic level 2) bluegill were collected and analyzed to assess metals, mercury and methyl mercury accumulated from environmental media in Upper and Lower Factory and Lily Ponds and the Drinkwater River. Fillet and offal samples were collected for largemouth bass.

Bulk sediment samples were collected from Factory and Lily Ponds and the Drinkwater River for use in laboratory based bioaccumulation studies with *Lumbriculus variegatus*. Targeted sediments were sampled from areas known to have a range of mercury sediment concentrations (Phase IIC), which allowed for assessment of Site-specific bioavailability of mercury across a range of high, moderate and low concentration gradient. This method was preferred rather than using standard uptake factors because it provided a basis for reducing the uncertainty associated with use of conservative literature based uptake values. This approach was applied to support assessment endpoints #1, 3, 4, 5, 9 and 10.

3.2 Exposure Assessment for Wildlife Receptors

3.2.1 Dietary Ingestion Exposure

Exposure route models for the identified pathways are outlined below for each of the avian and mammalian endpoint wildlife receptors considered in this assessment. The following provides the exposure assessment models used in the estimation of the potential average daily dosage ($ADD_{dietary\ potential}$).

Exposure parameters for each of the wildlife receptors evaluated were based upon USEPA (1993) or Sample et al. (1996) wildlife life history parameters for body weights, dietary composition, home ranges or foraging radius.

The total potential average daily dietary dosage is defined as the following:

$$ADD_{DietaryPotential} = (ADD_{Diet}) + (ADD_{DrinkingWater}) + (ADD_{Incid.Ingestion}) \quad \text{(Equation 1)}$$

where:

$ADD_{DietaryPotential}$	=	Dietary Potential average daily exposure dosage of COPEC (mg/Kg/day) to endpoint receptor
ADD_{Diet}	=	Average daily dosage of COPEC via dietary sources (mg/Kg/day)
$ADD_{DrinkingWater}$	=	Average daily dosage of COPEC via drinking water (mg/Kg/day)
$ADD_{Incid.Ingestion}$	=	Average daily dosage of COPEC via incidental ingestion of abiotic media (sediments and surface soil) (mg/Kg/day)

3.2.2 Exposure via Drinking of Surface Water

The relative contribution of metabolic water sources and dietary water content varies from species to species and with environmental conditions. For avian and mammalian receptors, the water ingestion rates (WI) (L/day) were estimated from the following equations (USEPA, 1993):

For mammals $WI\ (L/day) = (0.099\ (BW^{0.90}))$ (Equation 2)

For birds $WI\ (L/day) = (0.059\ (BW^{0.67}))$ (Equation 3)

where:

WI = Receptor specific water ingestion rate (L/day)
BW = Body weight of receptor (Kg)

Using the above equations, the average daily dosage ($ADD_{DrinkWater}$) is:

$$ADD_{DrinkingWater} = [((ME_{Surface\ water})(WI_{Receptor}))/BW](FE) \quad \text{(Equation 4)}$$

where:

$ADD_{DrinkingWater}$	=	Average daily dosage of contaminant via drinking of surface water (mg/Kg-day)
$ME_{Surface\ Water}$	=	Mean exposure concentration (mg/L) in surface water
$WI_{Receptor}$	=	Water ingestion rate (L/day) for receptor
FE	=	Areal forage effort (unitless) as fraction of home or forage range (1.0)
BW	=	Body weight (Kg) of receptor

3.2.3 Exposure via Incidental Ingestion of Media

Incidental ingestion of abiotic media followed the general equation by receptor species, type of media ingested, and the fraction of the identified media in the diet of the receptor considered on a species specific basis:

$$ADD_{Incid.\ Ingest.} = [((ME_{Media})(FS_{Media})(IR_{Total}))/(BW)](FE) \quad \text{(Equation 5)}$$

where:

$ADD_{Incid.\ Ingest.}$	=	Average daily dosage of contaminant via incidental ingestion of abiotic media (mg/Kg/day)
ME_{Media}	=	Mean exposure concentration (mg/Kg) in soil or sediment
FS_{Media}	=	Fraction of abiotic media in diet
IR_{Total}	=	Total food ingestion rate (Kg dry wt./day) (estimated from USEPA (1993))
FE	=	Areal forage effort (unitless) as fraction of home or forage range (assumed to be 1.0)
BW	=	Body weight (Kg) of receptor

The fraction of media in the diet was specific to each of the endpoint receptors as is the specific media ingested during feeding. For semi-aquatic species, the primary media considered are sediments incidentally consumed from feeding in the Drinkwater River, Lily and Factory Ponds. Surface soils are the fishery survey reaches. Two species of finfish, a predatory fish species, the largemouth bass (*Micropterus salmoides*), and an omnivorous fish, the bluegill sunfish (*Lepomis macrochirus*), were targeted for collection in the survey reaches identified on Plate 1 of the CSA. These target species were selected based on historical MADEP fish survey data and the species composition in both reference surveys and Site-influenced survey areas. These species were also collected as being representative species from different trophic levels.

In each reach, three adult individuals of the targeted fish species were collected, allowed to expire, placed in a zip-loc bag, and held on wet ice prior to processing. For the largemouth bass, three whole body individuals of similar size class were collected from each of the six reaches and composited into a single sample for each reach. The fish were kept cool prior to preparation for shipping. The composite samples were wrapped in aluminum foil and placed in a zip-loc bag with a label identifying the sample, date, time, analysis, and identified for composite resectioning. The sealed samples were picked up by the analytical laboratory (via courier) for analysis for total mercury, methyl mercury, percent lipids, and TAL metals. The analytical laboratory was responsible for resectioning the largemouth bass for a separate analysis of a "sportsman's fillet" and the offal (carcass and viscera remains). A composite sample (three fish per composite sample) of largemouth bass fillet and offal was collected from fishery survey reaches 1, 1A, 3A, 4, 5, 6 (below Factory Pond Dam) and 7 (Luddams Ford). A single individual of largemouth bass was captured from survey reach 2 for fillet and offal sampling. No fish were recovered from fishery survey reach 3, the Upper Drinkwater River Corridor. The fillet data were collected to support the human health risk characterization.

For the bluegill sunfish, three individuals (whole bodies) of a similar size class were collected from each of the reaches. The fish were kept cool prior to preparation for shipping. The three individuals from each reach were composited into a single sample. The composited samples were wrapped in aluminum foil, placed in a zip-loc bag with a label identifying the sample, date, time, and analysis. The sealed samples were picked up by the analytieal laboratory (via courier) for analysis for total mercury, methyl mercury, TAL metals, and percent lipids. A composite sample (three fish per composite sample) of whole body bluegill sunfish was collected from fishery survey reaches 1, 1A, 3, 3A, 4, 5, 6, and 7. The only survey reach where no bluegill sunfish samples were collected during the field investigation was fishery survey reach 3, the Upper Drinkwater River Corridor.

3.3.8 Macroinvertebrate Body Burden Sampling

Collection of composite, whole body samples in the crayfish species *Orconectes limosus* was attempted in each of the identified fish survey reaches. Crayfish funnel traps constructed of exterior half inch wire mesh with a quarter inch polypropylene mesh were baited with fish discards, dog food, or beef liver.

Hand collection techniques including debris searches and dip netting were also attempted. Crayfish were targeted as the species for collection because no larger gastropod or freshwater bivalve species were present in all reaches. Traps were fished in each area with limited success given the generally low abundance of crayfish at most locations. To maximize the trapping effort, combinations of bait were used when a single bait failed to capture crayfish. The crayfish trapping was initiated on August 11, 2003 and continued until September 10, 2003. This trapping period was extended for two additional weeks. The following numbers submitted for analysis are as follows:

Water Body of Collection	Fishery Reach	Location Identification	Species Collected	Number of Individuals Recovered and Submitted for Analysis
Northern Drinkwater River	1	NDRTRA121	*O. limosus*	1
Forge Pond	1A	FPTRA111	*O. limosus*	2
Eastern Channel Corridor	2	ECCTRA131	*O. limosus*	2
Lily Pond/Upper Factory Pond	4	LUFPTRA121	*O. limosus*	5
Middle/Lower Factory Pond	5	MLFPTRA131	*O. limosus*	1

The composite samples were kept cool prior to preparation for shipping. Composite samples were wrapped in aluminum foil and then placed in a zip-loc bag with a label identifying the sample, date, time, and analysis. Because of limited tissue mass available for select samples, chemical analyses were prioritized based upon COPECs, bioaccumulation, and risk potential. Correspondence with the MADEP indicated that the analysis hierarchy was acceptable given the limited tissue mass (T. Angus, Pers. Comm., Sept. 2003). Samples with sufficient tissue mass were analyzed for TAL metals, total mercury, methyl mercury, and percent lipids. Samples with insufficient tissue mass were analyzed for total mercury, methyl mercury, and percent lipids.

3.3.9 Toxicity Tests

Toxicity test performance was evaluated for acceptability and effectiveness using testing protocols and evaluation criteria provided in USEPA (2000) and ASTM (2001). Individual test performance is described below.

3.3.9.1 Amphipod Survival and Growth Tests

A single protocol anomaly was noted during the testing program. A greater than 50% change was observed in ammonia concentrations from the start of the test to the completion of the test in all samples (including the reference area samples and the laboratory control). No effect was noted for this protocol anomaly based upon a lack of observed toxicity in the laboratory control, the reference area, and the Site-specific samples.

Results for the 10-day *Hyalella azteca* survival and growth tests are presented in Table B-3-2. These results revealed no statistically significant reduction in survival in the test species among the sediment samples evaluated from the Site when compared to the habitat-specific reference tests. Survival of amphipods exposed to Factory Pond sediments ranged from 86% to 90%. Survival of amphipods exposed to riverine sediments from the Drinkwater River influenced by the Site ranged from 87% to 96%. Survival of amphipods exposed to sediments from the Marsh Upland Area was 76%.

A negative effect on growth was noted for a single sample collected from Factory Pond. A statistically significant reduction in growth was noted for sample MLFPTRA11 from the Middle/Lower Factory Pond area when compared to growth observed in the test populations exposed to the reference sediments. All other samples from both the lotic and lentic environments revealed comparable growth in amphipods relative to corresponding reference areas.

3.3.9.2 Midge Survival and Growth Tests

Protocol anomalies that were related to environmental monitoring criteria and temperature were noted during the testing program. A greater than 50% change was observed in ammonia, alkalinity, and water hardness concentrations from the start of the test (Day 0) to the completion of the test (Day 10) in all samples, including the reference area samples and the laboratory control. Testing protocol recommends that variation in the above parameters not vary by more than 50%. Temperature variation in the test chambers varied by greater than 3°C during the monitoring period. Mean temperature during the exposure period was 23°C, which is the recommended testing temperature. No effect was noted for the environmental anomalies observed during testing based upon the lack of toxic effects in the laboratory control, the reference area, and the Site-specific samples.

Results for the 10-day, *Chironomus tentans* survival and growth tests are presented in Table B-3-3. Results of the 10-day tests revealed no statistically significant reductions in survival among the evaluated sediment samples from the Site when compared to the habitat-specific reference results. Survival of midges exposed to Factory Pond sediments ranged from 81% to 93%. Survival of midges exposed to riverine sediments from the Drinkwater River receiving runoff from the Site ranged from 76% to 89%. Survival of midges exposed to sediments from the Marsh Upland Area was 84%.

No significant reductions in growth were observed in thirteen of the fourteen sediment samples. A statistically significant reduction in growth was noted for sample MUA21. Growth of midges exposed to sediments from the Marsh Upland Area was significantly lower than growth observed in midges exposed to wetland reference area sediments. All other samples revealed comparable or positive growth relative to the midges exposed to sediments from all corresponding reference areas.

3.3.9.3 Aquatic Annelid Survival and Bioaccumulation Studies

A two-phase approach to performing the 28-day bioaccumulation test was undertaken for evaluating survival and bioaccumulation. A 120-hour acute survival test using *Lumbriculus variegatus* was performed on each sample to assess survival and potential confounding effects of mortality on the bioaccumulation bioassay for the contaminants present. Table B-3-4 summarizes the results of the 4-day survival study and biomass recovery following the 28-day exposure period. Results of the survival study revealed 100% survival of *Lumbriculus variegatus* exposed to sediments from all fourteen locations.

With the determination of no acute effects, the bioaccumulation study was undertaken following the testing protocols outlined in USEPA (2000) and ASTM (2001). On Day 0, 5.0 grams of worms were added to each of four test replicas per sample (total tissue mass exposed per sample was approximately 20.0 grams). Worms were fed daily and excess food was removed from the test chambers. On Day 28, sediments were sieved and all worms were recovered and allowed to undergo depuration for 24 hours in clean water. Worm biomass recovered ranged from 9.5 to 13.3 grams for sediments from the Site and 15.5 grams from the laboratory control (Table B-3-5). Following the 24-hour depuration period, samples were composited, wrapped in aluminum foil and frozen (-20°C) until analysis. Worm tissue samples were homogenized and analyzed for total mercury, methyl mercury and percent solids at Frontier GeoSciences (Seattle, WA). EnviroSystems, Inc. (Hampton, NH) analyzed the worm tissues for TAL metals and percent lipids.

Table B-3-5 summarizes the results for the body burden analysis for the worm tissues collected following the 28-day bioaccumulation assay. In reviewing the body burden concentrations, beryllium, selenium, and vanadium were undetected in all collected samples including the laboratory control. The body burden of TAL metals in on-Site samples appeared to be comparable to that of the reference areas and laboratory controls. Total mercury and methyl mercury concentrations in on-Site samples displayed the greatest divergence from the observed concentrations in the laboratory control and reference areas.

In comparing the samples by habitat type, the total mercury concentration observed in the worms exposed to sediments from the riverine environment were the highest, followed by the wetland samples and the pond Site samples. All sample concentrations exceeded their respective reference sample concentration for total mercury and methyl mercury in each of the three aquatic environments sampled.

3.3.9.4 Survival and Growth Test of Fathead Minnow

No protocol anomalies related to environmental monitoring criteria or laboratory control performance were noted during the testing program. Results for the 10-day, *Pimephales promelas* larval survival and growth tests are presented in Tables B-3-6 and B-3-7. Results of the 10-day tests revealed no statistically significant reductions in survival among the surface water samples evaluated from the Site when compared to the habitat-specific reference results. Survival of minnows exposed to Factory Pond surface waters ranged from 88% to 98%. Survival of minnows exposed to riverine surface waters from the Drinkwater River ranged from 95% to 100%.

No significant reductions in growth were observed in six of the seven surface water samples tested (Table B-3-7). A negative effect on growth was noted for sample UDCTRA11SW in the Upper Drinkwater River Corridor. Growth of minnows exposed to surface waters from Factory Pond and the Drinkwater River revealed comparable or positive growth relative to the minnows exposed to reference area surface waters.

3.4 Refined Site Conceptual Model

The commercial and industrial activities at the Site resulted in the use of a variety of chemicals and processes that generated wastes associated with munitions and pyrotechnic products. Additionally, operations related to normal maintenance and up-keep likely included the use of other chemicals. Much of the Site has remained in a state of occupational abandonment that has resulted in the dumping of debris by trespassers.

A preliminary Conceptual Site Model (CSM) was developed and presented to MADEP prior to the initiation of Phase IID. The chemicals detected from previous field work are listed on Table B-3-8 and were used to develop the preliminary CSM. After data review and input from MADEP, the Phase IID field program was mobilized. Data from that field investigation and the previous studies referenced in this document were used to refine the CSM.

3.4.1 Terrestrial and Aquatic Habitats

Based upon the detection of contaminants in on-Site media, fate and transport characteristics at the Site and the environmental setting, a preliminary site conceptual model for ecological receptors was developed for the Site. Multiple terrestrial habitats and aquatic habitats were present at the Site.

Terrestrial habitats included:

- Terrestrial upland communities represented by broad-leafed forests and conifer dominated upland forest areas.

Wetland habitats included:

- Smaller areas of palustrine, forested corridor wetlands along the Drinkwater River (Northern Area).
- Lacustrine, emergent wetlands along Lily and Factory Ponds (Central and Southern Areas).
- Perched, scrub-shrub wetland area (Southern Area).

Aquatic habitats included:

- Lotic habitats of the Drinkwater River of the Site.
- Lacustrine, lentic habitats of Lily Pond and Factory Pond.

Ecological receptors observed from the above habitats included mammal, bird, reptile and amphibian species.

Exposure pathways consider the mechanism through which ecological receptors may be exposed to oil or hazardous material (OHM). Exposure routes consider the Site-specific routes of exposure through which a receptor may be exposed to OHM. Exposure of ecological receptors can result through direct contact or incidental ingestion with contaminated abiotic media or through ingestion of prey that has bioaccumulated from Site-related sources.

Based on review of the Site and available data, there is an indication that complete exposure pathways and exposure routes for ecological receptors exist. A summary of the conceptual site model and source of screening exposure concentrations are presented in Table B-3-9. Based on this initial analysis, a Stage II ERC was determined to be required.

The Stage II Evaluation utilized the risk assessment areas demarcated for the Human Health Risk Characterization to provide overall consistency in Site evaluation. These delineations subdivide the three original risk areas (North, Central, and South) into smaller parcels based on-Site history, present structures and operations, and current and expected future use.

3.4.2 Incomplete Exposure Pathway Analysis

Based on the industrial character of the areas within the northern part of the Site, specific risk assessment areas were evaluated to see if there was a complete exposure pathway for ecological receptors in these developed areas.

3.4.2.1 Northern Area Pathways Analysis

The northern portion of the Site was divided into an Upper North Area and Lower North Area as part of the risk assessment approach. The Upper North Area encompasses the defunct research and development buildings of the former Fireworks Facility and existing light industrial and commercial developments that are occupied daily and subject to both human and vehicular traffic.

The remaining area of the Upper North Area consists of abandoned buildings and research facilities. This area consists of buildings and structures in various stages of decay with areas of asphalt roadways contacting portions of the abandoned structures. Fragmented areas of vegetation are present throughout the area with more opportunistic vegetative growth occurring around the former roads and buildings. The fragmented areas of vegetation consist of a mixture of deciduous and coniferous trees with a shrub layer in the understory mostly associated with the riparian areas of the Drinkwater River. The area has evidence of trespasser activity and dumping of building debris and trash was present. The remaining areas of the Upper North Area are occupied by active commercial and industrial developments including a saw mill, autobody shops, light manufacturing, equipment storage yards, landscaping companies and construction companies. All of these areas are occupied during daylight hours and access roads carry vehicular traffic to and from these places of business. Each of the properties was estimated to be approximately 2 to 6 acres in size. The current land use designation in this portion of the Site is for industrial development by the Town of Hanover. The developed properties afford little to no significant habitat in these areas for fish or wildlife species. The Eastern Channel Corridor of the Drinkwater River bounds the Upper North Area and represents aquatic and riparian habitat for fish and semi-aquatic wildlife.

The Lower North Area encompasses the developed property and equipment storage yard for the Town of Hanover's DPW. This area consists of maintenance buildings, an equipment refueling area, and an open equipment yard covered by concrete slabs, crushed gravel and disturbed soils. The yard is subject to human and vehicular traffic on a daily basis. The property is bounded on the west by the riparian and riverine habitats of the Lower Drinkwater River Corridor. A narrow margin of mixed coniferous/ deciduous vegetation separates the maintenance yard and the riverine wetlands and channel of the Lower Drinkwater River Corridor. The riparian habitat and aquatic habitat of the Lower Drinkwater River Corridor represent habitat for use by fish and wildlife species. The equipment yard was estimated to be less than 6 acres in size and the current maintenance facility and yard affords little value as habitat for fish and wildlife species.

A screening of surface soil from the Upper North Area and Lower North Area identified OHM to be present in the soils of these areas. However, the developed nature of the properties present and the small size limit the exposure of fish and wildlife resources to these contaminants. Therefore, the exposure pathway for ecological receptors was judged to be incomplete in the developed areas. The wetland and aquatic habitats of the Eastern Channel Corridor and Lower Drinkwater River Corridor of the Drinkwater River afford significant value as fish and wildlife habitat and will be evaluated as part of the ERC for the Site.

3.4.2.2 Upper Drinkwater River Corridor Pathways Analysis

The outlet from Forge Pond discharges to the Drinkwater River in the northwest corner of the Site property. A water diversion control device below the outlet diverts water between the Upper Drinkwater River Corridor of the Drinkwater River and the Eastern Channel Corridor. The aquatic habitats of the two channel corridors are highly divergent in environmental character. The Upper Drinkwater River Corridor is a linear feature running north to south, with bottom substrates consisting of cobble and gravel substrates. The flow in the channel can form microhabitats consisting of riffles and runs along its length. During sampling for the Phase IIC and IID events, flow within the Upper Drinkwater River Corridor was highly variable with water levels ranging from significant flowing water volumes to near negligible water levels present. This variable remains a product of the diversion device operation below Forge Pond. The overhanging tree canopy creates a highly shaded stream channel with little or no submergent aquatic vegetation present in the stream bed. The banks of the channel are moderately vegetated given the highly shaded environment. The Upper Drinkwater River Corridor and its riparian habitat does support significant habitat for fish and semi-aquatic wildlife. No evidence of historical development or disposal activities related to the Site were apparent from Site record or observed along the banks of the Upper Drinkwater River Corridor.

In contrast to the Upper Drinkwater River Corridor, the Eastern Channel Corridor is an elongated, meandering channel with densely vegetated banks and a sporadically broken overhead canopy above the river channel. The breaks in the canopy allow for opportunistic growth of submergent aquatic macrophytes to grow in the stream channel. Benthic substrates in the Eastern Channel Corridor consisted of fine grain sands and silt with areas of mixed gravel. The flow is non-turbulent in nature with riparian emergent vegetation and existing bridge abutments from abandoned roads forming scattered eddies of circulation throughout the channel length. The Eastern Channel Corridor bounds the Upper North Area, which contains both historical Fireworks facilities and current industrial and commercial developments. Debris including glassware, piping, metal debris, tires, building debris and other debris are apparent throughout its length. Even with the presence of debris and former and existing developments, the Eastern Channel Corridor affords riparian and aquatic habitat for fish and semi-aquatic wildlife.

Phase IIC sampling of the surface water and sediments revealed elevated concentrations of mercury and lead, two Site-related contaminants, to be present in the Eastern Channel Corridor. Sampling of the Upper Drinkwater River Corridor revealed concentrations of metals to be comparable to the concentrations observed in background surface water and sediment samples of the Northern Drinkwater River above Forge Pond. Given the comparability of the concentrations, the lack of historical Fireworks disposal and natural setting, the Upper Drinkwater River Corridor was determined to not be impacted by OHM related to the Site. Focused investigations were directed towards the Eastern Channel Corridor and Lower Drinkwater River Corridor and its impoundments where Site-related OHM has been detected above background concentrations.

4.0 ANALYSIS AND EXPOSURE ASSESSMENT

The Analysis and Exposure Assessment presents the technical results of the measurement endpoints used as lines of evidence for characterizing risks to the assessment endpoints.

4.1 Benthic Community Assessment (Assessment Endpoint #1)

Assessment endpoint #1 is the protection and sustainability of benthic community structure in Factory and Lily Ponds, Drinkwater River areas, and Marsh Upland Area wetland to serve as a prey base.

4.1.1 Reference Station and Sediment Benchmark Comparison

All sediment samples were collected from the surface interval of 0-0.5 ft. Sediment benchmark values were collected from a prioritized list of technical sources. Benchmark values from these sources were categorized as low or high threshold benchmarks. The threshold effect concentration (TEC) and probable effect concentration (PEC) from MacDonald et al. (2000) were used as low and high benchmark values, respectively. Where values were not available from MacDonald et al. (2000), the lowest effects levels (LEL) and severe effects levels (SEL) from Persaud et al. (1993) were used as the low and high benchmarks. Secondary chronic values and the lowest chronic values from Jones et al. (1996) were used as the high and low benchmark values. Where values were not available from these three sources, alternate resources were used based upon availability. Low benchmarks were entered from Ingersoll et al. (1996) and USEPA (1992). Where a contaminant had no available benchmark, values from similar parent or chemically similar chemicals were applied. Surrogate values were used for methyl mercury (total mercury), Aroclor-1254 (total PCBs), endrin aldehyde (endrin), endrin ketone (endrin), gamma chlordane (chlordane), xylene(o) (xylene), and 2-methylnapthalene (1-methylnapthalene). No sediment-based benchmarks were available for aluminum, barium, beryllium, cobalt, dichlorodifluoromethane, freon, selenium, thallium, trichlorofluoromethane, vanadium, and vinyl chloride.

Exceedance of the low benchmark value indicates low risk to benthic communities whereas a concentration exceeding the high benchmark value indicates a potential risk to benthic communities. If a contaminant exceeded a benchmark value but did not exceed the concentration measured at the reference station by an order of magnitude, its presence was attributed to upstream sources unrelated to the Site and considered reflective of local conditions. A contaminant exceeding the high benchmark value and the concentration measured at the reference station by an order of magnitude is considered Site-related and is identified as a contaminant related to historical Site activities and as posing a potential risk to the benthic community.

Table B-4-1 compares detected concentrations of contaminants in freshwater riverine sediments of the Drinkwater River to the identified low and high benchmark values and reference station concentrations. A number of Site-related low benchmark exceedances were measured at ECCTRA12 including 1,1-dichloroethene, trans-1,2-dichloroethene, trichlorethene, endrin aldehyde, and endrin ketone. Endrin ketone also exceeded the low benchmark value at ECCTRA11 and antimony exceeded it at ECCTRA11 and LDCTRA10. Aroclor-1254 exceeded the high benchmark value and was considered Site-related in ECCTRA10. Total mercury also exceeded the high benchmark value and was considered Site-related in ECCTRA10 as well as ECCTRA11, LDCTRA11, and LDCTRA10.

Table B-4-2 compares detected concentrations of contaminants in freshwater pond sediments to low and high benchmark values and reference station concentrations. Concentrations of total mercury exceeded the high benchmark value in all pond sampling locations and were not considered reflective of local conditions. All other analyte concentrations were below benchmark values or were comparable to reference station concentrations.

Table B-4-3 compares detected concentrations of contaminants in freshwater wetland sediments to low and high benchmark values and reference station concentrations. Total mercury exceeded the high benchmark value in MUA21 and was not considered reflective of local conditions. All other analyte concentrations were below benchmark values or were comparable to reference station concentrations.

Results of this sediment benchmark and reference station comparison indicate that mercury is the main contaminant in all aquatic habitats in the Site. Sediment benchmark exceedances by 1,1-dichloroethene, trans-1,2-dichloroethene, trichlorethene, endrin aldehyde, endrin ketone, and antimony in the riverine habitat indicates low risk to benthic communities in the Eastern Channel Corridor and Lower Drinkwater River Corridor. Exceedance of the high benchmark value by Aroclor-1254 in the riverine habitat indicates potential biological harm to the benthic community in the Eastern Channel Corridor. Exceedance of the high benchmark value by total mercury in the riverine, pond, and wetland habitats indicates potential biological harm to the benthic communities present in all aquatic habitats on the Site.

4.1.2 Assessment of the Bioavailability and Toxic Potential of Soluble Extractable Metals Present in the Sediments

Results of the bioavailability and toxic potential assessment can be found in Table B-4-4. To assess the bioavailability of the heavy metals present to the benthic community, the SEM/AVS ratio was calculated. This ratio is the sum of the soluble extractable metals (SEM) divided by the acid volatile sulfide (AVS) concentration at each sampling station. A SEM/AVS ratio > 1 indicates that the identified metals at this station are bioavailable to faunal organisms. To assess the toxic potential of the sediments, the (ΣSEM)-AVS was divided by the fraction of total organic carbon (f_{oc}) at each station. A toxic potential <130 micromoles per gram organic carbon (umol/g_{oc}) implies that there is low toxic potential associated with the sediment (USEPA, 2000). A toxic potential between 130 and 3,000 umol/g_{oc} implies that toxic effects on the benthic invertebrate community are uncertain with the sediments evaluated. A toxic potential > 3,000 umol/g_{oc} implies that there is potential for toxic effects on the benthic invertebrate community present.

In riverine habitats, ECCTRA11 had a SEM/AVS ratio of 266.59 indicating that metals in the sediments at this station are bioavailable to the benthic invertebrate community present. All other riverine stations had SEM/AVS ratios < 1, indicating that the metals present were not bioavailable to the benthic invertebrate community present.

In pond habitats, MLFPTRA11 had a SEM/AVS ratio of 1.94 indicating that metals at this station are bioavailable to the benthic invertebrate community. All other pond stations had SEM/AVS ratios < 1, indicating that the metals were not bioavailable to the benthic invertebrate community at these locations.

In wetland habitats, both MUA21 and the reference station had SEM/AVS ratios < 1, indicating that the metals present at these sites were not bioavailable to the benthic invertebrate community present.

The toxic potential at all stations were < 130 umol/g_{oc}, implying that the metals present in the sediments have a low potential to have acute toxic effects on the benthic invertebrate community present.

4.1.3 Comparison of Sediment Pore-water Total Mercury and Methyl Mercury Concentrations to Surface Water Threshold Values

Sediment pore-water was sampled to determine total mercury and methyl mercury concentrations present at all stations within the surface interval of 0-0.5 ft. Results of this evaluation can be found in Table B-4-5. Total mercury concentrations in pore-water were compared to the freshwater GLWQI chronic and acute values of 0.00057 and 0.0017 ug/L (USEPA, 1980). Methyl mercury porewater concentrations were compared to the bioaccumulative conservation benchmark of 0.0005 ug/L. This benchmark is a guidance value designed to protect piscivorous wildlife from exposure to harmful levels of methyl mercury through their diet (USEPA, 1993).

All on-Site total mercury concentrations exceeded both the chronic and acute toxicity values. The highest total mercury concentrations were found in the riverine habitat where average concentrations were three orders of magnitude greater than those measured in the pond and wetland habitats.

All on-Site methyl mercury concentrations exceeded the bioaccumulative conservation benchmark. Average methyl mercury concentrations in the riverine habitat were an order of magnitude greater than those measured in the pond and wetland habitats.

No apparent spatial trend exists for total and methyl mercury concentration levels within each habitat although a spatial distinction does exist between the habitats. These results indicate that acutely toxic conditions for total and methyl mercury exist in all of the on-Site habitats.

4.1.4 Bioaccumulation Evaluation for *Lumbriculus variegatus*

The toxicological report for the aquatic earthworm, *Lumbriculus variegatus*, 28-day bioaccumulation test can be found in Attachment B2. The bioaccumulation evaluation was performed with sediments from reference stations NDRTRA10, FPTRA10, and WBK01, and on-Site locations ECCTRA12, ECCTRA11, ECCTRA10, LDCTRA11, LDCTRA10, LUFPTRA11, LUFPTRA10, MLFPTRA12, MLFPTRA11, MLFPTRA10, and MUA21. Body burden data for worms exposed to sediments from the on-Site stations were compared to those exposed to the reference station sediments for each habitat evaluated. Elevated body burden accumulation was observed for mercury in all habitats sampled.

Table B-4-6 presents the worm bioaccumulation data for riverine habitats. Several contaminants bioaccumulated at slightly elevated levels in the on-Site location compared to the reference station (Table B-4-6). Cadmium and silver both bioaccumulated at slightly elevated concentrations at all stations. Aluminum, manganese, and nickel were bioaccumulated at elevated levels in ECCTRA11 and ECCTRA10. Worms exposed to sediments from ECCTRA10 bioaccumulated at slightly elevated levels of cobalt in comparison to other stations. Station ECCTRA11 had the largest number of contaminants including antimony, chromium, iron, and lead in worm tissues. Elevated concentrations of barium and cobalt were bioaccumulated in ECCTRA12, LDCTRA11, and LDCTRA10. Stations LDCTRA11 and LDCTRA10 bioaccumulated nickel, station LDCTRA11 bioaccumulated arsenic, and LDCTRA10 bioaccumulated sodium. Elevated bioaccumulation of the above analytes were within one order of magnitude of reference station concentrations, therefore are considered reflective of local conditions. Total and methyl mercury bioaccumulated at elevated levels in all riverine locations. Total and methyl mercury bioaccumulated at levels one order of magnitude higher than the reference station in ECCTRA11, ECCTRA10, LDCTRA10, and LDCTRA11. Bioaccumulation of total and methyl mercury in these riverine locations were considerably elevated above reference station concentrations and were not considered reflective of local conditions.

In the pond habitat the bioaccumulation of contaminants appears randomly distributed (Table B-4-7). In LUFPTRA11 the contaminants aluminum, antimony, and manganese bioaccumulated at elevated levels. In MLFPTRA12 and MLFPTRA11 elevated bioaccumulation occurred for the contaminants barium, magnesium, potassium, and sodium. Silver also bioaccumulated at elevated levels in MLFPTRA12 whereas worms in sediments from MLFPTRA10 bioaccumulated elevated levels of aluminum and lead. Worms in sediments from LUFPTRA10 bioaccumulated the largest number of contaminants. These contaminants included aluminum, antimony, barium, cadmium, chromium, cobalt, copper, iron, lead, manganese, nickel, and silver. Elevated bioaccumulation of the above analytes were within one order of magnitude of reference station concentrations, therefore are considered reflective of local conditions. Total and methyl mercury bioaccumulated at levels one order of magnitude higher than the reference station in all pond locations. A negative correlation exists between distance downstream and levels of bioaccumulated mercury. Bioaccumulation of total and methyl mercury were considerably elevated above reference station concentrations and were not considered reflective of local conditions.

In the wetland habitat the on-Site location MUA21 bioaccumulated slightly elevated levels of barium, manganese, silver and sodium (Table B-4-8). Bioaccumulated levels of calcium, manganese, methyl mercury, and sodium may be considered reflective of local conditions due to high concentrations present in the reference station. Cobalt was not detected in the reference station but was present at MUA21 (0.29 ug/g). Bioaccumulated concentrations of total mercury were elevated in MUA21 close to one order of magnitude above levels in the reference station. Methyl mercury bioaccumulated at levels one order of magnitude higher than the reference station in MUA21 and is not considered reflective of local conditions.

Results of the *Lumbriculus* bioaccumulation evaluation verified that many of the heavy metals present in the sediments are bioavailable and therefore were able to be bioaccumulated by benthic macroinvertebrates. Bioaccumulated concentrations of total and methyl mercury are Site-related and highly elevated in all aquatic habitats on the Site. The potential for bioaccumulation of metals in benthic macroinvertebrates provides a pathway of exposure to insectivorous wildlife and poses a potential risk of biological harm.

4.1.5 Benthic Macroinvertebrate Communities Assessment

The benthic macroinvertebrate community was surveyed to determine if structural or functional impairment occurred as a result of exposure to surface sediment contamination. The benthic community laboratory data report can be found in Attachment B3. The community-based metrics used for the habitat-specific assessments include total taxa richness, mean taxa richness, mean community density, the Shannon-Weiner diversity index, community structure composition, the community loss index, functional feeding guilds, the ratio of subfamily Chironominae in the chironomid community, and the ratio of Oligochaeta to Chironomidae. Metrics were compared between stations sampled in riverine, pond, and wetland habitats present on-Site and from a reference habitat of similar physical characteristics.

4.1.5.1 Total Taxa Richness

Total taxa richness was expressed as the total number of individual taxa present at each sample station. Total taxa richness is the simplest measure of biotic diversity in the benthic community present at each station. A taxa richness value lower than the reference station may indicate an impacted community (Barbour et al., 1999).

In the riverine habitats total taxa richness was higher than the reference station (NDTRA10) at ECCTRA11 and ECCTRA10, and is lower than the reference station at ECCTRA12, LDCTRA11, and LDCTRA10 (Table B-4-9).

In the pond habitats total taxa richness was higher than the reference station (FPTRA10) at LUFPTRA11 and MLFPTRA11 (Table B-4-9), comparable to the reference station at MLFPTRA10 and, lower than the reference station at LUFPTRA10 and MLFPTRA12.

In the wetland habitats total taxa richness was slightly higher at MUA21 than at the reference station (WBK01) (Table B-4-10).

The lower taxa richness present at riverine locations ECCTRA12, LDCTRA11 and LDCTRA10 and pond locations LUFPTRA10 and MLFPTRA12 indicate that these are potentially impacted locations.

4.1.5.2 Mean Taxa Richness

Mean taxa richness was a metric calculated by summing the number of species sampled for each replicate at each station. This number was averaged over all the replicates by station to give the mean taxa richness for each station. A mean taxa richness value lower than the reference station may indicate an impacted community (Barbour et al., 1999).

In the riverine habitats, trends for mean taxa richness parallel those of total taxa richness (Table B-4-9). Mean taxa richness was higher than the reference station (NDTRA10) at ECCTRA11 and ECCTRA10 and was lower than the reference station at ECCTRA12, LDCTRA11 and LDCTRA10.

In the pond habitats, mean taxa richness was higher than the reference station at LUFPTRA11 and MLFPTRA11 (Table B-4-9) and lower than the reference station at LUFPTRA10, MLFPTRA12 and MLFPTRA10.

In the wetland habitats total taxa richness at MUA21 was higher than that observed at the reference station (Table B-4-10).

Based upon the trends observed, the riverine and pond locations ECCTRA12, LDCTRA11, LDCTRA10, LUFPTRA10, MLFPTRA12, and MLFPTRA10 are potentially impacted habitats.

4.1.5.3 Community Density

Average density is defined as the average number of benthic macroinvertebrates per square meter at each station. A reduction in overall community density may indicate an impacted community (Hicks, 1997). Density for each replicate was calculated as follows:

$$CD = \sum (p_i) / C \qquad \text{(Equation 14)}$$

where:

CD = Community Density (no. individuals/m^2)
p_i = total number of individuals in taxa i
C = 0.023 m^2

In riverine habitats, locations ECCTRA12, ECCTRA11, and ECCTRA10 have mean densities higher than the riverine reference station. The higher density at ECCTRA12 is significantly different from the density at the reference station. The mean density at LDCTRA11 was lower than at the reference station (Table B-4-9).

In the pond habitats, the mean densities at MLFPTRA10 and MLFPTRA11 are greater than that of the reference station, whereas densities at LUFPTRA11, LUFPTRA10, and MLFPTRA12, have sequentially (and significantly) lower mean densities than the reference station (Table B-4-9). In the wetland habitats the average density at MUA21 is about three times that of the reference station (Table B-4-10).

This analysis indicates that riverine location LDCTRA11 and pond locations LUFPTRA11, LUFPTRA10, and MLFPTRA12 are impacted habitats.

4.1.5.4 Community Diversity

The SWDI (Equation 13) is based upon information theory that integrates taxa richness and numerical abundance data resulting in a numerical value of diversity that can be compared between stations (Perkins, 1982). A high diversity index is indicative of high taxa richness and complex community structure.

The SWDI of the on-Site locations compared to the reference stations was reduced in all locations but ECCTRA11 and ECCTRA10.

In the riverine habitats the diversity was highest at ECCTRA10, ECCTRA11 and exceeded the value observed at the reference station (Table B-4-9). ECCTRA12, LDCTRA11, and LDCTRA10 had lower species diversity than the reference station.

In the pond habitat, diversity is higher than the reference station at LUFPTRA11 and MLFPTRA11 (Table B-4-9). Stations LUFPTRA10 and MLFPTRA10 had lower diversity than the reference station. In the wetland habitat, diversity was higher at the reference station than that observed at MUA21 (Table B-4-10).

These analyses indicate that the riverine and pond locations ECCTRA12, LDCTRA11, LDCTRA10, LFUP10, MLFPTRA10 and the wetland location MUA21 reflect a reduction in overall community diversity.

4.1.5.5 Benthic Macroinvertebrate Community Structure

Community composition can be analyzed by investigating the density of specific taxonomic groups present within benthic communities and can be used as an indicator of potential structural alteration in communities (Barbour et al., 1999). For the basis of analysis in this assessment, taxa are grouped using the taxonomic classification of order. Benthic macroinvertebrates can be used as bioindicators because many orders of benthic macroinvertebrates are sensitive or tolerant to pollution impacts. Reductions in pollution-sensitive taxa and a predominance of pollution-tolerant taxa in the community can be indicative of pollution effects or habitat degradation. For the purpose of this analysis some orders have been combined for simplicity or broken down to family level to increase analysis sensitivity given their predominance in the community (i.e., chironomids). Large-scale alterations in community structure in the benthic community present in the on-Site station compared to the reference station can be interpreted as an observed effect from pollution or habitat degradation.

Orders combined for this analysis include Oligochaeta and Hirudinae. The order Diptera will be separated into the family Chironomidae and Other Diptera.

Under the MCP, alterations in community structure may not be as significant if functional processes are still sustained by a different taxon or group of invertebrates. Therefore, from a regulatory standpoint alterations in community structure alone may not be interpreted as a significant alteration. For significant impacts to be related to the community structure and composition metric, an altered community structure coupled with altered community function form the basis for impairment.

In the riverine habitats, amphipod abundance was higher at ECCTRA11 and LDCTRA10 than at the reference station (Figure B-4-1) and was higher at ECCTRA10. Isopod abundance was lower at ECCTRA12, LDCTRA10, and LDCTRA11 than at the reference station with a statistically significant reduction found at LDCTRA11. Oligochaeta abundance was generally lower at on-Site locations than at the reference station with notable reductions in abundance at ECCTRA11 and LDCTRA10. Many orders present at the on-Site stations were not present at the reference station. These orders include Tricohptera, which was present at ECCTRA10 and ECCTRA11, Coleoptera, which was present at ECCTRA10, ECCTRA11, and LDCTRA10, and Hirudinae, which was present at ECCTRA11 and LDCTRA10. ECCTRA10 and LDCTRA10 lack representation of the grouping "Other Diptera" which was present at the reference station. LDCTRA11 did not have the Orders Bivalva, Amphipoda or Isopoda, which are present at the reference station. ECCTRA12 also lacks representation from the order Amphipoda and the abundance of isopods and bivalves remained low at this station. No representation of the family Chironomidae was noted at ECCTRA12 and reduced numbers of this order were present at LCDTRA11 and LDCTRA10.

Oligochaeta and Chironomidae dominated the benthic community at the reference station in the pond habitat (Figure B-4-2). Stations LUFPTRA11, LUFPTRA10, MLFPTRA10, and MLFPTRA12 show reduced Oligochaeta abundance compared to the reference station. Reductions in Oligochaeta abundance were statistically significant ($p<0.05$) at LUFPTRA11 and MLFPTRA12.

Chironomidae abundance increased relative to the reference station at LUFPTRA11, MLFPTRA10, and MLFPTRA11. Chironomidae abundance decreased significantly relative to the reference station at stations LUFPTRA10 and MLFPTRA12 ($p<0.05$). All samples from Factory Pond had greater taxa richness than the reference station. Some groupings that appeared in on-Site pond locations that did not appear in the reference station include Nematoda, Amphipoda, Hirudinae, and Isopoda. Bivalva was present in all stations but the reference station. In the wetland habitats, community structure and composition at MUA21 displayed a highly altered community compared to the reference station (Figure B-4-3). The family Chironomidae, other dipterans and the order Coleoptera increased in abundance relative to the wetland reference station. MUA21 had reduced abundance of Oligochaeta and Bivalva (both groups are infaunal organisms) relative to the reference station. The orders Amphipoda, Isopoda, and Megaloptera were found in the Marsh Upland Area stations but were absent from the reference station.

These results suggest that the riverine, pond, and wetland locations ECCTRA12, ECCTRA11, ECCTRA10, LDCTRA11, LUFPTRA11, LUFPTRA12, MLFPTRA12, and MLFPTRA10 support slightly altered benthic community structure.

4.1.5.6 Community Loss

The community loss index (CLI) is a measure of the loss of benthic taxa between a reference station and a potentially impacted benthic community. Higher CLI values indicate an increasing degree of dissimilarity between benthic communities in the sampled and reference stations (Plafkin et al., 1989). Values greater than 0.25 indicate a significant difference in community loss from the reference station and thus can be interpreted as an alteration in community structure. The CLI is calculated as follows:

$$CLI = (D - A) / E \qquad \text{(Equation 15)}$$

where:

CLI = Community Loss Index (unitless)
A = number of taxa common to both samples
D = total number (N) of taxa present at the reference station
E = total number (N) of taxa present at the on-Site station

The CLI displays no consistent spatial pattern or trend between the on-Site benthic communities and those present at the reference station of the habitats sampled. All the riverine and nearly all of the pond communities had CLI values > 0.25. The highest CLI values were associated with ECCTRA12, LDCTRA11, LDCTRA10, LUFPTRA10, MLFPTRA12, MLFPTRA10, and MUA2.

In the riverine habitats CLI values > 0.25 were observed at all locations (Table B-4-9). Stations ECCTRA11 and ECCTRA10 displayed the least (0.32, 0.35) whereas LDCTRA11 and LDCTRA10 displayed the greatest (1.11, 1.00) community loss. ECCTRA12 displayed intermediate community loss (0.75).

In the pond habitats CLI values are > 0.25 at all locations except MLFPTRA11 (0.13) (Table B-4-9). Community loss trends appeared randomly distributed downstream and no clear pattern was apparent.

In the wetland habitats the CLI value for MUA21 (0.63) was > 0.25 (Table B-4-10).

These results suggest that benthic communities at every on-Site location (except MLFPTRA11) have experienced significant community loss relative to the community assemblage at the reference benthic communities.

4.1.5.7 Functional Feeding Guilds

Each guild in the benthic community occupies a key functional role and contributes to the sustainability of the benthic community. When guild distribution in a community is altered, the ecosystem may experience a decrease in function at the community or ecosystem level resulting in the creation of a limiting factor within the aquatic community (i.e., elimination of a niche). Without a stable food chain dynamic, an imbalance in functional feeding groups will result, reflecting an altered food chain (Barbour et al., 1999). By comparing the distribution of functional guilds at each on-Site station with a reference community, the impact of the added stressor on the benthic community's ability to function may be determined.

In the riverine habitats, representation of the gatherer-collector guild at ECCTRA12 and ECCTRA10 increased relative to the reference station (Figure B-4-4). Predator guild abundance increased at ECCTRA11 and decreased by half at ECCTRA12 compared to the reference station. The scraper guild was absent at the reference station but was present at ECCTRA12, ECCTRA11, and ECCTRA10. Filterer-collector guild abundance was greater at ECCTRA11 and ECCTRA10 and lower at ECCTRA12, LDCTRA10, and LDCTRA11 relative to the reference station. ECCTRA10 had the highest abundance for all feeding guilds except predators. The collector-gatherer and predator functional feeding guilds were the dominant guilds observed in the riverine environments at all stations. No statistically significant trends ($p>0.05$) between on-Site and reference station guild abundance were found.

In the pond habitats, the gatherer-collector guild is dominant in the reference station as well as MLFPTRA10, MLFPTRA11 and LUFPTRA11, and LUFPTRA10 (Figure B-4-5). LUFPTRA10 and MLFPTRA12 showed a statistically significant ($p<0.05$) decline in representation of the gatherer-collector guild compared to the reference station. The filterer-collector and predator guilds showed greater abundances at LUFPTRA11, MLFPTRA12, MLFPTRA11, and MLFPTRA10 than at the reference station. LUFPTRA10 had greater abundance of the filterer-collector guild but decreased abundance of the shredder and predator guilds. An analysis of variance (ANOVA) revealed a statistically significant difference was found between the gatherer-collector ($p < 0.05$ (-) effect) and predator guilds ($p < 0.05$ (+) effect) for all pond stations. The parasite guild is present at the reference station as well as LUFPTRA11 and MLFPTRA11. Relative abundance of this guild was low but absent at the remaining pond locations.

In the wetland habitats, the composition of functional guild composition was altered at MUA21 compared to the reference wetland (Figure B-4-6). Gatherer-collector, scraper, and predator guild abundance increased at MUA21 relative to the reference station and filterer-collector abundance decreased.

These results suggest that the riverine, pond, and wetland stations ECCTRA12, ECCTRA11, ECCTRA10, LDCTRA11, LUFPTRA11, and MUA21 have altered functional guild composition relative to the reference benthic communities in similar habitats.

4.1.5.8 Ratio of Chironominae to All Other Chironomids

The sub-family Chironominae has been shown to have a tendency to increase in abundance and/or replace more sensitive taxa when benthic communities are exposed to pollution. These studies focused primarily on heavy metals (Winner et al., 1980). A comparison of the ratio of Chironominae to all other Chironomid taxa can help identify this shift in taxa. A shift towards a more dominant representation of the subfamily Chironominae suggests a greater tolerance to heavy metal contamination. The ratio is calculated as follows:

$$A = B / (C-D) \qquad \text{(Equation 16)}$$

where:

A = Ratio
B = Average number (N) of Chironominae taxa at the station
C = Average number (N) of Chironomids taxa at the station
D = Average number (N) of Chironominae taxa at the station

A value greater than one indicates that the sub-family Chironominae is dominant in the benthic community sampled. A value less than one indicates that other non-chironomids taxa are dominant at that station.

In the riverine habitats, the ratio of Chironominae to other Chironomids was > 1 at the reference station and at ECCTRA10 (Table B-4-9). ECCTRA12, ECCTRA11, LDCTRA11, and LDCTRA10 have ratios < 1 indicating a community where other chironomid taxa were dominant.

In the pond habitats, all ratios including the reference station favored the sub-family Chironominae. At MLFPTRA12 the ratio was zero because no chironomids outside of the sub-family Chironominae were present. Ratios favoring the sub-family Chironominae exceeded that of the reference station at LUFPTRA11, MLFPTRA11, and MLFPTRA10.

In the wetland habitats, the ratio at the reference station favored the sub-family Chironominae (Table B-4-10). The ratio at the on-Site station (MUA21) was zero due to the absence of chironominae taxa.

4.1.5.9 Ratio of Chironomidae to Oligochaeta

In general, the family Chironomidae (midges) tends to be more tolerant to heavy metal stressors than the aquatic Oligochaeta (aquatic worms) due to the nature of the organism's osmotic regulation (Brinkhurst, 1974). The ratio of Chironomidae to Oligochaeta can be a useful metric for assessing the effects of environmental stressors on benthic communities. The ratio was calculated as follows:

stations are in an urban setting. Because of this influence of non-point source pollution, both the on-Site and the reference stations appear impacted by anthropogenic sources of organic enrichment.

The watershed-based effects from organic enrichment make the inferential value of this metric very limited.

4.1.5.12 EOT Richness

In freshwater wetlands, the orders Ephemeroptera, Odonata, and Trichoptera (EOT) are known to contain many families that are relatively sensitive to impairment. High numbers of families within these orders indicate an unimpacted wetland community (Hicks, 1997). EOT richness was calculated as the sum of individuals from these orders sampled at a given location.

EOT richness was zero for both the on-Site (MUA21) and reference (WBK01) wetland locations because no individuals from the orders Ephemeroptera, Odonata or Trichoptera were identified in the samples (Table B-4-10).

The inability to differentiate any trend in EOT due to their absence in both environments render this metric of no inferential value here.

4.1.5.13 Community Taxa Similarity Index

The community taxa similarity index (CTSI) is a measure of taxa similarity between reference area wetlands and potentially impacted wetland areas. Index ratios range from 0% (no similarity to the reference station) to 100% (complete similarity to the reference data). This metric was calculated as:

$$CTSI = 100 - (X / 2) \quad \text{(Equation 20)}$$

where:

CTSI = Community Taxa Similarity Index (%)
X = Γ(Y)
Y = absolute value (W – Z)
W = Number of individuals of taxonomic order "w" at the reference station
Z = Number of individuals of taxonomic Order "w" at the on-Site station

The CTSI value for station MUA21 was 13% (Table B-4-10). Hicks (1997) interprets a CTSI <25% as indicative of a highly altered wetland benthic community. Based upon the Hicks (1997) interpretation this indicates that MUA21 supports highly altered community structure compared to that found at the reference benthic community.

4.1.5.14 Community Trophic Similarity Index

The community trophic similarity index (CTrSI) is a measure of the similarity of trophic guild structure between reference area wetlands and potentially impacted wetland areas. The CTrSI value may range from 0 (no similarity in trophic guild structure between communities) to 100% (total similarity in trophic guild structure between communities) (Hicks, 1997). This metric was calculated as follows:

$$CTrSI = 100 - (X / 2) \quad \text{(Equation 21)}$$

where:

CTrSI	=	Community Trophic Similarity Index (%)
W	=	Number of individuals (N) of feeding guild "w" in the reference station
Z	=	Number of individuals (N) of feeding guild "w" at the study station
X	=	Γ(Y)
Y	=	the absolute value (W – Z)

The CTrSI value for MUA21 was 60% (Table B-4-10). This value indicates that a 60% degree of similarity in the feeding guild structure exists between station MUA21 and the reference station. Hicks (1997) defines CTrSI values between 25% to 75% as indicating a significant difference in trophic level relationships between a potentially impacted wetland and a reference wetland area. These results suggest that MUA21 supports an altered functional feeding guild structure compared to that found in the wetland reference benthic community.

4.1.6 Sediment Toxicity Testing

Whole sediment toxicological testing was performed using surface sediments from the Drinkwater River, Lily Pond, Upper and Lower Factory Pond, and the Marsh Upland Area. Corresponding reference areas were also sampled for assessing potential toxicological effects for ubiquitous contaminants not solely associated with the Site.

4.1.6.1 Amphipod (*Hyalella azteca*) Survival and Growth Tests

Results for the 10-day *Hyalella azteca* survival and growth tests are presented in Table B-3-2. The final laboratory report from EnviroSystems, Incorporated is provided in Attachment B4. All tests were evaluated for acceptability and effectiveness using testing protocols and evaluation criteria provided in USEPA (2000) and ASTM (2001). A single protocol deviation was noted during the testing program. A greater than 50% change was observed in ammonia concentrations from the start of the test to the completion of the test in all samples including the reference area samples and the laboratory control. No effect was noted for this protocol deviation on the test outcomes based upon a lack of observed toxicity in the laboratory control, the reference area and the Site-specific samples.

Results of the 10-day tests revealed no statistically significant reduction in survival in the sediment samples evaluated when compared to the habitat-specific reference tests. Survival of amphipods exposed to Factory Pond sediments ranged from 86% to 90%. Survival of amphipods exposed to riverine sediments from the Drinkwater River adjacent to the Site ranged from 87% to 96%. Survival of amphipods exposed to sediments from the Marsh Upland Area was 76%.

A negative effect on growth was noted for a sample collected from Factory Pond. A statistically significant reduction in growth was noted for sample MLFPTRA11 from Lower Factory Pond when compared to growth observed in test populations exposed to reference sediments from Forge Pond. All other samples revealed comparable or positive growth relative to the amphipods exposed to sediments from the corresponding reference areas.

4.1.6.2 Midge (*Chironomus tentans*) Survival and Growth Tests

Results for the 10-day, *Chironomus tentans* survival and growth tests are presented in Table B-3-3. The laboratory report from EnviroSystems, Incorporated is provided in Attachment B5. Performances of the tests were evaluated for acceptability and effectiveness using testing protocols and evaluation criteria provided in USEPA (2000) and ASTM (2001). Protocol anomalies related to environmental monitoring criteria and temperature were noted during the testing program. A greater than 50% change was observed in ammonia, alkalinity and water hardness concentrations from the start of the test (Day 0) to the completion of the test (Day 10) in all samples, the reference area samples and the laboratory control. Temperature variation in the test chambers varied by greater than 3°C during the monitoring period. Mean temperature during the exposure period was 23°C, which is the recommended testing temperature. No effect from the observed environmental conditions was determined to have impacted the test results.

Results of the 10-day tests revealed no statistically significant reductions in survival among the sediment samples evaluated from the Site when compared to the habitat specific reference results. Survival of midges exposed to Factory Pond sediments ranged from 76% to 89%. Survival of midges exposed to riverine sediments from the Drinkwater River receiving runoff from the Site ranged from 81% to 93%. Survival of midges exposed to sediments from the Marsh Upland Area was 84%.

No significant reductions in growth were observed in 13 of 14 sediment samples tested. A negative effect on growth was noted for a sample collected from the Marsh Upland Area. A statistically significant reduction in growth was noted for sample MUA21. Growth of midges exposed to sediments from the Marsh Upland Area was significantly lower than growth observed in midges exposed to the wetland reference area sediments. All other samples revealed comparable or positive growth relative to the midges exposed to sediments from corresponding reference areas.

4.1.6.3 Aquatic Annelid (*Lumbriculus variegatus*) Survival Tests

The laboratory report for the aquatic worm, *Lumbriculus variegatus* bioaccumulation test is provided in Attachment B2. A two-phase approach to performing the test was undertaken concurrently for evaluating survival and bioaccumulation potential. A 120-hour acute, survival test using *Lumbriculus variegatus* was performed on each sample to assess survival and potential confounding effects of mortality on the bioaccumulation potential of contaminants present. Table B-3-4 summarizes the results of the 5-day survival study. Results of the survival study revealed 100% survival of *Lumbriculus variegatus* exposed to sediments from all fourteen stations.

4.2 Plankton Assessment (Assessment Endpoint #2)

Assessment endpoint #2 was the protection and sustainability of freshwater plankton in Lily/Upper Factory and Lower Factory Ponds and the Drinkwater River to serve as a prey base in the pelagic food chain in these aquatic habitats.

Unfiltered surface water samples were collected from the on-Site riverine and pond habitats and corresponding reference sites (Plate 1 in the CSA). The samples were analyzed for VOCs, SVOCs, TAL metals, and methyl mercury. The maximum and average concentration values for samples from each riverine and pond site from Phase IIC and Phase IID data collection efforts were used in the benchmark comparison evaluation.

For this assessment endpoint, a screening level evaluation was performed to assess if surface water and potential groundwater discharge resulted in exposure to all aquatic life. For the surface water data evaluation, a TRV for algae and representative zooplankton was identified for assessing exposure specifically to the plankton community.

4.2.1 Groundwater Screening Level Benchmark Selection

Mean and maximum groundwater contaminant concentrations for the entire Site were screened using Ambient Water Quality Criteria (AWQC) benchmark values to qualitatively assess exposure to aquatic life via the groundwater discharge to surface water pathway. To account for subsequent dilution upon discharge and from plume infiltration, a default dilution value of 10 (MADEP, 1996) was used to estimate the exposure point concentration in the surface water body at the groundwater discharge point.

Screening level benchmark values were selected to compare to contaminant concentrations using a hierarchical selection process. AWQC values from USEPA (2002) were used as the acute and chronic screening values for groundwater preferentially to other benchmark values. Where AWQC values were not available, secondary acute and chronic values from Suter and Tsao (1996) were applied. Where values from these sources were not available, the Oak Ridge National Laboratory (ORNL) lowest chronic values for "all organisms" were applied from Suter and Tsao (1999). For explosive compounds, available secondary acute and chronic values from Talmage et al. (1999) were applied.

Acute and chronic screening values were not available for picric acid, tetryl, motor oil, 1,4-dioxane, isopropylbenzene, or methyl-t-butyl ether, therefore, these contaminants will be included for further analysis in the plankton assessment for surface water. Calcium, iron, magnesium and sodium are essential elements/nutrients and bio-regulated by living organisms, therefore, they were excluded from the groundwater screening process.

Results of the groundwater screening level comparison can be found in Table B-4-11. Mean and maximum concentrations of 4-amino-2,6-dinitrotoluene, HMX, 1,1,1-trichloroethane, 1,1-dichloroethane, 1,1-dichloroethene, 1,2,3-trichlorobenzene, total 1,2-dichloroethene, acetone, benzene, chloroform, cis-1,2-dichloroethene, methylene chloride, tetrachloroethene, toluene, bis(2-ethylhexyl)phthalate, butylbenzylphthalate, beryllium, cadmium, chromium, cobalt, copper, manganese, selenium, silver, thallium, vanadium, nitrobenzene, nitroglycerin, total freon, trichlorofluoromethane, and zinc did not exceed the respective acute or chronic values. Because none of these analytes exceed a conservative screening level benchmark, it may be concluded that these contaminants are not considered as COPECs in the groundwater at the Site.

Mean concentrations of trichloroethene, aluminum, barium, iron, lead, and nickel exceeded chronic values at multiple sub-areas for which groundwater data were available. Maximum concentrations of trichlorethene and lead also exceeded acute screening values in groundwater from the Lower North Area and Southern Disposal Area, respectively. Concentrations of aluminum and barium were comparable to background concentrations. Mean and maximum concentrations of mercury exceeded the acute and chronic screening values in groundwater from the Marsh Upland Area. The screening level assessment identified trichlorethene, aluminum, barium, lead, mercury, and nickel as COPECs in the groundwater at the Site.

4.2.2 Benchmark Exceedances in Groundwater by Area of Concern

The Proposed Greenway Area did not have any benchmark exceedances. Various contaminants were found to exceed benchmark values in all of the Site areas of concern. The maximum concentration of iron exceeded the chronic value in the Southern Conservation Area with detected levels in all four samples. Mean and maximum concentrations of aluminum and barium exceeded the chronic value in the Central Commercial Area in the one sample analyzed. Mean and maximum concentrations of barium in the Upper North Area exceeded chronic values in all of the 15 samples and maximum concentrations of trichlorethene, aluminum, nickel, and iron exceeded chronic values with detectable levels present in samples evaluated. Mean and maximum concentrations of iron and barium exceeded chronic values with detectable levels present in four of the five samples from the Lower North Area and maximum concentrations of trichlorethene exceeded acute values with detectable levels present in seven of the nine samples. In the Southern Disposal Area maximum concentrations of aluminum and barium exceeded chronic values with detectable levels in all of the three samples. Mean and maximum concentrations of nickel and iron also exceeded chronic values. The mean concentration of lead exceeded the chronic value with detectable levels in two of the three samples and the maximum concentration of lead also exceeded the acute value in the Southern Disposal Area. Finally, mean and maximum concentrations of mercury exceeded both the acute and chronic values and was the only contaminant to exceed a benchmark in the one sample at the Marsh Upland Area. These results suggest that potential COPECs in the groundwater at the Site are specific to a more defined area. In the Marsh Upland Area, mercury is the main potential groundwater COPEC and is also the only contaminant to exceed the chronic value for both the mean and maximum values whereas the groundwater at the Proposed Greenway Area does not appear to contain any potential COPECs. Iron may be a potential COPEC at the Southern Conservation Area as well as at the Upper North, Lower North, and Southern Disposal Areas. Aluminum and barium may be potential COPECs at the Southern Conservation Area. The Upper North, Lower North, and Southern Disposal Areas each have three to five potential COPECs, with acute exceedances of trichlorethene in groundwater of the Lower North Area and lead in the Southern Disposal Area.

4.2.3 Surface Water Comparison to AWQC

Several contaminants detected in surface water exceeded the chronic AWQC in the riverine and pond stations sampled (Tables B-4-12 and B-4-13). The average concentration of carbon disulfide exceeded the chronic AWQC in the Eastern Channel Corridor and Lily Pond/Upper Factory Pond. Average concentrations of aluminum, barium, and manganese exceeded the chronic value at all stations sampled, including the reference areas for both the riverine and pond habitats. Average concentrations of iron exceeded the chronic value in all riverine and pond stations. Average concentrations of silver exceeded the chronic value in the riverine stations at the Northern Drinkwater River reference station and the Lower Drinkwater River Corridor and in Lily Pond/Upper Factory Pond. Maximum concentrations of silver exceeded the chronic value in the reference stations in Forge Pond, the Eastern Channel Corridor, and Lower Factory Pond.

Concentrations of aluminum, barium, iron, manganese, and silver in the on-Site pond and riverine habitats were comparable to reference Site concentrations. This observation indicates that the concentrations of these contaminants in on-Site surface waters are reflective of local conditions and therefore not related to historical activities at the Site. Carbon disulfide concentrations exceeded concentrations from the reference station where levels were undetected for both the riverine and pond habitats. This observation indicates that the observed concentrations of carbon disulfide in the surface water of the riverine and pond habitats may be reflective of local conditions related to the Site.

4.2.4 Surface Water Sample and Zooplankton/Phytoplankton Benchmark Comparison

A number of contaminants exceeded the zooplankton and phytoplankton lowest chronic values (LCVs) from Suter and Tsao (1996) in the riverine and pond habitats (Tables B-4-14 and B-4-15). The average concentration of copper and iron exceeded the LCV for zooplankton and the LCV for phytoplankton in all riverine and pond sites sampled. However all on-Site contaminant concentrations in the riverine and pond habitats were comparable to or below concentrations in their corresponding reference stations. The comparable concentrations indicate that the elevated concentrations of calcium, copper, and iron in the surface water in the Site are reflective of local conditions.

4.3 Fish Assessment (Assessment Endpoint #3)

Assessment endpoint #3 was the protection and sustainability of a forage and predatory fish community structure in Lily Pond, Factory Pond and Drinkwater River comparable to similar warm water environments.

4.3.1 Surface Water Reference Station and Benchmark Comparison for Warm Water Fishery Protection

Surface water samples were taken throughout the riverine and pond habitats on-Site and in reference sites (Plate 1 in the CSA). The maximum and average values for samples taken from each riverine and pond site from Phase II C and Phase II D data collection efforts can be found in Tables B-4-12, B-4-13, B-4-16, and B-4-17 along with corresponding screening level benchmarks for the water quality benchmark for protection of warm water fisheries. The selected ecological benchmark values for screening surface water data for the protection of warm water fisheries was the lowest chronic value for fish survival, growth and reproduction in the review conducted by Suter and Tsao (1996).

A number of contaminants exceeded the LCV for fish from Suter and Tsao (1996) in the riverine and pond sites sampled (Tables B-4-16 and B-4-17). The maximum concentration of iron exceeded the LCV for fish survival and growth in all of the riverine and pond sites sampled. The average concentration of copper in surface water exceeded the LCV for fish in the Lower Drinkwater River Corridor. The average concentration of silver surface water exceeded the LCV for fish in the Northern Drinkwater River reference station, the Eastern Channel Corridor, the Lower Drinkwater River Corridor, and all of the pond areas.

All on-Site contaminant surface water concentrations in the riverine and pond habitats were comparable to within an order of magnitude to the concentrations in their respective reference stations. This indicates that the elevated levels of copper, silver and iron in the surface water in the Site are reflective of local conditions. Therefore, ambient levels of metals and VOCs in surface water do not indicate an excessive exposure to fish from historical Site activities.

4.3.2 Fish Community Structure and Function

Sampling of the fish community at the Site was conducted by electrofishing in the Drinkwater River (Reach 1), Forge Pond (Reach 1A), the Eastern Channel Corridor (Reach 2), the Lower Drinkwater River Corridor (Reach 3A), Lily Pond/Upper Factory Pond (Reach 4), and Middle/Lower Factory Pond (Reach 5). Each survey reach was subdivided into three subreaches. Samples were collected from each subreach by habitat. The electroshocker was implemented for the same duration at the same current and amplitude in each subreach during the surveys. After each shocking period, collected fish were held in plastic buckets prior to being processed. Fish were identified to species, measured for total length (cm), weighed (grams) and visually examined for external condition. The weight of each fish was measured using an Ohaus electronic scale (Ohaus Corp., Florham Park, NJ Model CT600-S). Visual examinations for external condition included fin condition, missing or raised scales, fungal infections, parasites, gill coloration and condition, and eyeshape which could signal stress induced by Site contaminants. The fish were released unharmed after the data had been collected.

A total of 182 fish of 11 taxa were collected from all of the sampled reaches. No fish were collected from the Upper Drinkwater River Corridor (Reach 3) due to lack of water. The Drinkwater River reference area was combined into a single reach during the survey due to the abbreviated length of this water body above the Site. The number of individuals collected from all reaches sampled ranged from 10 in the Eastern Channel Corridor (Reach 2) to 54 in Forge Pond (Reach 1A- Reference) and Middle/Lower Factory Pond (Reach 5) (Figure B-4-7). The number of taxa observed in the sampled reaches ranged from four in the Drinkwater River (Reach 1 – Reference) to nine in Lily Pond/Upper Factory Pond (Reach 4) (Figure B-4-8). Largemouth bass, bluegill sunfish, and pumpkinseed, were common to all reaches sampled (Tables B-4-18 through B-4-23).

A total of 40 fish of 5 taxa were collected from the river reaches. The greatest number of individuals and taxa were observed in the Lower Drinkwater River Corridor, Reach 3A (Figures B-4-9 and B-4-10). The number of individuals collected and taxa observed were similar across the Northern Drinkwater River, Eastern Channel Corridor, and Lower Drinkwater River Corridor reaches from which fish were collected. Fish species collected included largemouth bass, bluegill sunfish, pumpkinseed, American eel, and yellow perch. Largemouth bass and American eel were the co-dominant species collected in the reference river reach (Figure B-4-11), while pumpkinseed was the dominant taxa in the Eastern Channel Corridor (Reach 2) (Figure B-4-12), and largemouth bass and pumpkinseed were the dominant taxa in the Lower Drinkwater River Corridor (Reach 3A) (Figure B-4-13). The guild structure in the Northern Drinkwater River reference reach and in the Lower Drinkwater River Corridor were similar, consisting of a 3:2 ratio of piscivores to generalists (Figures B-4-14 and B-4-15). The guild structure in the Eastern Channel Corridor consisted of a 7:3 ratio of generalists to piscivores (Figure B-4-16). The apparent difference in predator-to-prey ratios between habitats may be divergent in part due to differences in the habitat structure of riverine habitats sampled. The Northern Drinkwater River and Lower Drinkwater River Corridor habitats consisted of slower velocity, deeper habitats with submerged snags and limited aquatic vegetation. The Eastern Channel Corridor habitat displayed wider variability in depth, velocity and density of aquatic vegetation.

A total of 142 fish of 11 taxa were collected from the pond reaches. The same number of individuals, 54, were collected in Forge Pond (FP-Reach 1A) and in the Middle/Lower Factory Pond (Figure B-4-17). The number of taxa collected were similar across all three pond reaches (Figure B-4-18). Fish collected from the ponds included largemouth bass, bluegill sunfish, pumpkinseed, American eel, yellow perch, chain pickerel, brown bullhead, golden shiner, black crappie, and two unidentified juvenile species (believed to be sunfish). Bluegill were the dominant taxa collected in the reference pond reach (Figure B-4-19) and in the Middle/Lower Factory Pond reach (Figure B-4-20). Yellow perch were the dominant taxa in the Lily Pond/Upper Factory Pond (Reach 4) (Figure B-4-21). The guild structure in the reference pond reach and in the Middle/Lower Factory Pond were similar, consisting of approximately a 1:1 split of piscivores to generalists (Figures B-4-22 and B-4-23). The guild structure in the Upper Factory Pond consisted of a 3:1 ratio of piscivores to generalists (Figure B-4-24).

River reaches appeared to provide a more limited habitat than pond reaches for fish. The similarities in the number of fish caught, taxa observed, community structure and trophic guild structure between the reference reaches (river and pond) and the downstream reaches indicate the presence of similar, warm-water fish communities upstream and downstream of the Site. No Site-related impacts on community structure or function were discernible from this data. Alternate methods of fish collection, such as gill netting and rod and reel, resulted in the catch of similar taxa to electroshocking methods and similar community and guild structure.

4.3.2.1 Indices of Condition

Indices of condition were calculated for each of the fish species caught by electroshocking in the river and pond reaches. These data were used to assess the relative condition of the fish collected in the river and pond reference locations and the downstream river and pond locations. This data is summarized in Tables B-4-24 and B-4-25.

The Fulton index of condition (K) was calculated as the quotient of fish length to weight for each individual collected by species. Comparisons between the reference populations and the on-Site conditions indices were based upon mean comparisons. K was calculated as:

$$K = \frac{W}{(L)^3} \qquad \text{(Equation 22)}$$

where:

K = Fulton index of condition (grams/cm^3)
L^3 = Total length (TL) of the fish cubed (cm^3)
W = Weight of the fish (grams)

The indices of condition declined in the Eastern Channel Corridor populations (Reach 2) compared to the reference river populations for two species, the bluegill sunfish and American eel (Figures B-4-25 through B-4-28). In both of these instances, only one individual was collected in the Reach 2 sample location. The indices of condition for largemouth bass and pumpkinseed were greater for those fish collected from Reach 2 than the reference river location. Indices of condition for all species except the American eel were greater at the Lower Drinkwater River Corridor sample location (Reach 3A), downstream of Reach 2, than at the reference river location. Indices of condition for fish collected from Reach 3A were greater for all species than for those collected from Reach 2, with the exception of the pumpkinseed, which were similar to reference populations.

The indices of condition for all species except the American eel declined in Lily Pond/Upper Factory Pond (Reach 4) relative to the reference pond location (Figures B-4-29 through B-4-33). Only one American eel was collected at the Reach 4 sample location making inferential usefulness very limited for this species. The indices of condition for fish collected from Middle/Lower Factory Pond (Reach 5) were greater for largemouth bass and chain pickerel, but lower for all other observed species. Indices of condition for fish collected from Reach 5 were greater for all species than for those collected from Reach 4, with the exception of the American eel. However, only one individual of the American eel was collected at both of those sample locations.

4.3.3 External Examination of Endemic Fish for Evidence of Stressor Related Effects

Data collected during the fish community structure analysis included visual examinations for fin condition, missing or raised scales, fungus, parasites, gill coloration and condition, eye shape/color, and injuries, which could signal stress induced by contaminants. Percent occurrence of each condition was calculated and compared to the reference station (Table B-4-26).

In the riverine habitat an increased occurrence of cloudy eyes occurred in the Lower Drinkwater River Corridor (17.6%) compared to the Northern Drinkwater River reference area (7.1%) and an increased occurrence of ulcers/lesions occurred in the Eastern Channel Corridor (10%) compared to the reference (0%).

In the pond habitat an increased occurrence of parasite/cysts occurred in the Lily Pond/Upper Factory Pond reach (16.7%) compared to the reference (4.8%), an increased occurrence of ulcers/lesions occurred in Lily Pond/Upper Factory Pond (2.1%) and Middle/Lower Factory Pond (1.8%) compared to the reference area (0%), and an increased occurrence of malformities oecurred in Lily/Upper Factory Pond (2.1%) compared to the reference areas (0%).

A direct relationship was identified between the occurrence of ulcers/lesions and the contamination gradient of sediments. As distance downstream increased from the Eastern Channel Corridor (10%) to Lily Pond/Upper Factory Pond (2.1%) to Middle/Lower Factory Pond (1.8%), the occurrence of ulcers/lesions in fish decreases.

4.3.4 Body Burden Analysis of Endemic Fish

Table B-4-27 presents the whole body tissue data for bluegill sunfish collected from the reference areas and aquatic habitats adjacent to the Site. Comparison of reference tissue data to tissue data collected from riverine and pond habitats from the Site revealed COPEC concentrations comparable to (within an order of magnitude of) reference habitats.

Tables B-4-28 and B-4-29 present the calculated whole body concentrations for largemouth bass collected from fillet and offal data for largemouth bass. Whole body equivalent concentration of contaminants were detected using the method of Mierzykoski et al. (1993). Whole body equivalency was calculated using the following equation:

$$\text{Whole Body Concentration} = \frac{\{(\text{Fillet Tissue Concentration} * \text{Fillet Mass}) + (\text{Offal Tissue Concentration} * \text{Offal Mass})\}}{(\text{Fillet Mass} + \text{Offal Mass})}$$

(Equation 23)

where:

Whole body concentration (mg/Kg) = The whole body equivalent concentration (mg/Kg wet wt.)
Fillet Tissue Concentration (mg/Kg) = The measured fillet tissue concentration (mg/Kg)
Offal Tissue Concentration (mg/Kg) = The measured offal tissue concentration (mg/Kg)
Offal Mass (Kg) = The mass offal sample analyzed
Fillet Mass (Kg) = The mass of fillet sample analyzed

Within a given fish community, variation in concentration of methyl mercury within different species is linked to trophic level position and percent diet composition of other finfish (Wiener et al., 2002; Mierzykowski et al., 1993). Nearly all (>95%) of the mercury in finfish is in the form of methyl mercury. Fish assimilate inorganic mercury much less efficiently than methyl mercury from both food and water, and if absorbed, inorganic mercury is eliminated much more rapidly than is methyl mercury. Concentrations of methyl mercury in muscle tissue or whole fish typically increase with increasing age or body size, a pattern that has been observed repeatedly in surveys of mercury in fishes. The dietary uptake of methyl mercury in fish is influenced by their size, age, diet and trophic level position. In piscivorous species such as largemouth bass, the methyl mercury content of the diet and associated rate of mercury accumulation can increase with age, accelerating abruptly when the fish become large enough to switch from a diet of invertebrates to forage fish (Wiener et al., 2002). Toxic effects associated with mercury levels in tissues include effects on survival, reproduction and neurotoxicity (Beyer et al., 1996).

Currently there are no regulatory tissue based benchmarks or standards for acceptable body burden concentrations for the protection of fish species. A 1.0 mg/Kg wet wt. total mercury concentration guideline has been set for human consumption (USFDA, 2004). The primary and secondary literature was reviewed for identifying NOAEL- and LOAEL-based body burden concentrations for methyl mercury and total mercury in fish tissues. Fish species that occupy the higher trophic levels of the aquatic food chain and are primarily piscivorous in diet accumulate the highest body burden in freshwater environments (Mierzykowski et al., 1993). Therefore species such as largemouth bass will carry a greater whole body and fillet tissue concentration than smaller forage species like the bluegill (Weiner et al., 2002). Review of the available literature revealed that body burden-associated effects were noted for tissue concentrations based upon whole body, axial muscle and individual organ body burden levels. The largest data set for a tissue type that relates body burden levels to discrete effects was associated with axial muscle tissues and whole body tissue analyses (Beyer et al., 1996). Body burden studies have included a number of species including species of salmonids (trout and salmon), centrarchids (sunfish and temperate basses), and cyprinds (minnows). Endpoints studied included both acute and chronic effects on survival, growth, reproduction and neural toxicity (Beyer et al., 1996). In fish tissues, almost all mercury

(>95%) is in the form of methyl mercury and the most studied effects on the above endpoints have focused on methyl mercury (Weiner et al., 2002).

Effects on survival in relation to body burden concentrations are highly variable and range widely between species. Whole body burden concentrations in the range of 3.0 to 3.4 mg/Kg methyl mercury were shown by McKim et al. (1976) and Beyer et al. (1996) as equivalent to a no observed effects level for survival in brook trout (*Salvelinus fontinalis*). Brook trout with a body burden level less than 3.0 mg/Kg methyl mercury displayed no difference in survival relative to an unexposed reference population. A survival-based LOAEL for brook trout in the study revealed a reduction in survival of brook trout relative to a reference population in the whole body concentration range of 5.0 to 6.0 mg/Kg-methyl mercury (McKim et al., 1976). Friedmann et al. (2002) found that a whole body burden concentration of 5.4 mg/Kg total mercury had no effect on survival of largemouth bass. Snarski and Olson (1982) observed a 50% reduction in survival of fathead minnows following water-based exposure to 0.31 to 4.5 ug/L mercury. Whole body mercury concentrations measured in fish that had expired in the study was 4.2 mg/Kg. No effects on survival in the fathead minnow population was noted at whole body total mercury concentrations of 0.62 mg/Kg (Snarski and Olson, 1982).

In a field study on largemouth bass, Friedmann et al. (2002) found that body burden concentrations of 5.4 mg/Kg total mercury had no effect on survival of largemouth bass in wild populations. This value for largemouth bass falls within the ranges of values observed for other fish species and supports the assumption that the observed range in body burdens of the literature reviewed captures the threshold protective of largemouth bass survival. For application in the risk assessment, a NOAEL body burden concentration of 3.0 mg/Kg methyl mercury is applied. The observed LC50 of a whole body concentration of 4.2 mg/Kg methyl mercury is applied as the LOAEL for freshwater fish survival.

McKim et al. (1976) noted no effect on growth in brook trout at body burden concentrations less than 3.4 mg/Kg methyl mercury. A reduction in the growth rate of the exposed trout via dietary exposures was noted in fish with an equivalent body burden of 5.0 to 7.0 mg/Kg methyl mercury. Phillips and Buhler (1978) noted no effects on the growth of fingerling rainbow trout exposed to methylmercuric chloride via dietary exposure. The body burden concentrations observed in the rainbow trout ranged from 2.28 to 5.67 mg/Kg in the study. McKim et al. (1976) identified 5.0 mg/Kg of methyl mercury as the lowest effects level for impairing growth in brook trout. In fathead minnows, Snarski and Olson (1982) noted no effects on growth at concentrations of 0.8 mg/Kg of total mercury. In the same study, decreased larval growth was noted in fathead minnows with whole body concentrations of 1.4 mg/Kg. In a field study, Freidmann et al. (2002) found no difference in the length-to-weight condition index between largemouth bass in uncontaminated lakes (0.3 to 1.23 mg/Kg total mercury wet wt. in fillet tissue) and populations from a contaminated reservoir (5.4 mg/Kg total mercury wet wt. in fillet tissue). Because McKim et al. (1976) was a long-term study (>200 days), the 3.4 mg/Kg methyl mercury datum will be applied in the risk assessment as the tissue-based NOAEL for freshwater fish. The 5.0 mg/Kg methyl mercury concentration of Phillips and Buhler (1978) will be adopted as a LOAEL for body burden levels for the growth endpoint in freshwater fish.

Reproductive effects relative to body burden levels of methyl mercury have been noted in studies on brook trout and fathead minnows (*Pimphales promelas*). McKim et al. (1976) observed that viable egg production in gravid brook trout with less than 3.0 mg/Kg methyl mercury was comparable to a non-exposed population. Brook trout with whole body concentrations of 5.0 to 7.0 mg/Kg methyl mercury were found to have a higher incidence of deformities in fingerlings and suffer greater fingerling mortality (McKim et al., 1976). Hammereschmidt et al. (2002) in a study using fathead minnows observed no effect on egg production in adult females at whole body concentrations of 1.77 mg/Kg methyl mercury. In the same study, female fathead minnows displayed a 22% and 48% reduction in viable egg production at whole body concentrations of 2.37 and 4.06 mg/Kg methyl mercury. In a study of field populations, Friedmann et al. (2002) found that adult largemouth bass reproductive health as based upon the gonadal somatic indices (GSI) were similar in individuals from uncontaminated lakes (0.3 to 1.23 mg/Kg total mercury wet wt. in fillet tissue) and populations from a contaminated reservoir (5.4 mg/Kg total mercury wet wt. in fillet tissue). For application in the risk assessment, a NOAEL equivalent body burden concentration of 1.77 mg/Kg methyl mercury NOAEL in adult fish and a LOAEL body burden concentration of 2.37 mg/Kg methyl mercury for the reproductive endpoint in adult freshwater fish were selected as TRVs for this endpoint.

Methyl mercury is a neurological toxin that is associated with neurological effects manifested as alterations in behavior or physiology. The primary site of effects in fish has been the denaturization of the myelin sheath of the nervous system (Wiener et al., 2002). Neurological disorders in fish have largely been evaluated based upon alterations in behavior of an instinctive reflex. Many fish behaviors are sensitive and ecologically relevant indicators of contaminant toxicity at concentrations far lower than those associated with mortality. Alterations in fish behaviors following exposure to methyl mercury have been observed at body burden concentrations well below those associated with other chronic endpoints. Kania and O'Hara (1974) noted that adult mosquitofish (*Gambusia affinis*) exposed to mercury via diet displayed significantly slower predator avoidance behaviors in the presence of largemouth bass at body burden concentrations of >3.1 mg/Kg. No difference in predator avoidance behaviors was noted in exposed mosquitofish with 0.4 mg/Kg methyl mercury. Niimi and Kissoon (1994) found that rainbow trout (*Oncorhynchus mykiss*) with methyl mercury body burdens ≥ 4.0 mg/Kg displayed decreased feeding rates and the exposed population became emaciated relative to a non-exposed reference population. For application in the risk assessment, a NOAEL equivalent body burden concentration of 0.4 mg/Kg methyl mercury in adult fish and a LOAEL body burden concentration of 3.1 mg/Kg methyl mercury in adult fish was used for assessing the potential for neurological effects in freshwater fish. Table B-4-30 summarizes the tissue based NOAEL and LOAEL values for freshwater fish employed in this evaluation.

4.3.4.1 Piscivorous Fish Body Burden Assessment

Observed whole body burden levels of the piscivorous guild representative species, the largemouth bass, to laboratory-based studies revealed NOAEL exceedances for potential reproductive effects and altered behavior in largemouth bass from the Eastern Channel Corridor. A LOAEL-based tissue level for reproduction was exceeded for largemouth bass from the western channel area (Table B-4-31). All remaining body burden levels remained below NOAEL-based values for methyl mercury for endpoints related to survival, growth and reproduction. NOAEL-based exceedances for altered behavior were noted for all samples including the reference area samples collected from the Drinkwater River and Forge Pond. The LOAEL exceedance was based on a laboratory study with fathead minnows that identified a whole body concentration of 2.37 mg/Kg wet wt. in adult fish associated with a reduction in hatching of viable eggs following maternal dietary exposure of methyl mercury. No tissue based LOAEL exceedances for survival of fish for total mercury or methyl mercury were observed in the bluegill or largemouth bass samples collected from the Site.

Field-based studies of largemouth bass populations with elevated mercury concentrations (as total mercury) identified a NOAEL based fillet value of 5.4 mg/Kg for survival, growth and reproduction (Table B-4-32). Fillet tissue concentrations in largemouth bass collected from the Drinkwater River and Factory Pond were less than 5.4 mg/Kg in total mercury concentrations. The reproduction endpoint considered in this study focused on the gonadal somatic index as a measure of reproductive health and did not consider endpoints associated with post-hatching success of fry. No residue based tissue studies for largemouth bass assessing the post-hatching success following maternal exposure were identified in the literature.

4.3.4.2 Forage Base Species Body Burden Assessment

Comparison of reference tissue data to tissue data from aquatic habitats of the Site revealed order of magnitude exceedances for total mercury and methyl mercury on-Site. All other metals including lead, were comparable to or less than an order of magnitude in difference from corresponding reference habitats and thus were not determined to be of concern.

Observed whole body burden levels of total mercury and methyl mercury in bluegill sunfish were compared to laboratory-based studies that revealed NOAEL exceedances for potential altered behavior in sunfish in all habitats sampled including Forge Pond (Table B-4-33). This may lead to a reduction in predator avoidance response. No LOAEL-based tissue levels for reproduction were exceeded for bluegills from any habitat sampled. All remaining body burden levels remained below NOAEL based values for methyl mercury and total mercury for endpoints related to survival, growth and reproduction.

In a laboratory study with bluegill sunfish, Cember et al. (1978) demonstrated a 100% mortality of juvenile bluegill sunfish at whole body concentrations of greater than 6.5 mg/Kg methyl mercury. No tissue-based residue studies for bluegill sunfish assessing effects on post hatching success, reproductive potential in adults or growth were identified in the scientific literature.

4.3.5 Fathead Minnow (*Pimephales promelas*) Larval Survival and Growth Tests

Seven bulk water samples were collected via direct fill techniques from aquatic habitats located on the Site. Surface water toxicity testing was performed on the aquatic habitats of Factory Pond, Forge Pond and the Drinkwater River. Two of the seven locations served as reference areas. Forge Pond samples served as the reference samples for Factory Pond and the Drinkwater River upstream from Forge Pond served as the reference sample for reaches of the river potentially impacted by the Site.

Bottleware used was 7.5 liter, collapsible polyethylene jugs with Teflon lined caps. During collection, water temperature (°C), dissolved oxygen (mg/L), specific conductivity (mS/cm), turbidity (NTU), and redox potential (mV) data were collected from each sampling location (Plate 1 in the CSA). The collected water samples were sealed and held on wet ice under chain of custody until the laboratory courier picked the samples up from the Site trailer. The samples were used in seven-day, larval growth and survival tests with the freshwater fish species, the fathead minnow, *Pimephales promelas* using USEPA Method 1000 (USEPA, 2002). Tests were run in the bioassay laboratory facilities of EnviroSystems, Incorporated, Hampton, New Hampshire. All samples were collected and transported to the laboratory within 24 hours of collection.

Results for the seven-day, *Pimephales promelas* larval survival and growth test are presented in Tables B-3-6 and B-3-7. The laboratory report from EnviroSystems, Incorporated is provided in Attachment B6. Performance of the tests were evaluated for acceptability and effectiveness using testing protocols and evaluation criteria provided in USEPA (2002). No protocol anomalies related to environmental monitoring criteria or laboratory control performance were noted during the testing program.

Results of the seven-day tests revealed no statistically significant reductions in survival among the surface water samples evaluated from the Site when compared to the habitat specific reference results. Survival of minnows exposed to Factory Pond surface waters ranged 88% to 98%. Survival of minnows exposed to riverine surface waters from the Drinkwater River ranged 95% to 100%.

No significant reductions in growth were observed in six of seven surface water samples tested. A negative effect on growth was noted for sample UDCTRA11SW in the Upper Drinkwater River. Growth of fathead minnows exposed to surface waters from Factory Pond and the Drinkwater River revealed comparable or positive growth relative to the fathead minnows exposed to surface water reference areas.

4.4 Terrestrial and Semi-Aquatic Wildlife Exposure Assessment (Assessment Endpoints #4, 5, 6, 7, 8, 9, 10, 11, and 12)

Risks to candidate wildlife species were assessed to determine if identified contaminants pose a risk to higher trophic level species using the habitats present on the Site. Endpoint receptor species selected with concurrence of MADEP technical staff included both terrestrial and semi-aquatic wildlife species. Terrestrial species included the short tailed shrew (*Blarina brevicauda*), American woodcock (*Scolopax minor*) and the red-tailed hawk (*Buteo jamaicensis*). Semi-aquatic species included the mink (*Mustela vison)*, raccoon (*Procyon lotor*), belted kingfisher (*Ceryle alcyon*), mallard (*Anas platyrhynchos*), mute swan (*Cygnus olor)* and muskrat (*Ondatra zibethicus*).

Exposure parameters for the receptors, derived from the primary literature and reviews provided in USEPA (1993) and Sample et al. (1996), were presented in the scope of work for the Phase IID Site Investigation. All exposure parameters for selected wildlife receptors were representative of female exposure parameters (i.e., body weight and wet and dry ingestion rates for dietary and abiotic media). Dietary exposure assumed a 100% diet source and a 100% assimilation efficiency of contaminants from the exposure to environmental media.

Body burdens in fish, crayfish and aquatic worms were collected by TtFW (2004) and used in the dietary exposure pathways for the semi-aquatic wildlife exposure assessments. Body burden concentrations were expressed in wet weight for use in the dietary ingestion models.

In the absence of actual body burden concentrations for prey items in the terrestrial wildlife assessment, the prey body burdens were estimated using environmental media concentrations and a chemical-specific bioaccumulation factor. For diet-based exposures, observed mean concentrations in environmental media (i.e., surface soils, surface water or sediments) were used with a chemical-specific soil-to-biota/sediment-to-biota accumulation factor (BAF) for predicting invertebrate or aquatic plant body burdens from sediments or surface soils. Sources for contaminant-specific BAFs/BCFs were drawn from Sample et al. (1998) and USEPA (2003). Where no soil or sediment bioconcentration factors (BCFs) and surface water BCFs were available, a default bioaccumulation factor of 1.0 (DTSC, 1999) was applied. For exposure to aquatic plants, a sediment to aquatic plant accumulation factor from Jackson and Kaliff (1993) and Alberts et al. (1990) was applied to predict sediment-impacted tissue concentrations in aquatic plants.

The exposure models are based upon a linear design in the accumulation and transfer of contaminants from abiotic media sources through the food chain to the endpoint receptor. The exposure assessment does not consider metabolic pathways for the degradation and elimination of contaminants by both the endpoint and intermediate receptors (i.e., prey items). Most metals, including copper, manganese, zinc, and others, can be regulated and excreted by higher vertebrates (Eisler, 1986; Eisler, 1993).

For the semi-aquatic receptors, assessment areas were divided into defined areas of river and pond habitats. Riverine habitats were divided into the following reaches:

- Northern Drinkwater River above Forge Pond (Reference Area)
- Eastern Channel Corridor that meanders around the north area
- Lower Drinkwater River Corridor

The Upper Drinkwater River Corridor was found to have concentrations consistent with the reference areas and to not be impacted by historical activities at the Site and will not be considered further.

Pond habitats were divided into the following reaches:

- Forge Pond (Reference Area)
- Lily Pond and Upper Factory Pond
- Middle/Lower Factory Pond

The Marsh Upland Area was the only wetland area to be targeted given its history as a former disposal area. This wetland was considered individually in the assessment along with a corresponding wetland reference area.

4.4.1 Belted Kingfisher Exposure Assessment

Three lines of evidence were used as measurement endpoints to be evaluated for the piscivorous bird receptor group: (1) exposure modeling using species-specific and Site-specific analytical and biological data; (2) comparison of observed forage fish body burden concentrations to Canadian Tissue Residue Guidelines (CCME, 1999); and (3) avian field surveys related to species presence and relative abundance.

The belted kingfisher is a medium size bird that primarily feeds on small fish. They are typically found along rivers, streams, and along lake and pond edges. They prefer waters free of thick vegetation and dense canopies because these obscure their view in pursuit of prey. Nests are made in burrows within the steep earthen banks devoid of vegetation always proximal to bodies of water. Belted kingfishers generally feed on fish that swim near the surface or in shallow water (USEPA, 1993). The kingfisher was modeled for the riverine and pond aquatic habitats found on-Site and in the reference areas to assess the dietary exposures of COPECs to a breeding female. The model incorporates media data as well as small prey fish body burdens collected by TtFW (2004). Table B-4-34 summarizes the toxicity reference values used as NOAELs and LOAELs applied in the belted kingfisher exposure evaluation.

4.4.1.1 Belted Kingfisher Exposure Dosage Evaluation

4.4.1.1.1 Riverine Habitats

Tables B-4-35 to B-4-37 present the exposure assessment for the riverine habitats that were evaluated on-Site. The following is a summary of the exposure evaluation for riverine habitats:

- The exposure assessment for the Northern Drinkwater River reference area identified methyl mercury as having a NOAEL HQ of 10.4 and a LOAEL HQ of 1.04 for kingfishers. The primary exposure route contributing to the exposure to methyl mercury was the prey fish ingestion route which contributed 99.9% of the methyl mercury consumed (Table B-4-35).

- The exposure assessment for the Eastern Channel Corridor identified methyl mercury as having a NOAEL HQ of 40.6 and a LOAEL HQ of 4.1. The primary exposure route contributing to the exposure to methyl mercury was the prey fish ingestion route which contributed 99.9% of the methyl mercury consumed (Table B-4-36). The exposure assessment revealed a 300% increase in exposure from the fish ingestion route in these habitats compared to the reference exposure assessment.

- The exposure assessment for the Lower Drinkwater River Corridor identified methyl mercury as having a NOAEL HQ of 55.1 and a LOAEL HQ of 5.5. The primary exposure route contributing to the exposure to methyl mercury was the prey fish ingestion pathway which contributed 99.9% of the methyl mercury consumed (Table B-4-37). The exposure assessment revealed a 500% increase in exposure via fish ingestion route in these habitats.

- All remaining COPECs had NOAEL and LOAEL HQs less than 1.0.

4.4.1.1.2 Reference Habitat

Tables B-4-38 to B-4-40 provide the results of the exposure assessments for the reference habitat, Forge Pond.

- The exposure assessment for Forge Pond identified methyl mercury as having a NOAEL HQ of 18.1 and a LOAEL HQ of 1.8 for the kingfisher. The primary exposure route contributing to the exposure to methyl mercury was the prey fish ingestion route which contributed 99.9% of the methyl mercury consumed (Table B-4-38).
- The exposure assessment for the Lily Pond and Upper Factory Pond identified methyl mercury as having a NOAEL HQ of 46.9 and a LOAEL HQ of 4.7. The primary exposure route contributing to the exposure to methyl mercury was the prey fish ingestion route which contributed 99.9% of the methyl mercury consumed (Table B-4-39). The exposure assessment revealed a 260% increase in exposure from the fish ingestion compared to the reference exposure assessment.
- The exposure assessment for Lower Factory Pond identified methyl mercury as having a NOAEL HQ of 48.2 and a LOAEL HQ of 4.8. The primary exposure route contributing to the exposure to methyl mercury was the prey fish ingestion route which contributed 99.9% of the methyl mercury consumed (Table B-4-40). The exposure assessment revealed a 193% increase in exposure via the fish ingestion compared to the reference exposure assessment.
- All remaining COPECs had NOAEL and LOAEL HQs less than 1.0.

The primary exposure route for methyl mercury was the ingestion of prey fish (i.e., bluegill sunfish) from the habitats evaluated. Exposure to methyl mercury in both the riverine and pond reference habitats affirms that ambient exposure from other sources of methyl mercury appears minimal in the contribution of methyl mercury.

4.4.1.2 Comparison of Fish and Crayfish Tissue Residues to CCME Fish Residue Guidelines

The CCME (1999) had issued a 0.033 mg/kg residue-based guidance value for methyl mercury in fish tissues for the protection of wildlife consumers of aquatic biota. This value was based upon the protection of the most sensitive wildlife species potentially exposed. Forage fish (i.e., bluegill sunfish) and crayfish from the Forge Pond and the Northern Drinkwater River and the aquatic habitats of the Drinkwater River and Factory Pond associated with the Site were compared to the CCME (1999) tissue criteria to evaluate exposure to piscivorous avian receptors.

4.4.1.2.1 Fish

In the reference habitats of the Northern Drinkwater River and Forge Pond, the concentration of methyl mercury accounted for 100% of the mercury present in bluegill sunfish. In these reference habitats, concentrations of methyl mercury were 0.146 and 0.254 mg/Kg which are within the range (0.01-0.75 mg/Kg) reported for similar omnivorous fish (i.e., yellow perch) tissues collected from lakes that are unimpacted by discharges from across Massachusetts (MADEP, 1997). The concentrations from the Northern Drinkwater River, Forge Pond and the MADEP study exceed the 0.033 mg/Kg guidance value suggesting exposure from non-Fireworks sources.

Concentrations of methyl mercury in bluegill sunfish from the Eastern Channel Corridor and Lower Drinkwater River Corridor ranged 0.568-0.771 mg/Kg. These concentrations were 3.7 to 5.3 times higher that those observed in Northern Drinkwater River reference area and exceeded the residue-based methyl mercury guidance value.

Concentrations of methyl mercury in bluegill sunfish from Lily Pond/Upper Factory Pond and Middle/Lower Factory Pond ranged 0.656-0.675 mg/Kg. These concentrations were 2.6 to 2.7 times higher that those observed in Forge Pond. The concentrations in Lily and Factory Ponds exceeded the residue-based methyl mercury guidance value.

4.4.1.2.2 Crayfish

In the reference habitats of the Northern Drinkwater River and Forge Pond, the concentration of methyl mercury accounted for 100% of the mercury present in crayfish in these habitats. Background tissue concentrations of methyl mercury in crayfish were 0.0493 and 0.093 mg/Kg, which are comparable to the mean methyl mercury concentrations observed for the Sudbury River watershed (0.067 mg/Kg) (Haines et al., 1997) in Massachusetts and Grove Pond (0.027 mg/Kg) and Plow Shop Pond (0.046 mg/Kg) (Mierzykowski and Carr, 2000) in Ayer, Massachusetts. The concentrations from the Northern Drinkwater River, Forge Pond and other studies from Massachusetts surface waters exceed the 0.033 mg/Kg guidance value.

Methyl mercury in crayfish collected from the Eastern Channel Corridor represented 73% of the total mercury on a residue basis. Total mercury present in crayfish from the Eastern Channel Corridor was 0.583 mg/Kg and methyl mercury was 0.433 mg/Kg. This concentration exceeded the 0.033 mg/Kg guidance value.

Methyl mercury in crayfish collected from Lily Pond/Upper Factory Pond represented 91% of the total mercury on a tissue residue basis. Total mercury present in crayfish from Lily Pond/Upper Factory Pond was 0.255 mg/Kg and methyl mercury was 0.233 mg/Kg. Methyl mercury in crayfish collected from Middle/Lower Factory Pond represented 100% of the total mercury on a tissue residue basis. Total mercury present in crayfish from Middle/Lower Factory Pond was 0.152 mg/Kg and methyl mercury was 0.19 mg/Kg. The observed methyl mercury concentrations in Lily Pond/Upper Factory Pond and Middle/Lower Factory Pond exceeded the 0.033 mg/Kg fish tissue guidance value.

4.4.1.3 Avian Surveys

Results of the avian surveys revealed the presence of the belted kingfisher as well as other piscivorous bird species in the habitats of the Drinkwater River and Factory Pond. Other piscivorous bird species observed included black-crowned night herons and great blue herons. Statistical comparison of avian species richness between the reference habitat transect and the transects performed in the habitats of the Site revealed no significant difference in avian diversity present in the habitats surveyed.

4.4.2 Mallard Exposure Assessment

Two lines of evidence were used as measurement endpoints to be evaluated for this assessment endpoint receptor group: (1) exposure modeling using species-specific and Site-specific analytical and biological data and comparison to NOAELs and LOAELs; and (2) avian field surveys related to species presence and relative abundance.

The mallard is a dabbling duck that represents one of the most common waterfowl species present in the eastern United States. It is a common migrant and will overwinter in Massachusetts where open water permits. Ice cover and the lack of available open water habitat are the primary reasons for migration out of Massachusetts in winter (Veit and Peterson, 1993). An opportunistic omnivore, the mallard will feed on both aquatic vegetation and aquatic invertebrates in shallow freshwater habitats. The mallard is a non-diving waterfowl species and feeding is restricted in the shallow water areas associated with the shoreline of open water aquatic and wetland habitats. A highly tolerant species to human encroachment, the mallard is commonly seen in both rural and cosmopolitan areas and is very adaptable to habitats in urban settings.

4.4.2.1 Mallard Exposure Modeling

Because of this species' gregarious behavior and close association with freshwater ponds and wetlands, risks to this receptor were evaluated on an individual pond/riverine/wetland basis. Table B-4-41 identifies the NOAELs and LOAELs applied in the mallard duck exposure evaluation. The exposure of mallard duck to metals occurred via all exposure pathways and routes evaluated. The principal prey item used in the dietary assessment of the receptor was the observed concentration in the aquatic worm *Lumbriculus varigaetus* bioaccumulation study in the sediments of habitats evaluated.

Tables B-4-42 to B-4-44 present the exposure assessment for the riverine habitats. The following is a summary of the exposure evaluation for the riverine habitats assessed:

- The exposure assessment for the Northern Drinkwater River reference area identified zinc as having a NOAEL HQ of 1.62. No LOAEL HQs greater than 1.0 were noted in this habitat. The primary exposure route contributing to the zinc exposure was benthic invertebrate prey ingestion which contributed 99% of the zinc ingested in the mallard diet (Table B-4-42).
- The exposure assessment for the Eastern Channel Corridor identified lead (NOAEL HQ = 1.19), total mercury (NOAEL HQ = 5.2), methyl mercury (NOAEL HQ = 3.2 and zinc (NOAEL HQ = 1.5) having a NOAEL HQ in excess of 1.0 in this habitat. A LOAEL HQ = 2.6 was observed for the mallard for total mercury exposure in this habitat (Table B-4-43). The primary exposure routes contributing to the exposure to the above contaminants were the aquatic worms and aquatic macrophyte ingestion route which contributed greater than 90% of the exposure to the above contaminants. The exposure assessment revealed a mean increase in dietary exposure of 56% increase in lead, a 295% increase in total mercury, 700% increase in methyl mercury and a 7% decrease in zinc exposure from the aquatic worm and aquatic macrophyte ingestion route in this habitat compared to the Northern Drinkwater River reference area. Zinc exposure remained comparable to exposure observed in the Northern Drinkwater River reference area and was not deemed significant in this habitat.
- The exposure assessment for the Lower Drinkwater River Corridor identified total mercury (NOAEL HQ = 2.5), methyl mercury (NOAEL HQ = 2.3) and zinc (NOAEL HQ = 1.2) as having NOAEL HQs in excess of 1.0 in this habitat. A LOAEL HQ = 1.2 was observed for total mercury exposure in mallards in this habitat (Table B-4-44). The primary exposure route contributing to exposure to the above contaminants was via dietary ingestion of aquatic worms. This dietary source of exposure accounted for 64% of the total mercury and 94% of methyl mercury ingested by this receptor. Zinc exposure remained comparable to exposure observed in the reference area and was not deemed significant in this habitat.
- All remaining COPECs had NOAEL and LOAEL HQs less than 1.0.

Tables B-4-45 to B-4-47 present the exposure assessment for the pond habitats on-Site. The following is a summary of the exposure evaluation for the pond habitats:

- The exposure assessment for the reference area identified lead and zinc as having NOAEL HQs of 1.6 and 1.9, respectively. No LOAEL HQs greater than 1.0 were noted in this habitat. The primary exposure route contributing to lead and zinc exposure was via ingestion of aquatic worms and aquatic macrophytes which contributed 77% of the lead and 96% of the zinc ingested in the mallard diet (Table B-4-45).
- The exposure assessment for Lily Pond/Upper Factory Pond identified lead and zinc as having NOAEL HQs of 1.8 and 1.5. No LOAEL HQs greater than 1.0 were noted in this habitat. The primary exposure route contributing to lead and zinc exposure was via ingestion of aquatic worms and aquatic macrophytes which contributed 77% of the lead and 96% of the zinc ingested in the mallard diet (Table B-4-46). Lead and zinc exposure remained comparable to exposure observed in the Forge Pond reference area and was not deemed significant in this habitat.
- The exposure assessment for Middle/Lower Factory Pond identified zinc as having a NOAEL HQ of 1.6. No LOAEL HQs greater than 1.0 were noted in this habitat. The primary exposure route contributing to zinc exposure was via ingestion of aquatic worms and aquatic macrophytes which contributed 96% of the zinc ingested in the mallard diet (Table B-4-47). Zinc exposure remained comparable to the exposure observed in Forge Pond and was not deemed significant in this habitat.
- All remaining COPECs, including mercury and methyl mercury, had NOAEL and LOAEL HQs less than 1.0.

Tables B-4-48 and B-4-49 present the exposure assessment for the wetland background area and the Marsh Upland Area. The following is a summary of the mallard exposure evaluation for the background and Marsh Upland Area habitats:

- The exposure assessment for the background wetland area identified lead and zinc as having NOAEL HQs of 2.7 and 1.2. No LOAEL HQs greater than 1.0 were noted in this habitat. The primary exposure route contributing lead and zinc exposure was benthic invertebrate prey ingestion which contributed 80% of the lead and 98% of the zinc ingested in the mallard diet in this habitat (Table B-4-48).
- The exposure assessment for the Marsh Upland Area identified lead (NOAEL HQ = 12.1), total mercury (NOAEL HQ = 1.3), methyl mercury (NOAEL HQ = 48.6) and zinc (NOAEL HQ = 1.1) with NOAEL HQs in excess of 1.0 in this habitat (Table B-4-49). A LOAEL HQ = 1.2 for lead and a LOAEL HQ = 4.9 for methyl mercury were observed in the mallard exposure evaluation in the Marsh Upland Area. The primary exposure route contributing to the exposure to the above contaminants was the aquatic macrophyte ingestion route and the incidental sediment ingestion route, which combined contributed 96% of the exposure to lead and 99.7% of the methyl mercury ingested by the mallard. The exposure assessment revealed a mean increase in dietary exposure of 340% increase in lead, a 1,400% increase in total mercury and a 2,600% increase in methyl mercury exposure for the mallard in the Marsh Upland Area relative to the reference wetland. Zinc exposure remained comparable to exposure observed in the reference wetland area and was not deemed significant in this Marsh Upland Area.
- All remaining COPECs had NOAEL and LOAEL HQs less than 1.0.

4.4.2.2 Avian Surveys

Results of the avian surveys revealed the presence of the mallard duck in both the reference areas of the Drinkwater River and Forge Pond as well as riverine channels of the Drinkwater River and Factory Pond habitats. Comparison of avian diversity revealed no statistical difference in avian abundance between the reference habitats and the survey transects performed in the habitats of the Site.

4.4.3 American Woodcock Exposure Assessment

Two lines of evidence were used as measurement endpoints for the insectivorous bird assessment endpoint in this evaluation: (1) exposure modeling using species specific and Site-specific analytical and biological data; and (2) avian field surveys related to species presence and relative abundance.

The American woodcock is an insectivorous avian species with a specially adapted beak for probing for earthworms in soft, saturated soils. The woodcock has a small home range that encompasses a wide variety of terrestrial habitats. A breeding woodcock requires access to fresh water, protected nesting sites, and protected foraging areas. The woodcock is a ground nesting species and relies upon camouflage to evade predators during nesting periods. Woodcock forage on the ground in open areas and along habitat edges where soils are saturated and can be probed for earthworms (USEPA, 1993). They are crepuscular in habit and often feed during twilight hours and evening hours. Their diet consists of nearly 100% earthworms and other soft-bodied invertebrates. The woodcock was used to model the dietary exposure of this avian insectivore to COPEC concentrations in the on-Site terrestrial habitats. Tables B-4-50 and B-4-51 provide the bioaccumulation factors and the NOAELs and LOAELs used in this assessment for the American woodcock.

4.4.3.1 American Woodcock Exposure Dosage Evaluation

Tables B-4-52 and B-4-60 present the exposure assessment for the six terrestrial areas of concern and the Cold Waste Area evaluated for the Site. The following is a summary of the woodcock exposure evaluation for the background areas and on-Site habitats.

4.4.3.1.1 Terrestrial Reference Habitats

- The exposure assessment for the terrestrial reference habitats identified aluminum, chromium, lead and zinc as resulting in NOAEL HQs that exceed 1.0 in this habitat. (Table B-4-52). The lead LOAEL HQ also exceeded 1.0 in this habitat as well. The primary exposure route for all COPECs for the American woodcock was incidental soil ingestion.
- All remaining COPECs had NOAEL and LOAEL HQs less than 1.0.

4.4.3.1.2 Central Commercial Area

- The exposure assessment for the Central Commercial Area identified aluminum (NOAEL HQ = 26.6), chromium (NOAEL HQ = 5.0), and zinc (NOAEL HQ = 1.2) as producing NOAEL HQs in excess of 1.0 in this habitat (Table B-4-53). Exposure to lead generated HQs in excess of 1.0 for both the NOAEL and LOAEL HQs (18.6 and 1.9, respectively). The incidental soil ingestion route was the primary exposure route for the above COPECs in this habitat. However, all NOAEL and LOAEL HQs that exceed 1.0 in this habitat were equal to or comparable to exposures identified in the terrestrial reference area (FP NOAEL HQ = 24.7 for aluminum, NOAEL HQ = 2.6 for chromium, NOAEL HQ = 16.2 for lead, LOAEL HQ

1.6 for lead, and NOAEL HQ = 1.2 for zinc). Thus, all levels in the Central Commercial Area do not reflect contributions from historical Site activities.

- All remaining COPECs had NOAEL and LOAEL HQs <1.

4.4.3.1.3 Flood Plain Area

- The exposure assessment for the Flood Plain Area identified aluminum, barium, chromium, lead, total mercury, methyl mercury, and selenium as having NOAEL HQs in excess of 1.0 in this habitat (Table B-4-54). Lead and selenium also generated LOAEL HQs greater than 1.0 in this habitat (LOAEL HQs = 4.8 and 1.5, respectively).
- Although the NOAEL HQ for aluminum and chromium exceed 1.0 in this habitat (29.3 and 2.6, respectively), they were comparable to the corresponding NOAEL HQs in the terrestrial reference habitat (FP NOAEL HQ = 24.7 for aluminum; NOAEL HQ = 2.6 for chromium).
- The NOAEL and LOAEL HQs in this habitat for lead were 3 times higher than those for lead in the reference area. Incidental soil ingestion was the primary exposure route for exposure, and contributed 97% of lead exposure to the American woodcock. The exposure assessment revealed a mean increase in dietary exposure of 194% for lead from the incidental soil ingestion route in this habitat relative to reference habitats.
- Barium, total mercury, methyl mercury, and selenium HQs did not exceed 1.0 in the terrestrial reference habitats. However, in the Flood Plain Area they displayed NOAEL HQs that exceeded 1.0 (NOAEL HQ = 1.3, 1.0, 4.1, 2.9, respectively), and selenium also showed a LOAEL HQ that exceeded 1.0 (LOAEL HQ = 1.5) in this habitat.
- All remaining COPECs had NOAEL and LOAEL HQs less than 1.0.

4.4.3.1.4 Marsh Upland Area

- The exposure assessment for the Marsh Upland Area identified aluminum, chromium, lead and total mercury as producing NOAEL HQs exceeding 1.0 (NOAEL HQ = 12.5, 2.0, 55.9, and 154.8, respectively) (Table B-4-55). Lead and total mercury also showed LOAEL HQs greater than 1.0 (LOAEL HQ = 5.6 and 77.4, respectively).
- The NOAEL HQs for aluminum and chromium in this habitat were less than the NOAEL HQs for the same COPECs calculated in the reference habitat. Therefore, aluminum and chromium will no longer be considered COPECs in this habitat.
- In this habitat, incidental soil ingestion was the primary exposure route for the American woodcock, and contributed 97% of the exposure to lead. The exposure assessment revealed a mean increase in dietary exposure of 246% for lead from the incidental soil ingestion route in this habitat relative to the reference habitat. The NOAEL and LOAEL HQs in this habitat for lead exposure were approximately 3.5 times higher than those for lead in the reference habitat.
- Total mercury NOAEL and LOAEL HQs did not exceed 1.0 in the terrestrial reference habitat. However, in the Marsh Upland Area, the exposure assessment identified NOAEL and LOAEL HQs that exceeded 1.0 (NOAEL HQ = 154.8; LOAEL HQ = 77.4).
- All remaining COPECs had NOAEL and LOAEL HQs less than 1.0.

4.4.3.1.5 Proposed Greenway Area

- The exposure assessment for the Proposed Greenway Area identified aluminum, chromium, lead, total mercury, and zinc as having NOAEL HQs exceeding 1.0 (NOAEL HQ = 15.5, 2.7, 17.4, 2.3, and 1.0, respectively). Lead and total mercury also had LOAEL HQs greater than 1.0 (LOAEL HQ = 1.7 and 1.2, respectively) (Table B-4-56).
- The NOAEL HQs for aluminum and zinc in this habitat were less than the NOAEL HQs observed in the terrestrial reference site. The NOAEL HQ for chromium, and the NOAEL HQ and LOAEL HQ for lead in this habitat were comparable to the corresponding HQs in the reference habitat. Therefore these metals will not be considered COPECs.
- Total mercury NOAEL and LOAEL HQs did not exceed 1.0 in the reference habitat. However, in the Proposed Greenway Area habitat the exposure assessment identified NOAEL and LOAEL HQs that exceeded one (NOAEL HQ = 2.3; LOAEL HQ = 1.2) for total mercury. The primary exposure route for total mercury for the American woodcock in this habitat was the incidental soil ingestion route.
- All remaining COPECs had NOAEL and LOAEL HQs less than 1.0.

4.4.3.1.6 Southern Conservation Commission Area

- The exposure assessment for the Southern Conservation Commission Area identified aluminum, barium, cadmium, chromium, lead, total mercury, zinc, and di-n-octylphthalate as having NOAEL HQs in excess of 1.0 in this habitat. Barium, lead, total mercury, and di-n-octylphthalate also showed LOAEL HQs above 1.0 in this habitat (Table B-4-57).
- Although the NOAEL HQ for aluminum exceeds 1.0 in this habitat (NOAEL HQ = 29.2), the corresponding exposure and NOAEL HQ in the terrestrial reference habitat (NOAEL HQ = 24.7) was comparable.
- The NOAEL HQs for chromium and zinc and the NOAEL HQ and LOAEL HQ for lead exceeded 1.0 in this habitat and in the terrestrial reference site. However, the NOAEL HQs for chromium and zinc (NOAEL HQ = 4.3 and 6.6, respectively) and the NOAEL HQ and LOAEL HQ for lead (NOAEL HQ = 45.5; LOAEL HQ = 4.5) in this habitat were 1.7 times higher for chromium, 3.3 times higher for lead, and 5.5 times higher for zinc than the corresponding HQs observed in the terrestrial reference habitat (NOAEL HQ = 2.6 for chromium; NOAEL HQ = 1.2 for zinc; NOAEL HQ = 16.2 for lead; LOAEL HQ = 1.6 for lead) above the reference area exposure. The primary exposure route for these chemicals in this habitat was incidental soil ingestion. The exposure assessment revealed a mean increase in dietary exposure of 67% for chromium, 181% for lead, and 455% for zinc from the incidental soil ingestion route in this habitat relative to the reference habitat.
- Barium, cadmium, total mercury, and di-n-octylphthalate NOAEL HQs and barium, total mercury, and di-n-octylphthalate LOAEL HQs did not exceed 1.0 in the reference habitat. However, in the Southern Conservation Commission Area, the exposure assessment identified NOAEL and/or LOAEL HQs in excess of 1.0 for the above COPECs (NOAEL HQs = 4.2, 1.6, 2.6, and 41.9, respectively; LOAEL HQs = 2.1, 1.3, and 4.2, respectively). Incidental soil ingestion contributes 99%, 68%, and 52% of the exposure to American woodcock for barium, total mercury and di-n-octylphthalate, respectively. Terrestrial invertebrate ingestion was the primary exposure route for cadmium in the American woodcock, contributing 62% of total exposure.
- All remaining COPECs had NOAEL and LOAEL HQs less than 1.0.

4.4.3.1.7 Southern Disposal Area

- The exposure assessment for the Southern Disposal Area identified aluminum, arsenic, barium, cadmium, chromium, copper, lead, nickel, selenium, and zinc as having NOAEL HQs in excess of 1.0 in this area. Barium, chromium, copper, lead, selenium, and zinc showed LOAEL HQs greater than 1.0 (Table B-4-58).
- Although the NOAEL HQ for aluminum exceeded 1.0 in this habitat (NOAEL HQ = 21.7), it is less than the corresponding NOAEL HQ in the terrestrial reference habitat (FP NOAEL HQ = 24.7). Therefore, aluminum will not be considered further in this assessment.
- The NOAEL HQs for chromium and zinc and the NOAEL and LOAEL HQs for lead exceeded 1.0 in this area and in the terrestrial reference habitat. However, the NOAEL HQs for chromium and zinc (NOAEL HQ = 44.9 and 127.5, respectively) and the NOAEL HQ and LOAEL HQ for lead (NOAEL HQ = 237.1; LOAEL HQ = 23.7) in this habitat are 17 times higher for chromium, 15 times higher for lead, and 106 times higher for zinc than the corresponding HQs observed in the terrestrial reference site (NOAEL HQ = 2.6 for chromium; NOAEL HQ = 1.2 for zinc; NOAEL HQ = 16.2 for lead; LOAEL HQ = 1.6 for lead). The primary exposure route for these COPECs in this area was incidental soil ingestion. The exposure assessment revealed a mean increase in dietary exposure of 165% for chromium, 1,366% for lead, and 10,650% for zinc from the incidental soil ingestion relative to the reference location.
- Arsenic, barium, cadmium, copper, nickel and selenium NOAEL HQs and barium, chromium, copper, selenium, and zinc LOAEL HQs did not exceed 1.0 in the terrestrial reference habitat. However, in the Southern Disposal Area the exposure assessment identified NOAEL and/or LOAEL HQs exceeding 1.0 for these COPECs (NOAEL HQs = 1.8, 25.3, 7.5, 5.5, 1.0, 8.6, respectively; LOAEL HQs = 12.6, 9.0, 4.2, 4.3, 14.1, respectively). Incidental soil ingestion contributes between 70% and greater than 99% of the exposure to these COPECs for the American woodcock in this habitat. Terrestrial invertebrate ingestion was the primary exposure route for cadmium exposure, contributing 62% to total exposure.
- All remaining COPECs had NOAEL and LOAEL HQs less than 1.0.

4.4.3.1.8 Cold Waste Area

Table B-4-59 presents the TRVs used in the American woodcock Cold Waste Area assessment.

- The exposure assessment for the Cold Waste Area identified cyanide, aluminum, cadmium, vanadium, and di-n-butylphthalate as having NOAEL HQs in excess of 1.0 in this area. Arsenic, barium, chromium, cobalt, copper, lead, mercury, selenium, and zinc showed NOAEL and LOAEL HQs greater than 1.0 in this habitat (Table B-4-60).
- The NOAEL HQs for aluminum, chromium, and zinc exceeded 1.0 in this area and in the terrestrial reference habitat. The NOAEL HQ for aluminum (NOAEL HQ = 29.5) was equivalent to the corresponding HQs observed in the terrestrial reference site (NOAEL HQ = 24.7). The NOAEL and LOAEL HQs for chromium and zinc (NOAEL = 40.8 and LOAEL = 8.2 for chromium; NOAEL = 8.2 and LOAEL = 30.6 for zinc) were 15 and 230 times higher than the corresponding HQs observed in the terrestrial reference site (NOAEL HQs = 2.6, 1.2, respectively). The primary exposure route for aluminum and vanadium in this area was incidental soil ingestion representing 99% of exposure to these COPECs. The primary

exposure route for cadmium in this area was terrestrial invertebrate ingestion representing 62% of exposure to cadmium. The exposure assessment revealed a mean increase in dietary exposure of 119% for aluminum and 99% for chromium for the incidental soil ingestion route in this habitat relative to the background location. The exposure assessment revealed a mean increase in dietary exposure of 8,056% for chromium for the terrestrial invertebrate ingestion route in this habitat relative to the background location.

- The NOAEL and LOAEL HQs for lead exceeded 1.0 in this area and in the terrestrial reference habitat. However, the NOAEL and LOAEL HQs for lead (NOAEL HQ = 980.6; LOAEL HQ = 98.1) in this habitat are 60 times higher than the corresponding HQs observed in the terrestrial reference site (NOAEL HQ = 16.2 for lead; LOAEL HQ = 1.6). The primary exposure route for lead in this area was incidental soil ingestion representing 97% of exposure to the American woodcock. The exposure assessment revealed a mean increase in dietary exposure of 6,051% for the incidental soil ingestion route in this habitat relative to the background location.
- Cyanide, cadmium, vanadium, and di-n-butylphthalate NOAEL HQs did not exceed 1.0 in the terrestrial reference habitat. However, in the Cold Waste Area the exposure assessment identified NOAEL HQs exceeding 1.0 for these COPECs (NOAEL HQs = 40, 4.2, 1.0, and 6.0, respectively). Arsenic, barium, cobalt, copper, mercury, and selenium NOAEL HQs did not exceed 1.0 in the terrestrial reference habitat. However, in the Cold Waste Area the exposure assessment identified NOAEL and LOAEL HQs exceeding 1.0 for these COPECs (NOAEL HQs = 5.6, 503.3, 3.9, 5.5, 2.3, and 6.3 respectively; LOAEL HQs = 1.9, 251.0, 2.0, 4.2, 1.1, and 3.2 respectively). Incidental soil ingestion contributes between 68% and greater than 99% of the exposure to arsenic, barium, cobalt, copper, mercury, selenium and vanadium for the American woodcock in this habitat. The exposure assessment revealed a mean increase in dietary exposure of 1,106%, 80,835%, 2,005%, 9,737%, 1,295%, 749%, and 163% for the incidental soil ingestion route in this habitat relative to the background location. Terrestrial invertebrate ingestion was the primary exposure route for cadmium and di-n-butylphthalate exposure, contributing 62% and 57% of total exposure. The exposure assessment revealed a mean increase in dietary exposure of 6,200% and 2,053% for the terrestrial invertebrate ingestion route in this habitat relative to the background location.
- All remaining COPECs had NOAEL and LOAEL HQs less than 1.0.

4.4.3.2 Avian Surveys

Results of the avian surveys revealed the presence of the American woodcock in the terrestrial habitats present on the Site. Comparison of avian diversity revealed no statistical difference in avian abundance between the reference habitats and the habitats of the Site.

4.4.4 Red-Tailed Hawk Exposure Assessment

Two lines of evidence were used as measurement endpoints for the carnivorous bird assessment endpoint in this evaluation: (1) exposure modeling using species specific and site-specific analytical and biological data; and (2) avian field surveys related to this species' presence and relative abundance.

The red-tailed hawk is a large carnivorous raptor common to mixed landscaped habitats of the northeastern U.S. and is a resident and migrant raptor species of Massachusetts. Migrants are commonly seen in the months of March and October during spring and fall migration periods. They are very tolerant of roadway traffic and are common sights along the forested medians of highways. An opportunistic carnivore, the red-tailed hawk feeds on small vertebrates (i.e., small mammals, birds and reptiles) and will feed on carrion during periods of prey scarcity.

The red-tailed hawk has a large home range of 1,722 acres (697 Ha) with a preference for mixed landscape habitats containing old fields, wetlands, and pastures for foraging, perching and nesting. They are full time residents in the habitats of Massachusetts and are most abundant in winter (Veit and Peterson, 1993). Few accounts of breeding have been recorded in Massachusetts habitats (Veit and Peterson, 1993). Red-tailed hawks hunt from an elevated perch, often near woodland edges (USEPA, 1993). The red-tailed hawk was evaluated on an area of concern basis and on a Site-wide basis. Tables B-4-61 and B-4-62 summarize the NOAELs and LOAELs applied in the red-tailed hawk exposure evaluation.

4.4.4.1 Red-tailed Hawk Exposure Dosage Evaluation

Tables B-4-63 to B-4-69A present the exposure assessments for the terrestrial habitats evaluated present on-Site. The following is a summary of the exposure evaluation for the terrestrial habitats assessed:

4.4.4.1.1 Terrestrial Reference Habitats

- The exposure assessment for Forge Pond identified aluminum and lead exposures as producing NOAEL HQs that exceed 1.0 in this area habitat. The primary exposure route for these elements is incidental soil ingestion (Table B-4-63).

4.4.4.1.2 Central Commercial Area

- The exposure assessment for the Central Commercial Area identified aluminum (NOAEL HQ = 4.8) and lead (NOAEL HQ = 3.3) as having NOAEL HQs in excess of 1.0 in this area. However, the NOAEL HQs that exceeded 1.0 in this habitat were comparable to corresponding HQs observed in the terrestrial reference area (NOAEL HQ = 4.4 for aluminum; NOAEL HQ = 2.9 for lead). The primary route contributing to the exposure was the incidental soil ingestion route (Table B-4-64).
- All remaining COPECs had NOAEL and LOAEL HQs less than 1.0.

4.4.4.1.3 Flood Plain Area

- The exposure assessment for the Flood Plain Area identified aluminum (NOAEL HQ = 5.2) and lead (NOAEL HQ = 8.5) as having NOAEL HQs in excess of 1.0 in this habitat (Table B-4-65). Aluminum and lead NOAEL HQs also exceed 1.0 in the terrestrial reference area. The aluminum NOAEL HQ in this habitat is comparable to the corresponding NOAEL HQ in the reference area, and the NOAEL HQ for lead is approximately three times higher than the corresponding NOAEL HQ in the reference area.
- The primary exposure route for aluminum and lead for the red-tailed hawk in this area and the reference habitat area was the incidental soil ingestion route. The exposure assessment revealed a mean increase of 193% for lead from the incidental soil ingestion route in this habitat relative to the reference habitat area.
- All remaining COPECs had NOAEL and LOAEL HQs less than 1.0.

4.4.4.1.4 Marsh Upland Area

- The exposure assessment for the Marsh Upland Area identified aluminum (NOAEL HQ = 2.2), lead (NOAEL HQ = 10.0), and total mercury (NOAEL HQ = 18.9) as having NOAEL HQs in excess of 1.0 in this habitat. The LOAEL HQ for lead and total mercury also exceed 1.0 in this habitat (LOAEL HQ = 1.0 for lead and 9.5 for total mercury) (Table B-4-66).
- Although the NOAEL HQ for aluminum exceeds 1.0 in this habitat (NOAEL HQ = 2.2) it is less than the corresponding NOAEL HQs in the terrestrial reference habitat (FP NOAEL HQ = 4.4).
- The NOAEL HQ for lead is approximately 3.5 times higher in this habitat as compared to the terrestrial reference habitat. The primary exposure route for the red-tailed hawk in both habitats was incidental soil ingestion. The exposure assessment revealed a mean increase in dietary exposure of 243% for lead compared to the reference habitat area from the incidental soil ingestion route.
- Total mercury NOAEL HQs and lead and total mercury LOAEL HQs did not exceed 1.0 in the terrestrial reference habitat. However, the exposure assessment for this habitat identified NOAEL and/or LOAEL HQs exceeding 1.0 for these COPECs (NOAEL HQs = 18.9 for total mercury; LOAEL HQs = 1.0 and 9.5 for lead and total mercury, respectively). Incidental soil ingestion contributes 96% and 98% of the exposure to the red-tailed hawk in this habitat from lead and total mercury, respectively.
- All remaining COPECs had NOAEL and LOAEL HQs less than 1.0.

4.4.4.1.5 Proposed Greenway Area

- The exposure assessment for the Proposed Greenway Area identified aluminum (NOAEL HQ = 2.8) and lead (NOAEL HQ = 3.1) as having NOAEL HQs in excess of 1.0 in this habitat (Table B-4-67). However, the NOAEL HQs that exceeded 1.0 in this habitat were less than or comparable to exposures identified in the reference habitat area (NOAEL HQ = 4.4 for aluminum; NOAEL HQ = 2.9 for lead). The primary exposure route contributing to exposure was incidental soil ingestion.
- All remaining COPECs had NOAEL and LOAEL HQs less than 1.0.

4.4.4.1.6 Southern Conservation Area

- The exposure assessment for the Southern Conservation Area identified aluminum (NOAEL HQ = 5.2), lead (NOAEL HQ = 8.2), zinc (NOAEL HA = 1.0) and di-n-octylphthalate (NOAEL HQ = 5.2) as generating NOAEL HQs in excess of 1.0 in this habitat (Table B-4-68).
- Although the NOAEL HQ for aluminum exceeds 1.0 in this habitat (NOAEL HQ = 5.2), it is comparable to the NOAEL HQs in the terrestrial reference habitat (NOAEL HQ = 4.4).
- The NOAEL HQ for lead was approximately three times higher in this habitat as compared to the terrestrial reference site. The primary exposure route for the red-tailed hawk to lead in both habitats was incidental soil ingestion. The exposure assessment revealed a mean increase in dietary exposure of 181% for lead from the incidental soil ingestion route in this habitat relative to the background location.
- Zinc and di-n-octylphthalate NOAEL HQs did not exceed 1.0 in the terrestrial reference habitat. However, in this habitat the exposure assessment identified NOAEL HQs equal to or

exceeding one for these COPECs (NOAEL HQ = 1.0 for zinc and NOAEL HQ = 5.2 for di-n-octylphthalate). Incidental soil ingestion is the primary exposure route for the red-tailed hawk in this habitat from zinc and di-n-octylphthalate.

- All remaining COPECs had NOAEL and LOAEL HQs less than 1.0.

4.4.4.1.7 Southern Disposal Area

- The exposure assessment for the Southern Disposal Area identified aluminum, barium, chromium, lead, selenium, and zinc as having NOAEL HQs in excess of 1.0 in this habitat (Table B-4-69). Barium, chromium, lead, and zinc also produced LOAEL HQs greater than 1.0 in this habitat for the red-tailed hawk.
- Although the NOAEL HQ for aluminum exceeds 1.0 in this habitat (NOAEL HQ = 3.9), it is less than the corresponding NOAEL HQ in the terrestrial reference site (FP NOAEL HQ = 4.4).
- The NOAEL HQ for lead exceeded 1.0 in this area and in the terrestrial reference site. However, the NOAEL HQ for lead (NOAEL HQ = 42.5) in the Southern Disposal Area was approximately 15 times higher than the corresponding HQs from the terrestrial reference site (FP NOAEL HQ = 2.9 for lead). The primary exposure route for lead was incidental soil ingestion. The exposure assessment revealed a mean increase in dietary exposure of 1362% for lead from the incidental soil ingestion route in this habitat relative to the reference habitats.
- Barium, chromium, selenium, and zinc NOAEL HQs and barium, chromium, lead, and zinc LOAEL HQs did not exceed 1.0 in the terrestrial reference habitat. However, in this habitat the exposure assessment identified NOAEL and/or LOAEL HQs exceeding 1.0 for these COPECs (NOAEL HQs = 4.5, 8.1, 1.5, and 19.7 respectively; LOAEL HQs = 2.3, 1.6, 4.3, and 2.2, respectively). Incidental soil ingestion contributes between 80% to 98% of the exposure to the above stated COPECs in this habitat.
- All remaining COPECs with corresponding TRVs had NOAEL and LOAEL HQs less than 1.0.

4.4.4.2 Site-Wide Evaluation

Because of the large home range of this receptor (up to 150 acres per pair), the home range for this receptor has the potential to encompass the entire Fireworks Site for foraging, the mean exposure point concentration for COPECs detected in all areas (excluding the Upper North and Lower North Area) was assessed for exposure to this receptor.

- The Site-wide exposure assessment identified aluminum, lead and di-n-butylphthalate as having NOAEL HQs in excess of 1.0. No LOAEL HQs greater than 1.0 were observed for the red-tailed hawk in this evaluation (Table B-4-69A).
- Exposure to aluminum on a Site-wide basis remained comparable to background exposure dosages. Lead exposure was 3.6 times higher on a Site-wide basis compared to background exposures but did not exceed the LOAEL.
- Di-n-butylphthalate had a NOAEL HQ of 1.7 for the Site-wide evaluation and slightly exceeded the exposure dosage for this compound in the background evaluation.
- All remaining COPECs with corresponding TRVs had NOAEL and LOAEL HQs less than 1.0.

4.4.4.3 Avian Surveys

Results of the avian surveys revealed the presence of the red-tailed hawk in the terrestrial habitats present on the Site and the reference stations. Comparison of avian diversity revealed no statistical difference in avian abundance between the reference habitats and the Site.

4.4.5 Mute Swan Exposure Assessment

Two measurement endpoints were used as lines of evidence for the avian herbivore assessment endpoint receptor group: (1) exposure modeling using species-specific and Site-specific analytical and biological data, and (2) avian field surveys related to the species occurrence in the habitats present.

This waterfowl species is a resident of open water habitats and generally avoids densely vegetated channels because of its large size. It is one of the largest species of waterfowl found in Massachusetts and populations have established themselves in the southeastern part of the state. During winter months, this species is forced to migrate south in search of open water habitats. Migration can take the form of local, in-state movements during mild winters and interstate migrations during severe winters (Veit and Petersen, 1997). Mute swans are largely herbivorous in diet and feed extensively on submergent aquatic vegetation. A smaller fraction of their diet consists of small aquatic invertebrates (USEPA, 1993). The invertebrate portion of their diet fluctuates and is dependent upon local abundance of aquatic vegetation. Given their avoidance of smaller aquatic habitats with densely vegetated riparian habitats, it is unlikely that this species will be found in the Drinkwater River or Marsh Upland Area wetland. However, for purposes of assessing exposure in all habitats, the exposure of this species in the riverine and wetland habitats was assessed. Table B-4-70 summarizes the NOAELs and LOAELs applied in the mute swan exposure evaluation. The principal dietary source used in the exposure assessment of this receptor was aquatic submergent vegetation (pondweeds, *Potamogetion sp.*), which was modeled using the sediment concentrations in the habitats evaluated.

4.4.5.1 Mute Swan Exposure Modeling

4.4.5.1.1 Riverine Habitats

Tables B-4-71 to B-4-73 present the exposure assessment for the riverine habitats evaluated present on-Site. The following is a summary of the exposure evaluation for the riverine habitats assessed:

- The exposure assessment for the Northern Drinkwater River reference area identified no NOAELs or LOAEL HQs greater than 1.0 in this habitat (Table B-4-71).
- The exposure assessment for the Eastern Channel Corridor identified lead (NOAEL HQ = 1.44) and total mercury (NOAEL HQ = 14.2) as having NOAEL HQs in excess of 1.0 in this habitat (Table B-4-72). A LOAEL HQ = 7.1 was observed for total mercury exposure in this habitat for the swan. The primary exposure route contributing to the exposure to the above contaminants was the aquatic macrophyte ingestion route, which contributed greater than 85% of the exposure to the above contaminants. The exposure assessment revealed a mean increase in dietary exposure of 64% in lead and 680% in total mercury from the aquatic macrophyte ingestion route in this habitat. A LOAEL HQ = 7.1 was observed for total mercury exposure to the swan in this habitat. The exposure to lead in the Eastern Channel Corridor habitats remained slightly higher than that observed in the Northern Drinkwater River reference area.

- The exposure assessment for the Lower Drinkwater River Corridor identified lead (NOAEL HQ = 1.1) and total mercury (NOAEL HQ = 4.2) as having NOAEL HQs in excess of 1.0 in this habitat (Table B-4-73). A LOAEL HQ = 2.1 was observed for total mercury exposure in this habitat for the mute swan. The primary exposure route contributing to the exposure to the above contaminants was the aquatic macrophyte ingestion route which contributed greater than 85% of the exposure to the above contaminants. The exposure assessment revealed a mean increase in dietary exposure of 14% for lead and a 2,000% increase in total mercury from the aquatic macrophyte ingestion route in this habitat relative to the background location. The exposure to lead in the Lower Drinkwater River Corridor habitats remained slightly higher than that observed in the Northern Drinkwater River area. This increase was not deemed to contribute to a significant increase in lead exposure.
- All other COPECs had NOAEL and LOAEL HQs less than 1.0.

4.4.5.1.2 Pond Habitats

Tables B-4-74 to B-4-76 present the exposure assessment for the pond habitats evaluated present on-Site. The following is a summary of the exposure evaluation for the pond habitats assessed:

- The exposure assessment for the Forge Pond reference area identified lead as having a NOAEL HQ of 2.4. No LOAEL HQs greater than 1.0 were noted in this habitat. The primary exposure route contributing to lead exposure was via the ingestion of aquatic submergent vegetation, which contributed 87% of the lead ingested in the swan diet (Table B-4-74).
- The exposure assessment for Lily Pond/Upper Factory Pond area identified aluminum (HQ = 1.1), chromium (NOAEL HQ = 1.0), lead (NOAEL HQ = 4.8) and total mercury (NOAEL HQ = 2.6) as having NOAEL HQs greater than 1.0. A LOAEL HQ = 1.3 for total mercury was noted in this habitat. The primary exposure route was the ingestion of aquatic macrophytes which contributed 70% to 90% of the exposure to the above COPECs (Table B-4-75). Aluminum and chromium exposure remained comparable to exposure observed in the Forge Pond reference area and were not deemed to be significantly elevated in this habitat.
- The exposure assessment for Middle and Lower Factory Pond identified lead (NOAEL HQ = 1.6) and total mercury (NOAEL HQ = 2.2) as having NOAEL HQs in excess of 1.0 in this habitat. A LOAEL HQ = 1.1 was observed for total mercury in this habitat. The primary exposure route contributing to total mercury exposure was via ingestion of aquatic macrophytes which contributed 90% of the total mercury ingested in the swan diet (Table B-4-76).
- All remaining COPECs had NOAEL and LOAEL HQs <1.

4.4.5.1.3 Wetland Habitats

Tables B-4-77 and B-4-78 present the exposure assessment for the wetland reference habitat and the Marsh Upland Area. The following is a summary of the mute swan exposure evaluation for the wetland reference and Marsh Upland Area habitats:

- The exposure assessment for the wetland reference area identified lead as having a NOAEL HQ of 6.6. No LOAEL HQs greater than 1.0 were noted in this habitat. The primary exposure route contributing to lead exposure was the ingestion of aquatic submergent vegetation which contributed 84% of the lead in the swan diet (Table B-4-77).

- The exposure assessment for the Marsh Upland Area identified lead (NOAEL HQ = 44.4), total mercury (NOAEL HQ = 3.9), and methyl mercury (NOAEL HQ = 229) with NOAEL HQs in excess of 1.0 in this habitat. LOAEL HQs greater than 1.0 for lead (LOAEL HQ = 4.4), total mercury (LOAEL HQ = 1.9), and methyl mercury (LOAEL HQ = 22.8) were observed in the swan exposure evaluation in the Marsh Upland Area (Table B-4-78). The primary exposure route was the aquatic macrophyte ingestion route which contributed 76% of the exposure to lead, 89% of the exposure to total mercury and 90% of the methyl mercury ingested by the swan. The exposure assessment revealed a mean increase in dietary exposure of 571% for lead, a 3,200% increase in total mercury and a 217,000% increase in methyl mercury exposure for the swan in the Marsh Upland Area relative to the background wetland.
- All remaining COPECs had NOAEL and LOAEL HQs less than 1.0.

4.4.5.2 Avian Surveys

Surveys for birds were conducted by random visual encounter and line transect methods during three survey periods. Five transects were located to cover major habitat types, four transects were located on-Site and one reference transect was located off-Site. During the survey period, a total of 44 avian species were recorded, 29 of which were recorded during the line transect surveys. Eight bird species were recorded along Transect T1 while Transect T2 and T3 each yielded 15 avian species. Nineteen species of birds were recorded along Transect T4. The reference transect, Transect T5, yielded 17 avian species.

Results of the avian surveys revealed the presence of the mute swan in the aquatic habitats of Upper and Lower Factory Pond. This species was not observed in the reference habitats of Forge Pond. Comparison of avian diversity revealed no statistical difference in avian abundance between the reference habitats surveyed and the habitats surveyed within the Site.

4.4.6 Mink Exposure Assessment

Three measurement endpoints were used as lines of evidence to be evaluated for the piscivorous mammal assessment endpoint: (1) exposure modeling using species-specific and Site-specific analytical and biological data; (2) comparison of observed fish body burden concentrations to (CCME, 1999) guidelines; and (3) mammalian field surveys related to species presence in on-Site habitats. The fish body burden comparison was discussed previously under the kingfisher in Section 4.4.1.2

The mink is a small, nocturnal, carnivorous mammal that primarily feeds on aquatic prey species including small fish and invertebrates. Its diet can vary widely with the inclusion of amphibians, small mammals, birds and muskrats depending upon local abundance and habitats. It is considered one of the most abundant mammalian carnivores associated with aquatic and wetland habitats (USEPA, 1993). Mink are typically found along rivers, streams, and lake and pond edges where the majority of the habitat used for hunting is found. They prefer river and pond banks with thick vegetation and dense canopies where the cover will favor shallow water and better entrapment of prey. Mink feed on smaller fish species or age groups (i.e., fish < 6 inches in length) that are captured in shallow water by entrapment (USEPA, 1993). The mink is expected to utilize the riverine, pond and wetland habitats present on the Site. Given the lack of a viable fish population in the Marsh Upland Area due to the limited amount of standing water, mink populations are expected to exploit the prey resources associated with the Drinkwater River and Factory Pond habitats rather the Marsh Upland Area. The mink was modeled for the riverine and pond aquatic habitats found on-Site and in the river and pond reference habitats to assess the dietary exposures to COPECs. The model incorporates media data as well as small fish body burdens (TtFW, 2004). Table B-4-79 summarizes the TRVs used as NOAELs and LOAELs applied in the mink exposure evaluation.

4.4.6.1 Mink Exposure Modeling

4.4.6.1.1 Riverine Habitat

Tables B-4-80 to B-4-82 present the exposure assessment for the riverine habitats. The following is a summary of the exposure evaluation for the riverine habitats assessed:

- The exposure assessment for the Northern Drinkwater River reference habitat identified aluminum (NOAEL HQ = 8.9), methyl mercury (NOAEL HQ = 1.1), and thallium (NOAEL HQ = 5.2) with NOAEL HQs in excess of 1.0 in this habitat. No LOAEL HQs greater than 1.0 were calculated in the mink exposure evaluation in the Northern Drinkwater River reference area (Table B-4-80).
- The exposure assessment for the Eastern Channel Corridor identified aluminum (NOAEL HQ = 12.7), antimony (NOAEL HQ = 3.4), methyl mercury (NOAEL HQ = 4.4), and thallium (NOAEL HQ = 5.8) with NOAEL HQs in excess of 1.0 in this habitat (Table B-4-81). A LOAEL HQ = 1.3 for aluminum and a LOAEL HQ = 2.7 for methyl mercury were observed in the mink exposure evaluation in this habitat. The primary exposure routes contributing to exposure were the small fish ingestion route (methyl mercury, thallium) and the incidental sediment ingestion route (antimony and aluminum). Combined, these routes contributed greater than 96% of the exposure. The exposure assessment revealed a mean increase in dietary exposure of a 39% increase in aluminum and a 300% increase in methyl mercury exposure for the mink in this habitat relative to the Northern Drinkwater River. Thallium and antimony exposures remained comparable to that in the Northern Drinkwater River reference habitat and were not deemed to be significant in the Eastern Channel Corridor.
- The exposure assessment for the Lower Drinkwater River Corridor identified aluminum (NOAEL HQ = 11.9), antimony (NOAEL HQ = 1.1), methyl mercury (NOAEL HQ = 6.0), and thallium (NOAEL HQ = 6.9) with NOAEL HQs in excess of 1.0 in this riverine habitat (Table B-4-82). A LOAEL HQ = 1.2 for aluminum and a LOAEL HQ = 3.6 for methyl mercury were calculated in the mink exposure evaluation in the Lower Drinkwater River Corridor habitats. The primary exposure routes were the small fish ingestion route (methyl mercury, thallium) and the incidental sediment ingestion route (antimony and aluminum). Combined, these routes contributed greater than 99% of the exposure. The exposure assessment revealed a mean increase in dietary exposure of 32% for aluminum and a 420% increase in methyl mercury exposure relative to the Northern Drinkwater River. Thallium and antimony exposures remained comparable to that in the Northern Drinkwater River reference habitat and were not deemed to be significant in the Lower Drinkwater River Corridor.
- All remaining COPECs had NOAEL and LOAEL HQs less than 1.0.

4.4.6.1.2 Pond Habitats

Tables B-4-83 to B-4-85 present the exposure assessment for the pond habitats. The following is a summary of the exposure evaluation for the pond habitats:

- The exposure assessment for the Forge Pond reference area identified aluminum (NOAEL HQ = 26.8), methyl mercury (NOAEL HQ = 1.9), and thallium (NOAEL HQ = 5.9) with

NOAEL HQs in excess of 1.0 in this habitat. A LOAEL HQ = 2.68 was calculated for aluminum in the mink exposure evaluation (Table B-4-83).

- The exposure assessment for the Lily Pond/Upper Factory Pond area identified aluminum (NOAEL HQ = 24.5), antimony (NOAEL HQ = 1.6), arsenic (NOAEL HQ = 1.1), methyl mercury (NOAEL HQ = 5.1), and thallium (NOAEL HQ = 5.8) with NOAEL HQs in excess of 1.0. A LOAEL HQ = 2.5 for aluminum and a LOAEL HQ = 3.1 for methyl mercury were calculated in the mink exposure evaluation in the Lily Pond/Upper Factory Pond habitats (Table B-4-84). The primary exposure routes were the small fish ingestion route (arsenic, methyl mercury, thallium) and the incidental sediment ingestion route (antimony and aluminum). Combined, these routes contributed greater than 96% of the exposure. The exposure assessment revealed a mean increase in dietary exposure of 159% in methyl mercury exposure relative to the Forge Pond Area. Thallium, arsenic and antimony exposure remained comparable to that in the Forge Pond reference area and were not deemed to be significant in the Lily Pond/Upper Factory Pond habitats.
- The exposure assessment for the Middle/Lower Factory Pond area identified aluminum (NOAEL HQ = 14.8), arsenic (NOAEL HQ = 1.3), methyl mercury (NOAEL HQ = 5.3) and thallium (NOAEL HQ = 5.8) with NOAEL HQs in excess of 1.0 in this habitat (Table B-4-85). A LOAEL HQ = 1.5 for aluminum and a LOAEL HQ = 3.1 for methyl mercury were calculated in the mink exposure evaluation in the Middle/Lower Factory Pond habitats. The primary exposure routes were the small fish ingestion route (arsenic, methyl mercury, thallium) and the incidental sediment ingestion route (aluminum). Combined, these routes contributed greater than 98% of the exposure. The exposure assessment revealed a mean increase in dietary exposure of 165% in exposure to methyl mercury in this habitat relative to the Forge Pond reference area. Aluminum, thallium and arsenic exposures remained comparable to that calculated for the pond background area and were not deemed to be significant in the Middle/Lower Factory Pond habitats.
- All remaining COPECs had NOAEL and LOAEL HQs less than 1.0.

4.4.6.2 Mammalian Surveys

Results of the mammalian survey revealed the presence of the mink in the aquatic habitats of Upper and Lower Factory Pond at the Site. No evidence of the mink was noted along the habitats of Drinkwater River. Evidence of this species was not observed in the reference habitats of Forge Pond or the Northern Drinkwater River. The mammalian survey data suggest that this species is in low abundance in all habitats surveyed. Mammalian diversity remained consistent across habitats present on the Site and in the reference habitats.

4.4.7 Raccoon Exposure Assessment

Three measurement endpoints were used as lines of evidence to be evaluated for the ominivorous mammal assessment endpoint: (1) exposure modeling using species-specific and Site-specific analytical and biological data; (2) comparison of the body burden of bioaccumulative metals in the principal prey item, crayfish, to the CCME (1999) guidance value for mercury; and (3) results of mammalian field surveys related to this species' presence on the Site. The crayfish bioaccumulation comparison was discussed previously under the Kingfisher in Section 4.4.1.2.

The raccoon is a medium-size, opportunistic mammal that feeds on aquatic prey species including larger invertebrates and occasionally small fish in aquatic and wetland habitats. In upland habitats, the diet shifts toward a greater inclusion of mast and berries from a strictly aquatic prey diet. It is nocturnal in habit and is rarely seen during the day. Its diet can vary widely with the inclusion of upland fruits and mast, berries, amphibians, small mammals, birds and carrion. It is highly opportunistic in diet and will exploit prey resources based upon local abundance and habitats. Larger aquatic invertebrate species such as crayfish compose a major proportion of its diet associated with aquatic habitats (USEPA, 1993). It is considered to be tolerant to human disturbance (USEPA, 1993). Racoons are common along rivers, streams, and lake and pond edges where the majority of the associated habitat is used for foraging. They prefer river and pond banks with little or no vegetation where the cover will limit access to the waterbody or entrapment of prey. In addition to crayfish, smaller fish species (i.e., fish < 6 inches) may also be captured fortuitously, though their capture represents only a small fraction of the raccoon's diet. The raccoon is a species expected to utilize all the riverine, pond and wetland habitats on-Site. This species is expected to exploit the prey resources associated with the Drinkwater River and Factory Pond. The raccoon was modeled in the riverine and pond habitats found on-Site and in the river and pond reference areas to assess the dietary exposures of COPECs. The model incorporates environmental media data, as well as crayfish and small fish (i.e., bluegill sunfish) body burdens (TtFW, 2004).

4.4.7.1 Raccoon Exposure Modeling

Table B-4-886 summarizes the toxicity reference values used as NOAELs and LOAELs applied in the raccoon exposure evaluation.

4.4.7.1.1 Riverine Habitats

Tables B-4-87 to B-4-89 present the exposure assessment for the riverine habitats evaluated. The following is a summary of the exposure evaluation for the riverine habitats:

- The exposure assessment for the Northern Drinkwater River reference area identified aluminum (NOAEL HQ = 35.5), antimony (NOAEL HQ = 1.7), arsenic (NOAEL HQ = 1.7), silver (NOAEL HQ = 2.5), and thallium (NOAEL HQ = 10.8) with NOAEL HQs in excess of 1.0 in this habitat. LOAEL HQs greater than 1.0 were calculated for aluminum (LOAEL HQ = 3.6) and thallium (LOAEL HQ = 1.1) in the Northern Drinkwater River area (Table B-4-87).
- The exposure assessment for the Eastern Channel Corridor identified aluminum (NOAEL HQ = 49.1), antimony (NOAEL HQ = 10.6), arsenic (NOAEL HQ = 1.1), total mercury (NOAEL HQ = 3.3), and thallium (NOAEL HQ = 3.0) with NOAEL HQs in excess of 1.0 in this habitat (Table B-4-88). A LOAEL HQ = 4.9 for aluminum and a LOAEL HQ = 1.1 for antimony were calculated in the raccoon exposure evaluation in the Eastern Channel Corridor habitats. The primary exposure routes were the crayfish ingestion route (thallium) and the incidental sediment ingestion route (aluminum, antimony, arsenic and total mercury). Combined, these routes contributed greater than 96% of the exposure. The estimated exposure to aluminum, arsenic and thallium were less than or comparable to the exposure in the Northern Drinkwater River reference area and will not be considered further. The exposure assessment revealed a mean increase of 524% in dietary exposure to antimony and a 250% increase in total mercury exposure for the raccoon in this habitat relative to the Northern Drinkwater River reference area.
- The exposure assessment for the Lower Drinkwater River Corridor identified aluminum (NOAEL HQ = 40.5), antimony (NOAEL HQ = 1.4), methyl mercury (NOAEL HQ = 1.2), and thallium (NOAEL HQ = 8.0) with NOAEL HQs in excess of 1.0 in this habitat (Table B-4-89). A LOAEL HQ = 4.1 for aluminum was calculated in the raccoon exposure evaluation. The primary exposure routes were the crayfish ingestion route (antimony and thallium), the incidental sediment ingestion route (aluminum), and the forage fish ingestion

route (methyl mercury). Combined, these routes contributed greater than 99% of the exposure. The estimated exposure to aluminum, antimony and thallium were less than or comparable to the exposures calculated in the Northern Drinkwater River background area and will not be considered further. The exposure assessment revealed a mean increase of 524% in dietary exposure to antimony and a 32% increase in methyl mercury exposure for the raccoon estimated relative to the Drinkwater River background area.

- All remaining COPECs had NOAEL and LOAEL HQs <1.

4.4.7.1.2 Pond Habitats

Tables B-4-90 to B-4-92 present the exposure assessment for the pond habitats evaluated present on-Site. The following is a summary of the exposure evaluation for the pond habitats assessed:

- The exposure assessment for the Forge Pond reference area identified aluminum (NOAEL HQ = 104.4), arsenic (NOAEL HQ = 1.0), thallium (NOAEL HQ = 4.4), and vanadium (NOAEL HQ = 1.3) with NOAEL HQs in excess of 1.0 in this habitat. A LOAEL HQ = 10.4 was calculated for aluminum in the raccoon exposure evaluation in this habitat (Table B-4-90).
- The exposure assessment for the Lily Pond/Upper Factory Pond area identified aluminum (NOAEL HQ = 95.3), antimony (NOAEL HQ = 3.4), arsenic (NOAEL HQ = 1.2), methyl mercury (NOAEL HQ = 1.0), thallium (NOAEL HQ = 3.6), and vanadium (HQ = 1.5) with NOAEL HQs in excess of 1.0 in this habitat (Table B-4-91). A LOAEL HQ = 9.5 for aluminum was calculated in the raccoon exposure evaluation in the Lily Pond/Upper Factory Pond habitats. The primary exposure route contributing to the exposure to the above contaminants was the crayfish ingestion route (antimony, arsenic, methyl mercury, thallium and vanadium) and the incidental sediment ingestion route (aluminum). Combined, these routes contributed greater than 99% of the exposure to the above contaminants ingested by the raccoon. The calculated exposure to aluminum, arsenic, thallium and vanadium were less than or comparable to the exposures observed in the Forge Pond Area and were reflective of local conditions and will not be considered further. The exposure assessment revealed a mean increase in dietary exposure of 161% in methyl mercury exposure for the raccoon in this habitat relative to the background area.
- The exposure assessment for the Middle/Lower Factory Pond area identified aluminum (NOAEL HQ = 54.6), methyl mercury (NOAEL HQ = 1.1), and thallium (NOAEL HQ = 3.3) with NOAEL HQs in excess of 1.0 in this habitat (Table B-4-92). A LOAEL HQ = 5.5 for aluminum was calculated in the raccoon exposure evaluation in the ML habitats. The primary exposure route were the crayfish ingestion route (methyl mercury, thallium) and the incidental sediment ingestion route (aluminum). Combined, these routes contributed 99% of the exposure. The estimated exposure to aluminum and thallium was less than or comparable to the exposures calculated in the Forge Pond reference area and were reflective of local conditions and will not be considered further. The exposure assessment revealed a mean increase in dietary exposure of 166% in exposure to methyl mercury relative to the Forge Pond reference area.
- All remaining COPECs had NOAEL and LOAEL HQs less than 1.0.

The absence of a viable fish and crayfish population in the Marsh Upland Area wetland is due to the lack of consistent standing water. Utilization of this habitat by the raccoon was expected to be limited. Based upon habitat preferences, the raccoon was expected to exploit the prey resources associated with the Drinkwater River and Factory Pond habitats.

4.4.7.2 Mammalian Surveys

Results of the mammalian survey revealed the presence of the raccoon in the terrestrial, wetland and aquatic habitats of the Eastern Channel Corridor, Lower Drinkwater River Corridor, Lily Pond/Upper Factory Pond and Middle/Lower Factory Pond habitats at the Site. The evidence of their occurrence included the presence of tracks and direct observation of this species in on-Site habitats. Evidence of the raccoon was noted along the habitats of Northern Drinkwater River and Forge Pond. This indicates that raccoons are utilizing the habitats present on the Site. The survey data indicated that the raccoon was abundant in Site habitats.

4.4.8 Short-Tailed Shrew Exposure Assessment

Two measurement endpoints were used as lines of evidence for this assessment endpoint receptor group in this evaluation: (1) exposure modeling using species-specific and Site-specific analytical and biological data and comparison to species specific NOAELs and LOAELs; and (2) mammalian field surveys related to species presence and relative abundance.

The short-tailed shrew is an insectivorous, small mammal species common to a variety of vegetation covertypes including open fields, upland forests and forested wetlands. Possessing a high metabolic rate, the shrew is an aggressive predator whose diet is largely made up of soil invertebrates such as earthworms but will include larger prey such as mice and voles if presented with the opportunity (USEPA, 1993). Cryptic in habit, it is primarily nocturnal and utilizes runways excavated by other small mammals in leaf litter to move about on the forest floor. Its home range varies between 0.25 to 8.90 acres (0.1 to 3.6 Ha) depending upon habitat structure and prey availability (USEPA, 1993). Larger carnivores, including owls, hawks and foxes, frequently prey upon the shrew (USEPA, 1993).

4.4.8.1 Short-tailed Shrew Exposure Dosage Assessment

Table B-4-93 presents the species-specific NOAELs and LOAELs applied in the ERC for this species. Tables B-4-94 to B-4-102 present the exposure assessments for the terrestrial habitats present on-Site. The following is a summary of the exposure evaluation for the terrestrial habitats assessed:

4.4.8.1.1 Terrestrial Reference Habitats

- The exposure assessment for the Forge Pond identified nitroglycerine and thallium as having NOAEL HQs that exceed 1.0 in this area habitat (Table B-4-94). Aluminum NOAEL and LOAEL HQs exceed one in this habitat. The primary exposure route for the short-tailed shrew was via the terrestrial invertebrate ingestion.

4.4.8.1.2 Central Commercial Area

- The exposure assessment for the Central Commercial Area identified nitroglycerin (NOAEL HQ = 1.45) as having NOAEL HQs in excess of 1.0 in this area (Table B-4-95). Aluminum and thallium produced both NOAEL and LOAEL HQs (NOAEL HQs = 25.83 and 16.7, respectively; LOAEL HQs = 2.58 and 1.67, respectively) in excess of 1.0.
- Although the NOAEL HQ for nitroglycerine exceeded 1.0 in this habitat (NOAEL HQ = 1.45), it is less than the corresponding NOAEL HQs in the terrestrial reference habitat (FP NOAEL HQ = 2.78). The NOAEL HQ and LOAEL HQ for aluminum NOAEL HQ =

25.83; LOAEL HQ = 2.58) were comparable to the HQs in the terrestrial reference habitat (NOAEL HQ = 24.01; LOAEL HQ = 2.40 for aluminum).

- The NOAEL HQ for thallium is approximately two times higher than the exposure in the terrestrial reference habitat. The primary exposure route for the short-tailed shrew was terrestrial invertebrate ingestion. The exposure assessment revealed an increase in the dietary exposure of 116% for thallium in this habitat relative to the reference location exposure.
- The thallium LOAEL HQ did not exceed 1.0 in the terrestrial reference habitat. However, in the Central Commercial Area the exposure assessment identified a LOAEL exceeding 1.0 for thallium (LOAEL HQs = 1.67). Terrestrial invertebrate ingestion contributes 97% of the exposure to short-tailed shrew in this habitat to thallium.
- All remaining COPECs had NOAEL and LOAEL HQs less than 1.0.

4.4.8.1.3 Flood Plain Area

- The exposure assessment for the Flood Plain Area identified antimony (NOAEL HQ = 2.44) NOAEL HQs and aluminum NOAEL and LOAEL HQs (NOAEL HQs = 28.39; LOAEL HQs = 2.84) in excess of 1.0 in this habitat (Table B-4-96).
- Although the NOAEL HQ and LOAEL HQ for aluminum exceeded 1.0 in the Flood Plain Area, they were comparable to the corresponding NOAEL HQ and LOAEL HQ in the terrestrial reference habitat (NOAEL HQ = 24.01; LOAEL HQ = 2.84).
- The antimony NOAEL HQ did not exceed 1.0 in the terrestrial reference habitat. However, in this habitat, the exposure assessment identified a NOAEL HQ exceeding 1.0 for antimony (NOAEL HQs = 2.44). Terrestrial invertebrate ingestion contributed 98% of the antimony exposure to short-tailed shrew.
- All remaining COPECs had NOAEL and LOAEL HQs less than 1.0.

4.4.8.1.4 Marsh Upland Area

- The exposure assessment for the Marsh Upland Area identified antimony and total mercury (NOAEL HQs = 1.48 and 18.93) as having NOAEL HQs in excess of 1.0. Aluminum produced both NOAEL and LOAEL HQs (NOAEL HQ = 12.16; LOAEL HQ = 1.22) in excess of 1.0 in the Marsh Upland Area (Table B-4-97).
- Although the NOAEL and LOAEL HQs for aluminum exceeded 1.0, they were less than the corresponding NOAEL and LOAEL HQs in the terrestrial reference habitat (NOAEL HQ = 24.01; LOAEL HQ = 2.84).
- Antimony and total mercury NOAEL HQs did not exceed 1.0 in the terrestrial reference habitat. The exposure assessment identified NOAEL HQs exceeding 1.0 for antimony and total mercury (NOAEL HQs = 1.48 and 18.93, respectively). Terrestrial invertebrate ingestion contributed 98% of the antimony and total mercury exposure to the short-tailed shrew.
- All remaining COPECs had NOAEL and LOAEL HQs less than 1.0.

4.4.8.1.5 Proposed Greenway Area

- The exposure assessment for the Proposed Greenway Area identified antimony and silver (NOAEL HQs = 2.14 and 2.44, respectively) as producing NOAEL HQs in excess of 1.0.

Aluminum and thallium resulted in exposures greater than 1.0 for the NOAEL and LOAEL HQs (NOAEL HQs = 15.07 and 14.20; LOAEL HQs = 1.51 and 1.42, respectively) (Table B-4-98).

- Although the NOAEL and LOAEL HQ for aluminum exceeded 1.0 in this habitat, the HQs were less than the corresponding NOAEL and LOAEL HQs in the terrestrial reference habitat (NOAEL HQ = 24.01; LOAEL HQ = 2.84).
- The NOAEL HQ for thallium was approximately two times higher as compared to the terrestrial reference habitat. The primary exposure route for thallium exposure was terrestrial invertebrate ingestion. The exposure assessment revealed a mean increase in dietary exposure of 83% for thallium from the terrestrial invertebrate ingestion route relative to the reference area.
- The NOAEL HQ for antimony and the LOAEL HQ for thallium did not exceed 1.0 in the terrestrial reference habitat. However, in the Proposed Greenway Area, the exposure assessment identified a NOAEL HQ and LOAEL HQ exceeding 1.0 for antimony and thallium, respectively (NOAEL HQ = 2.14 for antimony; LOAEL HQ = 1.42 for thallium). Terrestrial invertebrate ingestion contributes 97% of the exposure to short-tailed shrew to antimony and thallium.
- All remaining COPECs had NOAEL and LOAEL HQs less than 1.0.

4.4.8.1.6 Southern Conservation Area

- The exposure assessment for the Southern Conservation Area identified nitroglycerin, antimony, cadmium, silver, and hexachlorobenzene (NOAEL HQs = 4.82, 7.59, 1.61, 2.92, and 1.02, respectively) as producing NOAEL HQs in excess of 1.0. Aluminum generated NOAEL and LOAEL HQs in excess of 1.0 (NOAEL HQ = 28.33; LOAEL HQ = 2.83) in this habitat (Table B-4-99).
- Although the NOAEL and LOAEL HQs for aluminum exceed 1.0 in this habitat they are less than the corresponding NOAEL HQ and LOAEL HQ in the terrestrial reference habitat (NOAEL HQ = 24.01; LOAEL HQ = 2.84).
- The NOAEL HQ for nitroglycerin was approximately two times higher in this habitat as compared to the terrestrial reference habitat. The primary exposure route for nitroglycerin exposure was terrestrial invertebrate ingestion. The exposure assessment revealed a mean increase in dietary exposure of 73% for nitroglycerin relative to the background location.
- The NOAEL HQs for antimony, cadmium, silver, and hexachlorobenzene did not exceed 1.0 in the terrestrial reference habitat. However, in this habitat the exposure assessment identified NOAEL HQs exceeding 1.0 for the above COPECs (NOAEL HQs = 7.59, 1.61, 2.92, 1.02). Terrestrial invertebrate ingestion contributes greater than 97% of the exposure to the short-tailed shrew to antimony, cadmium, silver, and hexachlorobenzene in this habitat.
- All remaining COPECs had NOAEL and LOAEL HQs less than 1.0.

4.4.8.1.7 Southern Disposal Area

- The exposure assessment for the Southern Disposal Area identified arsenic, barium, cadmium, lead, selenium, silver, methyl iodide, and trichloroethylene (NOAEL HQs = 1.98, 1.60, 7.78, 1.09, 1.23, 11.23, 1.79, 7.29, respectively) as producing NOAEL HQs in excess of 1.0 in this habitat (Table B-4-100). Aluminum, antimony, copper, and zinc generated HQs in excess of 1.0 for both the NOAEL and LOAEL HQs (NOAEL HQs = 21.11, 26.35, 4.92, and 4.05, respectively; LOAEL HQs = 2.11, 2.64, 1.23, and 2.03, respectively).

- Although the NOAEL and LOAEL HQs for aluminum exceeded 1.0 in this habitat, they were less than the corresponding NOAEL and LOAEL HQs in the terrestrial reference habitat (FP NOAEL HQ = 24.01; LOAEL HQ = 2.84).
- Antimony, arsenic, barium, cadmium, copper, lead, selenium, silver, zinc, methyl iodide, and trichloroethylene NOAEL HQs and antimony, copper, and zinc LOAEL HQs did not exceed 1.0 in the terrestrial reference habitat. However, in the Southern Disposal Area the exposure assessment identified NOAEL and/or LOAEL HQs exceeding 1.0 for these COPECs (NOAEL HQs = 26.35, 1.98, 1.60, 7.78, 4.92, 1.09, 1.23, 11.23, 4.05, 1.79, 7.29, respectively; LOAEL HQs = 2.64, 1.23, 2.03, respectively). Terrestrial invertebrate ingestion contributed 61% to 99% of the exposure to the short-tailed shrew to antimony, arsenic, barium, cadmium, copper, lead, selenium, silver, zinc, methyl iodide, and trichloroethylene.
- All remaining COPECs had NOAEL and LOAEL HQs less than 1.0.

4.4.8.1.8 Cold Waste Area

Table B-4-101 presents the TRVs applied in the Cold Waste Area for exposure assessment.

- The exposure assessment for the Cold Waste Area identified cadmium, lead, selenium, silver, vanadium, benzo(b)fluoroanthene, fluoroanthene, phenanthrene, and pyrene as having NOAEL HQs in excess of 1.0. Aluminum, antimony, arsenic, barium, copper, thallium, zinc, and hexachlorobenzene had NOAEL and LOAEL HQs greater than 1.0 in this habitat for the short-tailed shrew (Table B-4-102).
- The NOAEL HQs for thallium and NOAEL and LOAEL HQs for aluminum exceeded 1.0 in this area. The NOAEL and LOAEL HQs for aluminum and thallium (NOAEL HQ = 75.2 and LOAEL HQ = 7.5 for aluminum; NOAEL HQ = 77.2 and LOAEL HQ = 7.7 for thallium) were 3 to 10 times higher than that calculated in the terrestrial reference site (NOAEL HQ = 24.01 and LOAEL HQ = 2.40 for aluminum; NOAEL HQ = 7.74 and LOAEL HQ = <1 for thallium, respectively). The primary exposure routes were incidental soil ingestion (76% for aluminum and 12% for thallium) and soil invertebrate ingestion (23% for aluminum and 87% for thallium). The exposure assessment revealed a mean increase in dietary exposure of 620% for aluminum and 4,670% for thallium for the incidental soil ingestion route and mean increase in dietary exposure of 119% for aluminum and 989% for the terrestrial invertebrate ingestion route in this habitat relative to the reference location.
- Cadmium, lead, selenium, silver, vanadium, benzo(b)fluoroanthene, fluoroanthene, phenanthrene, and pyrene NOAEL HQs did not exceed 1.0 in the terrestrial reference habitat (Table B-4-102). In the Cold Waste Area, the exposure assessment identified NOAEL HQs exceeding 1.0 for these COPECs (NOAEL HQs = 4.3, 6.5, 1.1, 6.1, 1.4, 1.1, 1.4, 1.4, and 1.3, respectively). Aluminum, antimony, arsenic, barium, copper, thallium, zinc, and hexachlorobenzene NOAEL and LOAEL HQs did not exceed 1.0 in the terrestrial reference habitat. In the Cold Waste Area, the exposure assessment, NOAEL and LOAEL HQs exceeded 1.0 for these COPECs (NOAEL HQs = 1541.9, 8.8, 62.4, 5.8, 13.0, and 6.4, respectively and LOAEL HQs = 154.2, 1.8, 16.1, 1.5, 6.5, and 1.8, respectively). Invertebrate ingestion contributes between 61% and 99% of the exposure to antimony, arsenic, cadmium, copper, lead, selenium, silver, thallium, zinc, benzo(b)fluoroanthene, fluoroanthene, phenanthrene, pyrene, and hexachlorobenzene for the short-tailed shrew, and incidental soil ingestion contributed 76%, 60%, and 77% of the exposure to aluminum,

barium and vanadium. Together, terrestrial invertebrate and incidental soil ingestion were the primary exposure routes contributing 99.8% to 100% of exposure to the short-tailed shrew in the Cold Waste Area.

- All remaining COPECs had NOAEL and LOAEL HQs less than 1.0.

4.4.8.2 Mammalian Surveys

Given its small body size, nocturnal habits, and its use of subterrainean tunnels, the mammalian survey did not reveal the presence of the short-tailed shrew through direct observation. However, the survey did confirm the presence of small mammal runways and other small mammals (i.e., chipmunk and white-footed mouse) in the reference and on-Site habitats. Additionally, the survey revealed the presence of earthworms and other soil invertebrates that are typical shrew dietary items. This indicates that small mammals are utilizing the habitats present on the Site. The runways in the habitats were abundant throughout the Site.

4.4.9 Muskrat Exposure Assessment

Two lines of evidence were used as measurement endpoints to be evaluated for the herbivorous mammal assessment endpoint: (1) exposure modeling using species-specific and Site-specific analytical data and comparison to NOAEL and LOAELs; and (2) mammalian field surveys related to species presence and relative abundance.

The muskrat is a medium-size, herbivorous mammal that is a year-round resident of aquatic habitats in New England. The muskrat can be both diurnal and nocturnal in habit and feeds on submergent and emergent aquatic vegetation associated with riparian habitats. It is active year round and forages during all seasons of the year. Along river and pond banks, muskrats excavate burrows for lodges and rearing of young (Goldin, 1977). In marsh habitats, lodges constructed of emergent vegetation are used. It is highly adaptive in habits and tolerant to human disturbance (USEPA, 1993).

Muskrats are commonly found along rivers, streams, and lake and pond edges where the majority of the associated habitat is used for foraging and denning. They prefer river and pond banks with dense vegetation where the cover will limit predatory observation. The muskrat is a species expected to utilize all the riverine, pond and wetland habitats present on the Site. The muskrat was modeled in the riverine, pond and wetland habitats found on-Site and in reference habitat areas. The exposure model incorporates environmental media data (i.e., surface water and sediments) and utilized the aquatic plant uptake model of Jackson and Kalff (1993) to develop exposure point concentrations for the aquatic plant ingestion route based upon environmental media data collected (TtFW, 2004).

4.4.9.1 Muskrat Exposure Modeling

Table B-4-103 summarizes the toxicity reference values used as NOAELs and LOAELs applied in the muskrat exposure evaluation.

4.4.9.1.1 Riverine Habitats

Tables B-4-104 to B-4-106 present the exposure assessment for the riverine habitats. The following is a summary of the exposure evaluation for the riverine habitats:

- The exposure assessment for the Northern Drinkwater River reference area identified aluminum (NOAEL HQ = 70.1), arsenic (NOAEL HQ = 4.7), and thallium (NOAEL HQ =

10.8) with NOAEL HQs in excess of 1.0. A LOAEL HQ greater than 1.0 was observed for aluminum (LOAEL HQ = 7.0) in the Northern Drinkwater River (Table B-4-104).

- The exposure assessment for the Eastern Channel Corridor identified aluminum (NOAEL HQ = 91.7), antimony (NOAEL HQ = 51.0), arsenic (NOAEL HQ = 8.2), total mercury (NOAEL HQ = 10.8), silver (NOAEL HQ = 5.3), thallium (NOAEL HQ = 23.4), and vanadium (NOAEL HQ = 4.7) with NOAEL HQs in excess of 1.0 (Table B-4-105). A LOAEL HQ = 9.2 for aluminum, 5.1 for antimony, 1.1 for total mercury and 2.3 for thallium were calculated in the muskrat exposure evaluation in the Eastern Channel Corridor. The primary exposure route was the aquatic plant ingestion route. This route contributed greater than 90% of the exposure. The exposure to aluminum, arsenic and vanadium was less than or comparable to the exposure in the Northern Drinkwater River area and will not be considered further. The exposure assessment revealed a mean increase of 5540% in dietary exposure to antimony and a 199,000% increase in total mercury exposure relative to the Northern Drinkwater River area.
- The exposure assessment for the Lower Drinkwater River Corridor identified aluminum (NOAEL HQ = 73.4), antimony (NOAEL HQ = 10.0), arsenic (NOAEL HQ = 3.9), total mercury (NOAEL HQ = 1.9), silver (NOAEL HQ = 3.3), thallium (NOAEL HQ = 63.0) and vanadium (NOAEL HQ = 3.9) with NOAEL HQs in excess of 1.0 (Table B-4-106). A LOAEL HQ = 7.8 for aluminum was observed for the muskrat exposure evaluation. The primary exposure route was the aquatic plant ingestion route. Combined, these routes contributed greater than 98% of the exposure. The exposures to aluminum, arsenic and vanadium were less than or comparable to the exposure in the Northern Drinkwater River area. The exposure assessment revealed a mean increase of 978% in dietary exposure to antimony, a 3,340% increase in total mercury, a 52,831% increase in silver, and a 79,754% increase in thallium exposure relative to the Northern Drinkwater River area.
- All remaining COPECs had NOAEL and LOAEL HQs less than 1.0.

4.4.9.1.2 Pond Habitats

Tables B-4-107 to B-4-109 present the muskrat exposure assessment for the pond habitats evaluated. The following is a summary of the exposure evaluation for the pond habitats:

- The exposure assessment for the Forge Pond reference area identified aluminum (NOAEL HQ = 166.2), arsenic (NOAEL HQ = 2.3), silver (NOAEL HQ = 8.2), thallium (NOAEL HQ = 36.0), and vanadium (NOAEL HQ = 7.9) with NOAEL HQs in excess of 1.0 in this habitat. LOAEL HQs of 16.6 and 3.6 were observed for aluminum and thallium, respectively (Table B-4-107).
- The exposure assessment for the Lily Pond/Upper Factory Pond area identified aluminum (NOAEL HQ = 154.6), antimony (NOAEL HQ = 20.9), arsenic (NOAEL HQ = 8.2), lead (NOAEL HQ = 1.3), total mercury (NOAEL HQ = 1.6), selenium (NOAEL HQ = 1.4), silver (NOAEL HQ = 8.8), thallium (NOAEL HQ = 29.4), and vanadium (HQ = 8.5) with NOAEL HQs in excess of 1.0 (Table B-4-108). A LOAEL HQ = 15.5 for aluminum, 2.1 for antimony and 2.9 for thallium were calculated in the muskrat exposure evaluation in the Lily Pond/Upper Factory Pond habitats. The primary exposure route was the aquatic plant ingestion route. This route contributed greater than 99% of the exposure. The calculated exposures to aluminum, arsenic, silver, thallium and vanadium were less than or comparable to the exposures in the Forge Pond reference habitat and were reflective of local conditions. The exposure assessment revealed a mean increase in dietary exposure to total mercury of

5600% in total mercury exposure for the muskrat in this habitat relative to the Forge Pond reference area.

- The exposure assessment for the Middle/Lower Factory Pond area identified aluminum (NOAEL HQ = 99.5), antimony (NOAEL HQ = 4.8), arsenic (NOAEL HQ = 5.2), total mercury (NOAEL HQ = 1.3), silver (NOAEL HQ = 4.4), thallium (NOAEL HQ = 25.7) and vanadium (HQ = 4.9) with NOAEL HQs in excess of 1.0 in this habitat (Table B-4-109). LOAEL HQs = 9.9 for aluminum and 2.6 for thallium were calculated in the Middle/Lower Factory Pond habitats. The primary exposure route was the aquatic plant ingestion route. This route contributed greater than 99% of the exposure. The calculated exposures to aluminum, antimony, arsenic, silver, thallium and vanadium were less than or comparable to the exposures in the Forge Pond reference area and were reflective of local conditions. The exposure assessment revealed a mean increase in dietary exposure to total mercury of 4500% for the muskrat in the Middle/Lower Factory Pond habitat.
- All remaining COPECs had NOAEL and LOAEL HQs less than 1.0.

4.4.9.1.3 Wetland Habitats

Tables B-4-110 and B-4-111 present the exposure assessment for the wetland background area and the marsh upland area (Marsh Upland Area). The following is a summary of the muskrat exposure evaluation for the background and Marsh Upland Area habitats:

- The exposure assessment for the background wetland area (WBK) identified aluminum (NOAEL HQ = 123.1), antimony (NOAEL HQ = 19.5), arsenic (NOAEL HQ = 24.7), lead (NOAEL HQ = 1.6), selenium (NOAEL HQ = 1.5), silver (NOAEL HQ = 1.8), thallium (NOAEL HQ = 53.8), and vanadium (NOAEL HQ = 7.1) with NOAEL HQs in excess of 1.0 in this habitat. LOAEL HQs in excess of 1.0 included aluminum (LOAEL HQ = 12.3), antimony (LOAEL HQ = 12.3), arsenic (LOAEL HQ = 2.5), and thallium (LOAEL HQ = 5.4) in the muskrat exposure evaluation (Table B-4-110).
- The exposure assessment for the Marsh Upland Area identified aluminum (NOAEL HQ = 90.5), antimony (NOAEL HQ = 7.6), arsenic (NOAEL HQ = 4.2), lead (NOAEL HQ = 10.0), total mercury (NOAEL HQ = 2.4), methyl mercury (NOAEL HQ = 132.4), selenium (NOAEL HQ = 2.4), silver (NOAEL HQ = 10.6), and thallium (NOAEL HQ = 8.7) with NOAEL HQs in excess of 1.0 in this habitat. LOAEL HQs in excess of 1.0 included aluminum (LOAEL HQ = 9.1), lead (LOAEL HQ = 1.0), methyl mercury (LOAEL HQ = 79.5), and selenium (LOAEL HQ = 1.4) in the muskrat exposure evaluation (Table B-4-111). The calculated exposure to aluminum, antimony, arsenic, selenium, silver, thallium and vanadium were less than or comparable to the exposures calculated for the Forge Pond background area and were reflective of local conditions. The primary exposure route contributing to the lead, total mercury and methyl mercury exposures was the ingestion of aquatic macrophytes.
- All remaining COPECs had NOAEL and LOAEL HQs less than 1.0.

4.4.9.2 Mammalian Surveys

Results of the mammalian survey did not reveal the presence of the muskrats in the terrestrial, wetland and aquatic habitats of the Eastern Channel Corridor, Lower Drinkwater River Corridor, Upper and Lower Factory Pond at the Site. Habitat present on-Site was deemed to be supportive for muskrats, but their presence was not noted in Northern Drinkwater River or Forge Pond habitats.

Eight mammalian species and evidence of the occurrence of several small mammals (i.e., voles, shrews, and mice) were noted at the Site. Eight mammalian species, including small mammals, were noted along Transect 1 while Transects 2, 4, and 5 yielded five species. Four mammalian species and small mammals were recorded along Transect 3. The on-Site diversity of mammal populations observed during the transect survey were similar to those of reference station observations (Table B-1-7) with values ranging from 0.75-0.92. The lowest diversity index value was in the Central Area transect and the highest diversity index value was in the Southern Area transect.

4.4.10 Reptilian Exposure Assessment

The exposure assessment for reptiles considered a bimodal approach for assessing reptiles. Assessment of terrestrial reptiles utilized belt transect surveys and aquatic reptiles (i.e., freshwater turtles) were surveyed using basking and funnel trapping methods. These approaches were deemed the most appropriate as reptile TRVs for most contaminants are not available or cannot be directly related to an observed effect in field populations.

Three measurement endpoints were used as lines of evidence in the reptilian exposure assessment: (1) reptile abundance observed in the terrestrial habitats; (2) reptile abundance in the aquatic habitats; and (3) determination of an index of condition and health assessment of freshwater turtles captured in the aquatic habitats surveyed. Each endpoint evaluated observations made in the Site aquatic habitats and those observed in the reference area, Forge Pond. Each endpoint was evaluated using the observed trends in Site-related contaminant concentrations in the environmental media of the individual habitats surveyed.

Six reptilian species were observed at the Site. These species included *Thamnophis sirtalis sirtalis* (eastern garter snake), *Diadophis punctatus edwardsi* (northern ringneck snake), *Natrix sipedon sipedon* (northern water snake), *Elaphe obsoleta obsoleta* (black rat snake), *Chrysemys picta picta* (eastern painted turtle), and *Chelydra serpentina serpentina* (common snapping turtle). The black rat snake, a state-listed endangered species in Massachusetts, was observed in the central area of the Site.

4.4.10.1 Systematic Transect Surveys for Reptiles in Terrestrial Habitats

Semi-quantitative belt transect surveys were used to determine the relative abundance of reptiles observed in the terrestrial habitats of the Site to that observed in reference area habitats. Four systematic belt transect surveys were conducted in the on-Site habitats and one belt transect was performed in an off-Site reference habitat located to the north of the Site near Forge Pond. The Site was divided into four major areas for belt transect surveys: northern area, central area, western area and southern area. Transect lengths were 335 m, 1,250 m, 267 m, and 319 m, respectively. The off-site reference transect was located adjacent to Forge Pond along the Upper Drinkwater River and was 396 m in length.

Land use in the northern area was more industrial than in the central or southern areas and the western area remained completely forested. The greatest occurrence of Site-related contaminants in surface soils was associated with the northern and southern areas. Generally, contaminant concentrations were lower in the central area and lowest in the western area where occurrence of contaminants and their concentrations were similar to observed background concentrations.

A total of four reptilian species were observed during the belt transect surveys in Site terrestrial habitats. All of the reptile species encountered during the terrestrial habitat surveys were snakes. No terrestrial turtles (i.e., box turtles or wood turtles) were encountered. The four snake species encountered were the northern water snake, the black rat snake, the eastern garter snake and the northern ringneck snake. Two of these species, the eastern garter snake and the northern ringneck snake, were observed during the systematic transect surveys and the other two were opportunistic observations made during other wildlife surveys. During the systematic transect survey the eastern garter snake was observed once along the reference transect near Forge Pond (the reference station), once in the central area, and three times in the southern area. The northern ringneck snake was observed once in the southern area. No reptile species were observed during the systematic transect survey in the western area or in the northern area.

Observation data were normalized to standard units of search effort for each belt transect. The data normalization effort took into consideration the linear length of the transect and the total search time for each transect. The normalized encounter per unit effort was expressed in units of reptile encounters (of any species) per transect search effort (EPUS). The EPUS was calculated as follows:

$$EPUS = E/(T/D) \qquad \text{(Equation 24)}$$

where:

- EPUS = Rate of reptilian observations (n/Hrs Km^{-1} of transect searched)
- E = The total number of reptile observations (n) per transect
- T = Total search time per transect (Hrs)
- D = Total length of the transect searched (Km)

The southern area had the most encounters per unit search effort (n/HrsKm^{-1}) with 0.45 observations/HrsKm^{-1}, followed by the central area with 0.395 observations/HrsKm^{-1} and the reference area near Forge Pond (0.198 observations/HrsKm^{-1}). No reptiles were encountered in the northern and western area transects. The lack of observations of reptiles along the northern area transect may in part be related to the commercial and light industrial nature of land use in this area, which is subject to vehicular and human traffic. This disturbance would act as a deterrent to reptiles utilizing the limited habitat present. The low rate of reptilian observations in the western area transect was unexpected as this area represented the least disturbed habitat surveyed. The absence of reptilian observations in the western area may be attributable to the significant areas of palustrine wetlands that made the transects difficult to perform. The inability to quietly traverse this area may have alerted basking or roaming reptiles of the approach of the wildlife observers thus allowing them to evade detection.

The SWDI could only be calculated for the southern area where greater than one snake species was encountered. The southern area was determined to have a diversity index of 0.244. The observation of a single species in the remaining areas does not permit the calculation of the SWDI. Across all transects, the observation rate of snake species was low overall for both on-Site and reference area habitats surveyed.

The northern and southern areas have been identified as having the highest levels and widest distribution of contaminants in surface soils associated with historical Site operations. No trend was apparent in regard to the abundance of terrestrial reptiles encountered during the transect surveys. The western area, an area with no history of Fireworks use and high habitat quality, had no observations of terrestrial reptiles. The EPUS and diversity index were lower in the reference location than in the southern area transect on the Site. The absence of reptilian sightings in the northern area may be related to the developed nature of this area and low abundance of terrestrial reptiles across the Site. No trend was apparent in the rate of reptilian observations relative to contamination in the southern and central areas. Thus, the presence of any Site-related contamination is not causing a decrease in terrestrial reptilian diversity or abundance across the on-Site terrestrial habitats.

4.4.10.2 Freshwater Turtle Abundance in the Aquatic Habitats Present on the Fireworks Site

Freshwater turtle species are divided into basking species that routinely leave the water to sun themselves and to lay eggs, and bottom dwelling species that rarely leave the water except to lay eggs (Meyers-

Schone and Walton, 1994). To assess these distinct turtle populations, basking traps and baited funnel traps were deployed in the riverine and pond habitats at the Site and in Forge Pond.

Trap sets were located along a gradient of mercury contamination in the Drinkwater River and Factory Pond study area. In the on-Site habitats surveyed, the most contaminated sediments are associated along a gradient in mercury concentration in the following order: Lower Drinkwater River inlet >Lily Pond>Upper Factory Pond>Lower Factory Pond. It was hypothesized that if impacted, turtle abundance would show an inverse relationship to elevated mercury concentrations in sediments (i.e., a decline in turtle abundance with increasing mercury concentration in sediments). If turtle abundance was not affected by the presence of mercury in the environment, then abundance would show a more random trend across the contamination gradient.

Sampling resulted in the capture of two turtle species from the survey areas, the common snapping turtle (*Chelydra serpentina serpentina*) and the eastern painted turtle (*Chrysemys picta picta*). Both species are indigenous to New England and are among the most abundant reptilian species associated with warm water rivers and ponds in Massachusetts (Babcock, 1971).

The common snapping turtle is the largest freshwater turtle endemic to Massachusetts and grows to a large size with older individuals attaining weights in excess of 20 pounds. They are bottom dwelling turtles and rarely bask, but do leave the water to lay eggs during nesting, which usually occurs in early June (Babcock, 1971). Snapping turtles prefer shallow, soft bottomed, highly productive ponds and rivers with little or no current and prefer to occupy bottom habitats in the depth range of 0.5 to 1.5 meters (Brown et al., 1994; Obbard and Brooks, 1981). This long-lived species has recorded ages of 19 to 24 years in wild populations (Gibbons, 1968; Whitfield-Gibbons, 1968) and captive individuals are estimated to live in excess of fifty years (Pope, 1969). The common snapping turtle is carnivorous in diet and consumes a variety of snails, crayfish, insects, fish and small non-fish vertebrates, such as ducklings, muskrats and snakes. Small fish accounted for the majority of the diet for this species (Hammer, 1969). The non-fish prey types occur in less frequency accounting for less than 1% of the total diet. Hammer (1969) noted that snapping turtle diets appear opportunistic in regards to animal matter and reflect local and seasonal abundance of animal prey availability. Plant matter can be consumed with near equal frequency given a lack of animal prey (Hammer, 1969). Telemetry studies identified the home range of snapping turtles to range from 2.47 to 7.41 acres (1.0 to 3.0 Ha) of surface water body (Obbard and Brooks, 1981). The density of snapping turtles ranges <1 to 1.2 turtles per hectare in northern New England and Ontario populations (Brown et al., 1994; Hammer, 1969). The aquatic habitats of the Lower Drinkwater River, Lily Pond, Upper Factory and Lower Factory Pond contained optimal habitat for this species and were not deemed as limiting the populations present.

Eastern painted turtles are small basking turtles and are the most widely occurring species of basking turtle in New England (Babcock, 1971). Painted turtles prefer shallow, soft-bottomed, highly-productive ponds and rivers with little or no current and dense aquatic vegetation. This species routinely leaves the water for basking and nesting and can spend several hours out of the water during basking (Sexton, 1959). This species lives between 5-7 years in the wild, though longer-lived specimens have been recorded to survive up to 10 years in captivity (Pope, 1969). The painted turtle is omnivorous in diet eating a variety of plant and animal matter. Animal prey includes aquatic invertebrates like snails, aquatic worms, aquatic insects, small crayfish and small fish. Aquatic plants including pondweeds and other aquatic plants can account for up to 40% of the diet in this species (USEPA, 1993). Sexton (1959) reported a home range for this species of 60 to 140 meters and densities of 11.1 to 83 per Ha of surface water body in populations from Michigan and Saskatchewan. Density estimates for this species were extremely clumped around aquatic vegetation and were not homogenous in the habitats sampled (Sexton, 1959). The physical components of the aquatic habitats of the Lower Drinkwater River, Lily, Upper Factory and

Lower Factory Ponds contained good habitat for this species and were not determined to be limiting for the populations present in Lily and Factory Ponds.

4.4.10.2.1 Turtle Basking Trap Survey Results

The eastern painted turtle was the only species caught in the basking traps deployed on the Site. In the reference station one turtle, a common snapping turtle, was captured.

The field monitoring data summaries for the basking trap survey are summarized in Tables B-1-13 and B-1-16. One adult common snapping turtle was caught in the Forge Pond reference location.

A total of ten adults and two juvenile eastern painted turtles were captured in Lily Pond. Of these twelve turtles, two individuals were recaptured in the same trap during the survey. Twelve eastern painted turtles representing nine adults and three juveniles were captured in Upper Factory Pond, and three adult eastern painted turtles were captured in Lower Factory Pond. Because of the lack of recaptures, population sizes could not be estimated.

To normalize the capture data to uniform unit effort basis, capture rates were calculated for each location using the equation:

$$CR = n / TR \qquad \text{(Equation 25)}$$

where:

- CR = capture rate (turtles/trap hour)
- N = Total number of turtles captured (n)
- TR = Total hours of trap deployment (hrs)

Basking trap capture rates for all turtles are summarized in Table B-1-15. Capture rates for the basking traps ranged from 0.001-0.107 turtles/trap-hour. The highest rate of capture was in Upper Factory Pond (0.107) followed by Lily Pond (0.094), Lower Factory Pond (0.030) and finally Forge Pond (0.001). The low capture rate in Forge Pond may be a reflection of habitat structure where an abundance of submerged logs and rocks afforded a significant number of basking areas relative to the trap. Visual observations made from the shoreline of Forge Pond confirmed the presence of painted turtles in Forge Pond.

The low capture rate at the reference station makes analysis of abundance in on-Site traps difficult. However, no apparent trend exists between the observed contamination gradient and abundance of painted turtles on-Site, suggesting that contamination levels in Site sediments are not affecting the abundance of basking turtle species like the eastern painted turtles.

4.4.10.2.2 Turtle Funnel Trap Survey Results

Similar to the basking trap data, the eastern painted turtle and the common snapping turtle were the only turtle species captured. A nearly even 1:1 ratio of common snapping turtles and eastern painted turtles was captured in Site habitats whereas only snapping turtles were captured in the reference location. A summary of the field observations for the funnel trap effort can be found in Tables B-1-14 and B-1-17. No turtles were captured in the funnel traps set in Upper Factory Pond or the Lower Drinkwater River inlet. Similar to the basking trap effort, the snapping turtle was the only species captured in the funnel trap at the reference station.

To account for the sampling effort applied at each trap location, abundance data were normalized on a catch per unit effort basis (i.e., turtles/trap hour). Snapping turtle catches ranged from 0 to 0.028 turtles per trap hour in the habitats sampled. The reference station in Forge Pond had a capture rate of 0.026 turtles/trap hour. Moving in a downstream direction the capture rate dropped to 0 captures/trap hour in the Lower Drinkwater River, 0.006 captures/trap hour in Lily Pond, 0 captures/trap hour in Upper Factory Pond and recovered to 0.026 captures/trap hour in Lower Factory Pond.

Conversion of capture data to a unit of density as the sum of total individual turtles captured (excluding recapture data) per unit surface area of each of the habitats ranged from 0 to 0.45 snapping turtles per hectare of water surface. The highest density of snapping turtles was observed in the reference area of Forge Pond where density was estimated to be 0.45 snapping turtles per hectare and corresponds to the lower density range for this species reported from other habitats (Brown et al., 1994; Hammer, 1969). No snapping turtles were collected from the Lower Drinkwater River and density of snapping turtles in Lily/Upper Factory Pond was reduced to 0.09 snapping turtles/Ha. In Lower Factory Pond, the density of this species showed a recovery to densities similar to those observed in Forge Pond. Density of snapping turtles in Lower Factory Pond was 0.37 snapping turtles/Ha.

Relative to observed environmental gradients for mercury in sediments, snapping turtles were absent or showed lower capture rates and densities in the Drinkwater River Inlet and Lily/Upper Factory Pond, and increased in Lower Factory Pond to densities similar to those in the reference habitat. The observed decline in turtle abundance in the Lower Drinkwater River, Lily Pond and Upper Factory Pond corresponded to an increase in total mercury concentrations in sediments, suggesting a negative effect of mercury on turtle abundance at the Site. Albers et al. (1986) noted that along a mercury gradient where concentrations of mercury in sediments averaged 107.0 mg/Kg, snapping turtles were absent within the most contaminated area and densities recovered as mercury contamination subsided with distance from the suspected source. The exact cause for the absence of this species could not be determined but was suspected of being related to either toxic effects or a decrease in habitat value for use by this species (Albers et al., 1986). Golet and Haines (2001) noted that snapping turtles bioaccumulated mercury in most tissues but that snapping turtles may be able to eliminate mercury from body tissues at a greater rate than fish. Golet and Haines (2001) noted that piscivorous fish and snapping turtles collected from the same ponds revealed that piscivorous fish carry a higher body burden of mercury than the longer-lived snapping turtles.

4.4.10.3 Turtle Index of Condition and Health Assessment

The third measurement endpoint evaluated the relative health of the turtle populations surveyed through calculation of an index of condition similar to those applied to fish populations and performance of a health assessment based upon incidence of disease or parasitism between on-Site and reference area populations of turtles.

To assess the incidence of disease, each turtle captured in a basking or funnel trap was examined for the occurrence of the following conditions:

- Shell rot or shell disease (Lovich et al., 1996)
- Metabolic bone disease (Lewbart, 2001; Sparling et al., 2000)
- Deformed carapace or plastron scutes or shell structure (de Solla et al., 1998)
- External tumors or neoplasia (Sparling et al., 2000)
- Algae on the carapace
- Presence of ectoparasites (Klemm, 1985)

Because mercury is known to suppress the immune system in reptiles (Sparling et al., 2000), it was hypothesized that such a suppressive effect can manifest itself through a higher incidence of abnormal development or incidence of disease in exposed populations, such as:

Shell rot or shell disease is an opportunistic bacterial infection of the outer shell in freshwater turtles resulting in the deterioration of bone beneath the carapace or plastron scutes. The deterioration of the bone results in lesional pitting of the shell and subsequent infection of the underlying soft tissues (Lovich et al., 1996).

Metabolic bone disease is a nutritional disorder related to calcium metabolism that results in changes to skeletal structure and function. The primary causative agent is related to calcium deficiency in the diet or metabolic depletion/excess excretion of calcium. Effects of this disorder in turtles include abnormal calcification or distortion of carapace plates, fractured sutures between carapace or plastron plates and soft-shells (Sparling et al., 2000).

Missing or deformation of scutal plates of the carapace and plastron, missing tails and abnormal limb development in hatchling snapping turtles has been noted in snapping turtle populations exposed to bioaccumulating compounds (de Solla et al., 1998).

Neoplasic tumors have been observed in snapping turtles and other turtle species. Development of such growths remains poorly understood but may be linked to internal parasite load, opportunistic infection by viruses or soft-tissue tumor formation for exposure to toxic substances (Sparling et al., 2000).

Ectoflora such as filamentous algae and ecto-fauna such as leeches are common to both basking and bottom dwelling turtles. Several leech species (i.e., *Placobdella parasitica, P. ornata,* and *P. papillifera*) are host specific to freshwater turtles (Klemm, 1985). Their presence typically is not a detriment to the host but they are a common characteristic in native populations. Incidence of algae on the shells and the presence of leeches on turtles were observed to be 100% in sampled populations (Klemm, 1985).

The index of condition relating body weight and carapace length was calculated for each turtle species collected and was calculated as follows:

$$IC = W/L \qquad \text{(Equation 26)}$$

where:

- IC = Index of Turtle Condition (lb/inch)
- W = Turtle weight (lb)
- L = Carapace length (inch)

Interpretation followed methods applied in fish populations where an overall reduction in physical condition is reflected by a decline in the index of condition. All turtles collected by both funnel and basking traps were assessed by trap area.

4.4.10.3.1 Eastern Painted Turtles

No eastern painted turtles were captured in basking or funnel traps in the reference location (Forge Pond) or in the Lower Drinkwater River. Therefore, all comparisons of the health of eastern painted turtles were made between turtles captured in Lily, Upper Factory, and Lower Factory Ponds. Data collected on the index of condition and assessment of health of captured eastern painted turtles in Forge Pond, Lily Pond, and Upper and Lower Factory Pond can be found in Table B-1-18.

Indices of condition were similar in all three locations: Lily Pond (0.120), Upper Factory Pond (0.107), and Lower Factory Pond (0.107). On average, painted turtles captured in Lily Pond were slightly more robust. No clear relationship exists between the degree of sediment contamination and indices of condition for painted turtles captured in aquatic habitats on the Site. The lack of painted turtle captures in the reference area prevented comparison to a reference population.

Frequency of ectoparasitism was lowest in Lily Pond (7%) with leeches found on one of the fourteen captured painted turtles. The highest frequency of ectoparasitism was in Upper Factory Pond (33%) with leeches found on four of the twelve turtles. Lower Factory Pond had an intermediate frequency of ectoparasitism (13%) with leeches found on one of the eight turtles captured. No clear relationship exists between the degree of contamination and the frequency of ectoparasitism for painted turtles captured in the aquatic habitats on the Site. The absence of painted turtle captures in the reference area prevented comparison to a reference population.

The incidence of disease may be an indication of the immunological health of an animal population. One type of disease (shell rot or shell disease) was present in the turtles captured in Lily Pond with an incidence of 21%. Upper Factory Pond had the highest incidence of shell rot (25%) and the only occurrence of algal growth on the carapace (17%). The lowest incidence of shell rot was in Lower Factory Pond with a frequency of 13%. A slightly positive relationship exists between the degree of contamination and the frequency of shell rot for painted turtles at the Site. The absence of painted turtle captures in the reference area prevented comparison to a reference population.

Severity of shell disease has been studied in other turtle populations. In turtle populations where shell rot was determined to be severe, incidence of shell rot ranged from 35% to 74% in river cooters (*Pseudemys concinna*) and yellow-bellied sliders (*Trachemys scripta*) surveyed in Lake Blackshear, Georgia (Lovich et al., 1996). Snapping turtles collected by Lovich et al. (1996) did not show any shell rot infection in the same pond as the river cooters or yellow-bellied sliders. The increase in shell disease was not determined to have affected the population structure of the turtle species infected. Lovich et al. (1996) hypothesized that the presence of shell rot may be attributable to toxic or immunosuppressive chemicals or a dietary deficiency. The incidence of shell disease in painted turtles was negligible and not considered problematic.

4.4.10.3.2 Common Snapping Turtles

Common snapping turtles were captured in Forge Pond (four individuals), Lily Pond (one individual), and Lower Factory Pond (four individuals). No snapping turtles were captured at the Lower Drinkwater River or Upper Factory Pond locations. Because only one turtle was captured in Lily Pond, statistical comparison to Forge and Upper Factory Pond is difficult. Data collected on the index of condition and assessment of health of captured common snapping turtles in Forge Pond, Lily Pond, and Upper and Lower Factory Pond can be found in Table B-1-18.

The index of condition (as calculated in Equation 26) is a measurement of the robustness of an animal. Indices of condition were similar for all three locations, with the highest ratio in Forge Pond (1.10) followed by Lily Pond (0.99) and Lower Factory Pond (0.91). This suggests that where snapping turtles were captured, no overt impact on animal robustness was apparent.

Frequency of ectoparasitism was highest in Forge Pond with leeches found on three out of five snapping turtles (60%). No ectoparasitism was evident for the snapping turtle captured in Lily Pond (0%) and one out of four snapping turtles captured in Lower Factory Pond (25%) had leeches. When present, the leeches (*Placobdella* sp.) were attached to a front or rear limb. Ectoparasitism occurred on snapping turtles with a higher frequency in the reference location than in Site aquatic locations. Klemm (1985) indicated that ectoparastism of host turtle by the leech genus *Placobdella* was very common.

The incidence of disease is an indication of the immunological health of an animal population. Out of the five snapping turtles captured in Forge Pond no evidence of shell rot, metabolic bone disease, neoplasia, or shell deformity was observed (0%).

The single snapper collected from Lily Pond had shell rot and deformity. This individual had a 2 cm in diameter pit in the carapace (shell rot) and a single deformed tail scute. Snapping turtles from Lower Factory Pond had the highest incidence of metabolic bone disease (25%) and neoplasia (25%), as one of the four turtles captured at this location had a dorsal-lateral fracture along the carapace sutures on the anterior portion of the carapace and a soft tumor on its lower jaw. This turtle also had 5 deep (to soft tissue) shell pits in the carapace (shell rot) making the occurrence of shell rot in Lower Factory Pond 25%. A causal relationship between the degree of contamination and the abundance and incidence of disease in snapping turtles is difficult to assess given the low number of turtles captured. However, comparison between turtles captured in Forge Pond and those from the two on-Site locations reveals a higher incidence of disease in snapping turtles captured in aquatic habitats on the Site and a lower abundance noted in areas of higher mercury contamination.

4.5 Amphibian Assessment (Assessment Endpoint #14)

Assessment endpoint #14 is the protection and sustainability of amphibian populations and communities in Factory and Lily Ponds, Drinkwater River, and Marsh Upland Area wetland habitat. Three measurement endpoints considered included: (1) comparison of surface water data to amphibian benchmark values; (2) terrestrial and aquatic surveys for amphibian species; and (3) frog/toad audio callback surveys.

Direct and indirect observations of reptile and amphibian species were recorded when conducting transect surveys as well as when incidentally observed during other field activity. Amphibian species observed included: *Plethodon cinercus cinurcus* (red-backed salamander), *Rana clamitans melanota* (green frog), *Rana catesbeiana* (bullfrog), *Rana sylvatica* (wood frog), *Rana pipiens* (northern tree frog), *Bufo americanus* (American toad), and *Scaphiopus holbrooki holbrooki* (eastern spadefoot toad).

4.5.1 Surface Water Benchmark Comparison for Amphibian Protection

Surface water samples were taken throughout the riverine and pond habitats on-Site and in the Northern Drinkwater River and Forge Pond reference stations (Plate 1 in the CSA). The maximum and average values for samples taken from each riverine and pond site from Phase IIC and Phase IID data collection efforts can be found in Tables B-4-112 and B-4-113 along with corresponding screening level values for the protection of aquatic metamorphic amphibious life. The selected chronic and acute benchmark values used in the screening for copper, mercury, and zinc were the 10th and 50th percentile from NFESC (2003). The selected chronic and acute benchmark values used in the screening for lead were the total metal no observable effect concentration (NOEC) and lowest observable effect concentration (LOEC) from NFESC (2003).

None of the metals screened exceeded the chronic or acute benchmark values for amphibians from NFESC (2003) in the riverine pond sites sampled (Tables B-4-112 and B-4-113).

All on-Site contaminant surface water concentrations in the riverine and pond habitats were comparable to concentrations measured in the Northern Drinkwater River and Forge Pond, respectively. This indicates that the levels of copper, mercury, zinc, and lead in the surface water in the Site are reflective of local conditions. Therefore, ambient levels of metals in surface water do not indicate an excessive exposure to amphibian species from historical Site activities.

4.5.2 Amphibian Systematic Transect Survey

Eight species of amphibians were observed in the systematic transect survey. Species abundance per transect ranged from one to seven with the lowest species abundance in the Central Area and the highest in the Southern Area. In the Central Area the only species observed was the red-backed salamander. In the Northern Area, three species were observed including the red-backed salamander, the wood frog, and the gray tree frog. In the Western parcel, five species were observed. Abundance in this parcel was dominated by the wood frog. Other species observed included two other ranid species and two species of toads. At the Forge Pond reference station, five species were observed and red-backed salamanders dominated abundance in this area. Finally, in the Southern Area, seven species were observed. Species abundance was evenly distributed over seven of the eight species found overall at the Site. Forge Pond had the largest number of encounters per unit searched (66) followed by the Southern Area (45), the Northern Area (44), the Central Area (26), and the Western Parcel (19). The SWDI values for the five transects ranged from 0 to 0.8 with the lowest diversity occurring in the Central Area and the highest in the Southern Area.

The ratio of tree frogs (spring peeper and the gray tree frog) to ranid species (green frog, bullfrog, and wood frog) is often used as an indication of chemical or physical disturbance (Micacchion, 2002). As a relative trend, chemical or physical disturbance will cause the tree frog population to decline and the ranid population to increase. The ratio of tree frogs to ranids ranged from 0 to 2. The tree frog population was dominant in the Northern Area (ratio = 2) whereas the ranid population was dominant in the Western Parcel (ratio = 0) (0 tree frogs and 7 ranids), the Southern Area (0.6), and Forge Pond (0.33). No tree frogs or ranid species were found in the Central Area. This may be related to more upland habitat being present along transect routes.

4.5.3 Frog/Toad Audio Call Back Survey

The calls of five species of frogs and toads were identified throughout the six areas. Species distribution by area can be found in Table B-1-9. No calls were heard in the reference area, the Drinkwater River, or the Lower Drinkwater River. Three species calls were heard in the Upper Pond, which included two ranid and one tree frog species. Three species calls were also heard in the Lower Pond, which included one ranid and two toad species. Finally, two species calls were heard in the Marsh Upland, which included one ranid and one toad species. The SWDI was lowest in the Marsh Upland Area (0.29) and higher in the Upper (0.45) and Lower (0.48) Factory Ponds. The Upper Factory Pond station was the only area any tree frog calls were heard.

4.6 Terrestrial Plant, Soil Invertebrate, and Soil Microbial Processes Assessment (Assessment Endpoint #15)

Assessment endpoint #15 was the protection and sustainability of terrestrial plants, soil invertebrates, and soil microbial processes in the surface soils present on the Site. Three measurement endpoints were used as lines of evidence in this assessment endpoint: (1) comparison of concentrations of COPECs in surface soils to reference area concentrations; (2) comparison of concentrations of COPECs in surface soils to benchmarks for the protection of terrestrial plants; and (3) comparison of COPECs in surface soils to benchmarks for the protection of soil invertebrates and microbial processes.

4.6.1 Reference Station and Soil Benchmark Comparison

The reference habitat and soil benchmark comparison for surface soils can be found in Table B-4-114.

Mean and maximum concentrations of 2-methylnaphthalene, naphthalene, methyl mercury, cyanide, 4-nitrophenol, acenaphthene, 2,4,6-trinitrotoluene, fluorene, beryllium, 2,4-dinitrotoluene, 2-amino-4,6-dinitrotoluene, 4-amino-2,6-dinitrotoluene, and dibenzofuran did not exceed reference station concentrations. As a result, concentrations of these analytes on the Site were considered reflective of local conditions and eliminated as potential COPECs to the protection and sustainability of invertebrates, plants, and soil microbial processes. Analytes that did not have benchmark values or that exceeded both reference station concentrations and benchmark values were included in the benchmark screening to be protective of terrestrial plants, soil invertebrates, and soil microbial processes. Mean concentrations of cis-1,2-dichloroethene, trichlorethene, toluene, butylbenzylphthalate, antimony, chromium, copper, lead, mercury, nickel, and selenium exceeded benchmark values at one or more of the on-Site locations and were not considered reflective of local conditions (exceeded reference concentrations by more than one order of magnitude). Exceedances were mainly located in the Southern Disposal, Upper North, and Marsh Upland Areas.

Surface soil analyte concentrations in the Cold Waste Area that exceeded soil benchmark values in the Cold Waste Area also exceeded reference station concentrations by an order of magnitude for a number of analytes (Table B-4-117). These analytes included cyanide, antimony, arsenic, barium, cadmium, chromium, cobalt, copper, lead, mercury, nickel, sodium, and zinc, 2-methylnapthalene, acenaphthylene, chrysene, dibenzofuran, biethylphthalate, fluorine, hexachlorobenzene, and naphthalene.

4.6.2 Terrestrial Plant Benchmark Screening

The reference station and terrestrial plant benchmark comparison for surface soils can be found in Table B-4-115. Reference station and soil invertebrate / microbial processes benchmark comparison for surface soils can be found in Table B-4-123. Benchmarks for soil invertebrates are conservative values that include the protection of soil microbial processes. Eco-SSL terrestrial plant benchmark values from USEPA (2003) were applied where available. Where these values were not available the ORNL terrestrial plant values from Efroymson et al. (1997a) were applied. For soil invertebrate / microbial process benchmarks the Eco-SSL soil invertebrate benchmark values from USEPA (2003) were applied where available. Where these values were not available the ORNL soil invertebrate values from Efroymson et al. (1997b) were applied.

Terrestrial plant and soil invertebrate benchmark values were unavailable for 2-nitrotoluene, nitroglycerin, pentaerythritol tetranitrate PETN, iron, magnesium, butylbenzylphthalate, carbazole, acenaphthylene, anthracene, benzo(a)anthracene, benzo(a)pyrene, benzo(b)fluoroanthene, benzo(g,h,i) perylene, benzo(k)fluoroanthene, chrysene, dibenz(a,h)anthracene, di-n-octylphthalate, fluoroanthene, indeno(1,2,3-cd)pyrene, phenanthrene, pyrene, total PAHs, 1,2-dichloroethene (total), 2-butanone, bromomethane, cis-1,2-dichloroethene, freon (total), and vinyl chloride. Terrestrial plant benchmarks were also unavailable for aluminum and antimony and soil invertebrate benchmarks were unavailable for manganese, silver, thallium, and vanadium. Because no benchmark values were available, and they exceeded reference station concentrations, these analytes should be considered for further analysis.

Terrestrial plant benchmark values were not exceeded by mean and maximum soil analyte concentrations of arsenic, cadmium, and methyl mercury. Maximum concentrations of manganese exceeded the benchmark value at two of the eight sites. Mean and maximum concentrations of barium, chromium, copper, lead, mercury, nickel, selenium, silver, and zinc exceeded terrestrial plant benchmark values at one or more of the eight sites. Exceedances were mainly located in the Southern Disposal Area (eight exceedances) and in the Southern Conservation Area, Marsh Upland Area, and Upper North Area (two exceedances each). Because these analytes exceed both reference station concentrations by an order of magnitude and benchmark values they are considered potential COPECs and may compromise the sustainability of terrestrial plants on the Site.

All analytes that exceeded benchmark values in the surface soil benchmark comparison were included for comparison to the terrestrial plant, soil invertebrate, and soil microbial processes benchmark values. Benchmark values protective of terrestrial plants utilized for this comparison included USEPA (2003a) and Efroymson et al. (1997a). Metals exceeding terrestrial plant benchmark values included aluminum, antimony, barium, chromium, cobalt, copper, lead, manganese, mercury, nickel, selenium, thallium, vanadium, and zinc (Table B-4-114 and Table B-4-117). Benchmark values protective of terrestrial plants were not available for cyanide, magnesium, or any of the SVOCs.

4.6.3 Terrestrial Invertebrate Benchmark Screening

Soil invertebrate benchmark values were not exceeded by mean and maximum soil analyte concentrations of arsenic, cadmium, lead, and selenium. The maximum concentration of methyl mercury exceeded the benchmark value at one of the eight sites. Mean and maximum concentrations of aluminum, antimony, barium, chromium, copper, mercury, nickel, and zinc exceeded soil invertebrate benchmark values at one or more of the eight sites. Exceedances were concentrated in the Southern Disposal Area (6), Southern Conservation Area (3), Marsh Upland Area (2), and Upper North Area (2). Concentrations of aluminum were considered reflective of local conditions. Because these analytes exceed both reference station concentrations and benchmark values they are considered potential COPECs and may compromise the sustainability of soil invertebrates and microbial processes at the Site.

Benchmark values protective of soil invertebrates and soil microbial processes utilized for this comparison included USEPA (2002a) and Efroymson et al. (1997b). Metals exceeding soil invertebrate and soil microbial process benchmark values included antimony, barium, chromium, copper, lead, manganese, total mercury, nickel, vanadium, and zinc (Table B-4-116 and B-4-118). Benchmark values protective of soil invertebrates and soil microbial processes were not available for cyanide, arsenic, magnesium, thallium or any of the SVOCs.

5.0 ENVIRONMENTAL RISK CHARACTERIZATION

5.1 Assessment Endpoint #1 Protection and Sustainability of Benthic Macroinvertebrate Communities in Aquatic and Wetland Habitats

Six measurement endpoints were used as lines of evidence in characterizing risks for this assessment endpoint. These included: (1) comparison of sediment analyte concentrations to reference station concentrations and MADEP sediment benchmark values; (2) assessment of the acid volatile sulfide and bioavailability and toxic potential of soluble extractable metals present in the sediments; (3) comparison of sediment pore-water total mercury and methyl mercury concentrations with surface water threshold values for the protection of aquatic life; (4) bioaccumulation testing evaluation for *Lumbriculus variegatus* to determine Site-specific sediment to biota bioaccumulation factors for metals in sediments; (5) assessment of benthic macroinvertebrate communities present in aquatic habitats; and (6) toxicity testing of sediments in the aquatic habitats. Lines of evidence are summarized in the following sections.

5.1.1 Sediment Reference Station Comparisons and Sediment Benchmark Screening

References station comparisons and benchmark screening revealed the following:

- Sediment benchmark exceedances by 1,1-dichloroethene, trans-1,2-dichloroethene, trichlorethene, endrin aldehyde, endrin ketone, and antimony in the riverine habitat were determined to present a low risk to benthic communities in the Eastern Channel Corridor and Lower Drinkwater River.
- Metals including lead, mercury and zinc were associated with the largest number of background exceedances and exceedances of the TEC and PEC values in on-Site sediments. Pesticides, PCBs and PAHs were present in the sediments but were comparable to or only marginally elevated to background concentrations and not considered problematic. The volatile organic compounds 1,1-dichloroethene, trans-1, 2-dichloroethene and trichloroethene were detected in on-Site sediments at ECCTRA12 at concentrations above background concentrations.
- The highest concentrations of mercury and methyl mercury in sediments were identified in the Eastern Channel and the Lower Drinkwater River. Concentrations of both of these contaminants remained lower in sediments of the pond habitats in comparison to riverine habitats.
- Habitat wide exceedances of the TEC and PEC by total mercury in the riverine, pond, and wetland habitats indicated a potential risk to benthic community structure in all Site aquatic habitats.

Results of the sediment benchmark comparison revealed total mercury to be the most widely distributed of the contaminants present. To a lesser degree, lead and zinc also displayed elevated concentrations in excess of the upper threshold value (i.e., PEC) at isolated locations. The habitat wide exceedances of both the background concentration and the TEC and PEC identified potential risk to benthic communities from total mercury.

This measurement endpoint was characterized as having a moderate significance as the evaluation relied upon the use of generic sediment benchmarks deemed protective of benthic communities without consideration of Site-specific geochemistry or toxicological evaluations for the sediments in question.

5.1.2 Bioavailability and Toxic Potential of Soluble Extractable Metals

An evaluation of SEM levels yielded the following:

- The evaluation revealed that the metals in the sediments at ECCTRA11 from the Eastern Channel were bioavailable to the benthic macroinvertebrate community present.
- The evaluation indicated that the select metals in the sediments in the pond location MLFPTRA11 were bioavailable to the benthic macroinvertebrate community present.
- The evaluation indicated that the metals present in the sediments from all other aquatic habitats were not bioavailable to the benthic macroinvertebrate community present.
- The toxic potential of the metals present in all aquatic habitats of the Site implied a low potential of toxic effects on the benthic macroinvertebrate community present.
- Divalent metals, including cadmium, copper, lead, nickel, silver, zinc, and mercury, were predicted to be non-bioavailable for direct incorporation into tissues based upon a direct contact pathway. One area of the Eastern Channel Corridor (station ECCTRA11) had a concentration of soluble extractable metals in excess of the reactive sulfides present, indicating metals in the sediments at this location are bioavailable (SEM/AVS ratio = 266). One location in Lower Factory Pond (station MLFPTRA11) station displayed a marginal degree of bioavailability (SEM/AVS ratio = 1.94) associated with soluble extractable metal concentrations.
- The combined mitigating effect of available reactive sulfides and organic carbon (i.e., (SEM/AVS)/f_{oc}) indicated that none of the divalent metals (including total mercury) in the sediments was predicted to be toxic to infaunal organisms.

Results of this measurement endpoint revealed that metals (including mercury) were limited in bioavailability to one area (ECCTR11) in the Eastern Channel Corridor and marginally at one location (MLFPTRA11) in the MLFP. However, mitigating factors of reactive sulfide and total organic carbon rendered these areas as being non-toxic to benthic communities based upon the direct contact pathway.

This measurement endpoint was characterized as having a high significance as the evaluation considered chemical and Site-specific conditions that directly address bioavailability and toxicity. The SEM/AVS relationship evaluation has been demonstrated to be a reliable tool in identifying sediments containing heavy metals that are potentially toxic to infaunal organisms.

5.1.3 Screening of Mercury and Methyl Mercury in Sediment Pore-Water with Surface Water Threshold Values

The pore water evaluation screening yielded the following:

- Sediment pore-water concentrations of total mercury exceeded acute and chronic AWQC in all Site aquatic habitats.
- Sediment pore-water concentrations of methyl mercury exceeded acute AWQC in all aquatic habitats present on the Site.
- A positive, linear correlation was identified between total and methyl mercury concentrations measured in all habitats, with the Eastern Channel Corridor station being most highly correlated.

- No spatial trend for total and methyl mercury concentration levels within each habitat was apparent.
- Total and methyl mercury concentrations were higher in sediment pore-water in the riverine habitats of the Eastern Channel Corridor and Lower Drinkwater River Corridor.

Results of the evaluation revealed that pore water concentrations of total mercury and methyl mercury exceed acute and chronic screening benchmarks deemed protective of aquatic life if exposed directly. Mercury pore water concentrations also exceeded surface water screening level values for protecting piscivorous wildlife from exposure via food chain bioaccumulation through the surface water pathway.

This measurement endpoint was characterized as having a moderate significance as the evaluation considered chemical and Site-specific conditions that directly address bioavailability and toxicity.

5.1.4 Bioaccumulation Evaluation with the Aquatic Earthworm *Lumbriculus variegatus*

Results from the bioaccumulation study indicated the following:

- Body burden concentrations of total and methyl mercury were elevated one order of magnitude above reference station concentrations in all aquatic habitats on the Site.
- Bioaccumulation of all other metals revealed concentrations similar to concentrations in aquatic earthworms evaluated at the background station for each habitat.
- The greatest bioaccumulation of total mercury in aquatic earthworms was observed for sediments from ECCTRA10 (1,220 nannogram/gram [ng/g]) and ECCTRA11 (3,150 ng/g total mercury) in the Eastern Channel Corridor and LDCTRA10 (1,460 ng/g) and LDCTRA11 (885 ng/g) in the LDR. Bioaccumulation of methyl mercury by aquatic earthworms displayed similar trends as total mercury with higher concentrations being noted at the above locations.
- The bioaccumulation of total mercury in aquatic earthworms was lower in the pond and wetland habitats than that observed in riverine sample stations. Total mercury in aquatic earthworm tissues displayed a decreasing trend in aquatic earthworm body burden in moving downstream from the Eastern Channel Corridor. Body burden concentrations in Lily Pond/Upper Factory Pond were slightly higher (244 ng/g at LUFPTRA10 and 263 ng/g at LUFPTRA11) than that observed from Middle/Lower Factory Pond (208 ng/g at MLFPTRA10; 198 ng/g at MLFPTRA11 and; 103 ng/g at MLFPTRA12). The concentration of methyl mercury in aquatic earthworm tissues was observed to be similar in the ponds (2.75 to 4.75 ng/g) with the exception of 15 ng/g at LUFPTRA11 which exhibited slightly higher body burden concentrations.
- Bioaccumulation of total mercury and methyl mercury from Marsh Upland Area sediments by aquatic earthworms confirmed that both mercurial forms are capable of being bioaccumulated and introduced into the aquatic food chain. Concentrations of other metals remained comparable to uptake by aquatic earthworms exposed to wetland reference sediments.
- Bioaccumulation studies with aquatic earthworms confirmed the existence of a complete pathway for total mercury and methyl mercury introduction into the aquatic food chain. The Eastern Channel Corridor and Lower Drinkwater River sediments were associated with the highest concentrations of total mercury and methyl mercury in aquatic earthworm tissues. A gradient of declining body burden concentrations was observed in earthworm tissues in moving downstream from the Eastern Channel Corridor.

Results of the evaluation confirmed that sediment ingestion by deposit feeding invertebrates is a major link for the introduction of total mercury and methyl mercury into the aquatic food chain. This confirmation links directly the mercury sequestered in the sediment with the observed bioaccumulation in the aquatic food chains in the Eastern Channel Corridor, Lower Drinkwater River Corridor, Lily Pond/Upper Factory Pond, and Middle/Lower Factory Pond.

This measurement endpoint was characterized as having a high significance as the evaluation quantitatively measured bioaccumulation of metals (including total mercury) and methyl mercury in a representative infaunal organisms.

5.1.5 Benthic Macroinvertebrate Community Structure and Function

5.1.5.1 Riverine Habitats

Benthic macroinvertebrate community studies in riverine habitats showed the following:

- Taxa richness in the riverine benthic community displayed a minor decline at ECCTRA12, LDCTRA11 and LDCTRA10.
- Mean taxa richness on a replicate basis followed a similar trend as total taxa richness with minor declines being noted at ECCTRA12, LDCTRA11 and LDCTRA10. This decline was determined to be statistically significant.
- Community density displayed wide variation across the riverine habitats sampled. Increases in density were noted at ECCTRA12 and ECCTRA10. The observed increases at LDCTRA11 and LDCTRA10 in the Lower Drinkwater River Corridor were not statistically significant.
- The community loss index revealed the greatest dissimilarity to be between LDCTRA11 and LDCTRA10 and the Northern Drinkwater River reference community. Mean weighted pollution tolerance values displayed a greater pollution tolerant community at ECCTRA12.
- The SWDI declined by two thirds at ECCTRA12 and by one third at LDCTRA11 and LDCTRA10 in comparison to the Northern Drinkwater River reference community.
- The ratio of Chironomidae to Oligochaeta displayed wide variation across the riverine habitats sampled. Decreases in this ratio from the reference community were noted at ECCTRA12 and LDCTRA11. An order of magnitude increase in the ratio was noted at ECCTRA11.
- Representation by the sub-family Chironominae displayed a decline at all stations sampled from the Eastern Channel and Lower Drinkwater River relative to the reference station.
- Structural composition of the benthic community displayed wide variation in the area sampled with declines in all taxa except oligochaeta and isopoda at ECCTRA12.
- Community structure appears unaltered; however, the functional guild relationships within the Eastern Channel Corridor, Lower Drinkwater River Corridor, and Marsh Upland Area benthic communities appeared altered.

5.1.5.2 Pond Stations

Benthic macroinvertebrate community studies in pond habitats showed the following:

- Taxa richness and Shannon-Weiner diversity of the benthic community sampled from Lily/Upper Factory Pond and Lower Factory Pond displayed a similar or more diverse benthic community than observed at the reference station. The only exception was noted at MLFPTRA10 where Shannon Weiner diversity declined by one third from that observed at the Forge Pond reference station.
- Mean taxa richness on a replicate basis declined at LUFPTRA10, MLPTRA12 and MLFPTRA10 in comparison to the Forge Pond reference community.
- Community density displayed wide variation across the pond habitats sampled. Lower densities overall were noted at LUFPTRA10 and MLFPTRA12 compared to that observed in the reference communities present in the Forge Pond reference community.
- The community loss index revealed the greatest dissimilarities between LUFPTRA10, MLFPTRA12 and MLFPTRA10 and the reference community. The mean weighted pollution tolerance value for the communities present in Lily/Upper Factory Ponds and Lower Factory Ponds remained comparable to that observed in the reference community of Forge Pond.
- The SWDI showed slight declines at LUFPTRA10 and MLFPTRA10 when compared to the reference community.
- The ratio of Chironomidae to Oligochaeta displayed wide variation across the pond sampling stations. A shift in the ratio from an oligochaeta-dominated community to a chironomid dominated community was identified at LUFPTRA11, MLFPTRA12 and MLFPTRA10.
- Representation by the sub-family Chironominae remained comparable with the reference station at most of the pond sampling stations. The only exception was at MLFPTRA12 where no chironomids from the sub-family chironominae were observed.
- Though community structure appears altered, functional guild relationships within the benthic community remain similar.

5.1.5.3 Wetland Habitats

Benthic macroinvertebrate community studies in wetlands showed the following:

- Taxa richness, Shannon-Weiner diversity and mean taxa richness were similar between the Marsh Upland Area and reference wetland community.
- Density of benthic macroinvertebrates in the Marsh Upland Area wetland was triple that observed in the reference wetland community. The Marsh Upland Area wetland displayed a 63% community loss relative to the taxa assemblage present in the reference wetland.
- A distinct shift in the ratios of chironomids and oligochaetes in the communities was apparent with the Marsh Upland Area wetland community supporting fewer oligochaetes than the reference wetland. The sub-family chironominae was also absent from the Marsh Upland Area benthic taxa assemblage.
- The reference wetland and Marsh Upland Area wetland only shared 13% of the taxa identified at both stations. Trophic similarity between the stations was 60%. Trophic similarities of <25% are considered to be representative of a highly altered benthic

community. Though community structure appears altered, functional guild relationships within the benthic community remain intact.

Results of the benthic community surveys of the riverine, pond and wetland habitats indicate that the benthic community structure was altered along the gradient of observed sediment contamination. This alteration appears to take the form of shifts in invertebrate taxa from a worm dominated community to a more insect-dominated community. However, functional relationships within the altered community structure remains similar and the benthic communities continue to function and serve as prey base for fish communities. A confounding factor may be the effect of microhabitat characteristics that are independent of contamination effects and can contribute to slight alterations in community structure.

This measurement endpoint was characterized as having a high significance as it directly measured benthic community structure and function. As this was the primary goal for the protection of the assessment endpoint, this measurement endpoint represents the most direct line of evidence used.

5.1.6 Whole Sediment Toxicity Test Evaluation

The toxicity test results indicated the following:

- Results of the 10-day toxicity tests for *Hyalella azteca* and *Chironomus tentans* revealed no statistically significant reductions in survival in the sediment samples evaluated when compared to the habitat specific reference tests.
- Results of the 10-day toxicity tests for *Hyalella azteca* revealed a statistically significant reduction in growth for sample MLFPTRA11 from Lower Factory Pond when compared to growth observed in the sediments from Forge Pond. All other samples from the river, pond and wetland habitats revealed comparable or positive growth relative to the amphipods exposed to sediments from the reference areas.
- Results of the 10-day toxicity tests for *Chironomus tentans* revealed a statistically significant reduction in growth for midges exposed to sediments from wetland location MUA21 when compared to growth observed in wetland reference sediments from station WBK01. All riverine and pond samples revealed comparable or positive growth relative to the midges exposed to sediments from corresponding reference areas.

This measurement endpoint was characterized as having a high significance as it directly measured toxicity of Site-specific concentrations of contaminants to representative infaunal organisms present in the benthic community. This assessment affirmed the toxic potential evaluation, which predicted the sediments from throughout the study area to be non-toxic and effects on growth were minor.

5.1.7 Uncertainty Assessment

The uncertainty in the risk characterization is considered to be low for this assessment endpoint. The risk characterization considers six different lines of evidence that assess exposure either directly or indirectly to contaminants present in the sediments. The evaluation considered chemical, biological, ecological and toxicological measurement endpoints to assess risks for the protection and sustainability of benthic communities. Individually these endpoints consider direct evidence related to the assessment endpoint under evaluation. They also provide a basis for evaluating the potential pathway for introduction of bioaccumulating contaminants from sediments into the aquatic food chain. Because multiple lines of evidence were considered, the uncertainty associated with the final risk determination decreases given the weight of evidence applied. One line of evidence applied in this assessment endpoint was the comparison of the structure and function of the benthic community present in the aquatic habitats of the site to that in a comparable reference location (with these locations being selected because they were not impacted by the site and had the proper habitat features). A number of metrics were used in this comparison (e.g., total taxa richness, community density, community diversity, community structure). A reference location was selected, characterized and the findings were used as the baseline for the comparisons for each habitat type present (i.e., riverine, pond and wetland). This selection, characterization, and comparison process was conducted in accordance with the approved work plan. As the characteristics of a benthic community, as defined by these metrics, can vary within a habitat type over some distance, the characteristics of the reference location could likely be somewhat different for one or more metrics from one reference location to another. As these characteristics constitute the baseline for the comparisons associated with this measurement endpoint, this spatial variability in the benthic species would have an effect on the results of the comparisons. However, by considering a number of metrics of different forms and focus, the likelihood that the reference location for a particular habitat type would have dramatically atypical or unrepresentative characteristics from its surrounding area to the point that a misleading overall conclusion would be drawn is greatly reduced.

5.1.8 Risk Determination for Assessment Endpoint #1

Results of the exposure assessment and risk characterization identified Site-related sediment benchmark exceedances for total mercury and methyl mercury as occurring on a Site-wide basis. The bioavailability measurement endpoint predicted that the mercury concentrations though elevated were not directly bioavailable or predicted to be acutely toxic to benthic organisms. Benthic community surveys of the riverine, pond and wetland habitats determined that these habitats are able to sustain a diverse benthic community. However, structural changes in the benthic community sampled were noted at most stations and degree of structural alteration varied by both habitat and proximity to known sediment contamination. The ability of the aquatic habitats to support a benthic assemblage was also borne out with the results of the bioaccumulation study, which verified that mercury was being introduced into the aquatic food chain via the deposit feeding benthic invertebrates. Thus bioaccumulation could not be occurring if a toxic effect (i.e., elimination of benthic invertebrates) in the benthic community was apparent.

While structural alterations were present through the replacement of specific taxa, the functional trophic guilds present were sufficient to support and sustain a viable benthic community and to serve as a prey base for the fish communities present. Functional alterations in the benthic communities were noted in the Eastern Channel Corridor to a greater extent than in the Lower Drinkwater River. Functional guild shifts in response to an alteration in benthie community structure were apparent in the Marsh Upland Area. The shifts in both structural and functional relationships in the benthic communities present in Lily Pond/Upper Factory Pond and Middle/Lower Factory Pond were not apparent as observed in the riverine and wetland stations. Based upon the above lines of evidence, the elevated levels of total mercury and methyl mercury in the sediments of the Eastern Channel Corridor, Lower Drinkwater River Corridor, and the Marsh Upland Area pose a potential risk of biological harm to benthic communities present in these habitats.

5.2 Assessment Endpoint #2 Protection and Sustainability of Freshwater Plankton in Lily and Factory Ponds, and Drinkwater River to Serve as a Prey Base

Three measurement endpoints were used as lines of evidence in characterizing risks for this assessment endpoint. These included: (1) comparison of groundwater analyte concentrations to benchmark values protective of aquatic life; (2) comparison of surface water analyte concentrations to benchmark values protective of aquatic life; and (3) comparison of surface water analyte concentrations to benchmark values protective of planktonic plants and animals. These lines of evidence are discussed below.

5.2.1 Groundwater Benchmark Screening

Results of the groundwater exposure assessment revealed the following:

- Mean concentrations of total mercury exceeded GW-3 chronic and acute benchmark values for groundwater in the Marsh Upland Area and were not comparable to reference concentrations.
- Mean concentrations of trichloroethene, iron, lead, and nickel exceeded chronic benchmark values for groundwater in one or more on-Site locations and were not comparable to background concentrations.
- All other contaminant concentrations were below the acute and chronic benchmark values protective of aquatic life or were comparable to reference concentrations.

5.2.2 Surface Water Benchmark Screening

A comparison to surface water benchmark screening yielded the following:

- Mean concentrations of carbon disulfide exceeded the AWQC benchmark value in the riverine (Eastern Channel Corridor) and pond (Middle/Upper Factory Pond) habitats and were not comparable to reference area concentrations.
- All other contaminant concentrations in surface waters in Site aquatic habitats were below the AWQC benchmark values protective of aquatic life.

5.2.3 Plankton Benchmark Screening

All contaminant concentrations in surface waters in Site aquatic habitats were below the benchmark values protective of plankton or comparable to background concentrations. Thus, few exceedances of groundwater or surface water data were noted. The lack of exceedances supports the finding that exposure of this community appears low.

For this assessment endpoint, uncertainty in the risk characterization is considered to be moderate. Comparison of surface water concentrations to benchmark values protective of aquatic life and planktonic organisms provide moderate evidence for assessing both exposure and risk to this endpoint. Comparison of on-Site analyte concentrations to reference station concentrations supplements the benchmark screening by determining if an exceedance is Site-related.

5.2.4 Risk Determination for Assessment Endpoint #2

Results of the exposure assessment and risk characterization identified a Site-related benchmark exceedance in groundwater for total mercury in the wetland (Marsh Upland Area) habitat. A Site-related surface water exceedance was identified in the riverine (Eastern Channel Corridor) and pond (Middle/Upper Factory Pond) habitats for carbon disulfide. No Site-related analyte concentrations exceeded benchmark values protective of plankton. Based upon the above lines of evidence, no risk of potential biological harm exists for plankton in the aquatic habitats on the Site.

5.3 Assessment Endpoint #3 Protection and Sustainability of Forage and Predatory Fish Community Structure in Factory and Lily Ponds and the Drinkwater River Comparable to Similar Warm Water Environments

Five measurement endpoints were used as lines of evidence in characterizing risks for this assessment endpoint. These included: (1) comparison of surface water quality data to toxicity reference values for fish survival and to reference station concentrations; (2) evaluation of potential risk in aquatic media through sampling of endemic fish populations for community structure and comparison to reference populations; (3) gross external examination of endemic fish for evidence of stressor related effects in comparison to a reference population; (4) qualitative comparison of COPEC concentrations in tissues to reference station concentrations and comparison of methyl mercury concentrations to tissue based toxicity reference values from the primary literature; and (5) performance of survival and growth tests for using the Fathead Minnow (*Pimephales promelas*). The lines of evidence are discussed below.

5.3.1 Surface Water Reference Station and Benchmark Comparison for the Protection of Fish

A comparison of surface water concentrations to benchmark values yielded the following:

- In the riverine habitat the mean concentration of copper exceeded the LCV for fish in the Lower Drinkwater River Corridor and the average concentration of silver exceeded the LCV for fish in the reference station, the Eastern Channel Corridor, and the Lower Drinkwater River Corridor.
- In the pond habitat, the mean concentration of silver exceeded the LCV for fish in Lily Pond/Upper Factory Pond, Middle/Lower Factory Pond, and the Forge Pond reference station.
- All on-Site contaminant surface water concentrations in the riverine and pond habitats were comparable to within an order of magnitude to the concentrations in their respective reference stations suggesting that ambient levels of metals and VOCs in surface water do not indicate an excessive exposure to fish species from historical Site activities.

Results of the surface water comparison only revealed copper to exceed the aquatic life screening level benchmark in the riverine habitats of the Eastern Channel Corridor and Lower Drinkwater River Corridor. Remaining contaminants were deemed comparable to local conditions.

This endpoint was characterized as having a moderate significance as the evaluation relied upon the use of general aquatic life screening benchmarks deemed protective of aquatic life inclusive of freshwater fish. The benchmarks reflect protectiveness across multiple phlyogenetic groups and are not exclusive to fish alone.

5.3.2 Analysis of Fish Community Structure and Function

The fish community structure and function assessment showed the following:

- The assemblage of fish species present was common to warm water fisheries observed in other Massachusetts lakes and ponds (MADEP, 1997).
- Largemouth bass, bluegill sunfish, and pumpkinseed were common to all reaches sampled.
- The guild structure in the Northern Drinkwater River reference reach and in the Lower Drinkwater River Corridor were similar, consisting of a 3:2 ratio of piscivores to generalists. The guild structure in the Eastern Channel Corridor consisted of a 7:3 ratio of generalists to piscivores.
- The guild structure in the reference pond reach and in the Middle/Lower Factory Pond were similar, consisting of approximately a 1:1 split of piscivores to generalists. The guild

mercury for both endpoints were noted for larger, long lived piscivorous species (i.e., the largemouth bass) in the Eastern Channel Corridor habitats. NOAEL based exceedances for both of the above endpoints were noted in the habitats of Lily Pond/Upper Factory Pond and Middle/Lower Factory Pond. NOAEL based exceedances for reproductive and behavioral endpoints were noted for forage species (i.e., the largemouth bass) in the Eastern Channel Corridor habitats. NOAEL based exceedances for both of the above endpoints were noted in the habitats of Lily Pond/Upper Factory Pond and Middle/Lower Factory Pond. NOAEL based exceedances for reproductive and behavioral endpoints were noted for forage species (i.e., bluegill sunfish).

This endpoint was characterized as having a high significance as the evaluation considered Site-specific data related to observed bioaccumulation in fish from multiple trophic levels in the fish community present.

5.3.5 Survival and Growth Tests Using Fathead Minnow (*Pimephales promelas*) Larvae

The 7-day survival test revealed the following:

- Results of the 7-day tests revealed no statistically significant reductions in survival among the Site surface water samples evaluated when compared to the habitat specific reference results.
- A negative effect on growth was noted for sample UDCTRA11SW in the riverine reference station.
- Growth of minnows exposed to surface waters from Factory Pond and the Drinkwater River revealed comparable or positive growth relative to the minnows exposed to reference area surface waters.

Results of the surface water toxicity tests with the fathead minnow revealed no overt effects from exposure to surface water on survival, growth or behavior relative to the observed gradient in contamination. These data affirm that fish are not at risk of acute toxicity from exposure to contaminants detected in Site surface waters.

This endpoint was characterized as having a high significance as the evaluation considered a direct evaluation of toxicity of the surface water to a representative warm water fish species.

5.3.6 Uncertainty Assessment

For this assessment endpoint, uncertainty in the risk evaluation is considered to be low. Comparison of surface water contaminant concentrations to benchmark values protective of warm water fisheries provide a moderate level of certainty. Five separate measurement endpoints were used as lines of evidence to characterize risk to this assessment endpoint. Comparison of on-Site contaminant concentrations to reference station concentrations supplements the benchmark screening by determining if an exceedance is Site-related. Analysis of fish community structure and health, fish body burdens, and toxicity tests each provide an added level of confidence to the evaluation. As noted previously, consideration of multiple measurement endpoints within a weight of evidence framework reduces the uncertainty associated with the final risk determination. The measurement endpoints used in this weight of evidence approach included both the consideration of direct exposure to abiotic media related to acute and chronic effects (i.e., surface water comparisons to acute and chronic ambient surface water criteria) and consideration of cumulative exposure via all abiotic media (i.e., surface water and sediment) and dietary ingestion (via food chain biomagnificaton) using the critical body burden measurement endpoint. A potential risk was identified based on consideration of multiple measurement endpoints inclusive of both a direct exposure pathway and a cumulative exposure approach. The critical body burden approach reflects the intake from the surrounding water, the sediment and the diet of the fish and thus does address exposure from surface water, sediments and food chain contributions. The application of multiple measurement endpoints with regard to the potential for biological harm to the fish contributes to a low overall uncertainty with regard to the risk determination for this endpoint.

5.3.7 Risk Determination for Assessment Endpoint #3

Five separate measurement endpoints were used as lines of evidence to characterize risk to this assessment endpoint. Results of the exposure assessment and risk characterization indicate no effects on fish survival, growth, reproduction, or community function in Site aquatic habitats. However, a comparison of fish health revealed an increased occurrence of parasites/cysts, cloudy eyes, malformations, and ulcers/lesions in some riverine and pond sampling locations and a positive correlation between the occurrence of ulcers/lesions and COPEC concentrations in Site aquatic habitats. Fish body burdens of total and methyl mercury sampled on the Site were elevated in correlation with the contamination gradient. Numerous body burden NOEAL exceedances for methyl mercury were identified for reproductive and behavioral endpoints for fish sampled from riverine and pond locations on the Site. Body burden methyl mercury concentrations exceeded the NOAEL reproductive benchmark in the Eastern Channel Corridor. Body burden levels of methyl mercury and data collected on the health of the Site fish community indicates possible subchronic effects and potential risk of biological harm to the fish community from bioaccumulation of mercury.

5.4 Assessment Endpoint #4 Protection and Sustainability of Piscivorous Avian Populations Utilizing Factory Pond, Lily Pond, and Drinkwater River and Marsh Upland Area Habitats

Three measurement endpoints were used as lines of evidence in characterizing risks for this assessment endpoint. These included: (1) evaluation of exposure pathways and routes of exposure and comparison of predicted exposure dosages to NOAELs and LOAELs for a representative piscivorous bird species, the belted kingfisher; (2) comparison of prey fish and invertebrate tissue concentrations to Canadian tissue residue guidelines; and (3) performance of avian bird surveys to determine any reduction in avian diversity in the Site habitats. The lines of evidence are discussed below.

5.4.1 Belted Kingfisher Exposure Modeling

Exposure of the belted kingfisher was based upon utilization of the river and pond habitats associated with the Site where sustainable fish populations were present.

- Aquatic habitats present along the Drinkwater River and Factory Pond were found to be conducive for use by belted kingfishers for foraging.
- Principle exposure routes were identified as the ingestion of drinking water and dietary ingestion of aquatic prey (i.e., small fish) from the aquatic habitats present.
- The exposure assessment revealed the dietary ingestion pathway contributed the largest percentage of the daily dosage of contaminants for this receptor. The primary exposure route was via dietary ingestion of small fish.
- A LOAEL based exceedance for a sensitive reproductive endpoint was noted for methyl mercury for this species in the riverine and pond background exposure assessments.
- A LOAEL based exceedance was noted for methyl mercury for this species at exposure dosages in excess of background exposure levels in the habitats of the Eastern Channel, Lower Drinkwater River, Lily/Upper Factory Pond and Lower Factory Pond.

This measurement endpoint was characterized as having a high significance as the exposure assessment included use of Site-specific tissue data for prey fish and species-specific exposure parameters which were refined to the ecology of the belted kingfisher in the habitats present.

5.4.2 Comparison to CCME Tissue Residue Guidelines for Methyl Mercury for Protection of Wildlife Consumers of Aquatic Biota

This line of evidence revealed the following:

- Forage fish (i.e., bluegill sunfish), predatory fish (i.e., largemouth bass), and large macroinvertebrates (i.e., crayfish) collected from the aquatic habitats of the Drinkwater River and Upper and Lower Factory Ponds contained methyl mercury concentrations in excess of the CCME 0.033 mg/Kg protective guideline.
- Concentrations of total mercury and methyl mercury in fish tissues from the Eastern Channel Corridor, Lower Drinkwater River Corridor, Lily Pond/Upper Factory Pond and Middle/Lower Factory Pond were elevated above levels in fish from Massachusetts lakes not impacted by anthropogenic sources (MADEP, 1997).
- Exceedance of the 0.033 mg/Kg guideline was also observed in the reference areas of Forge Pond and the Upper Drinkwater River reference habitats outside any potential influence from historical Site operations. This indicates that sources such as atmospheric deposition and point waste water discharges were contributing to the exposure of fish and wildlife to mercury in the Drinkwater River watershed.
- Concentrations of total mercury and methyl mercury in fish tissues from Forge Pond and the Upper Drinkwater River reference areas were found to be comparable to levels of these contaminants in fish from Massachusetts lakes (MADEP, 1997) not impacted by anthropogenic sources.

This measurement endpoint was characterized as having a medium significance as the evaluation considered the comparison of measured tissue concentrations of methyl mercury to a generic tissue guideline. The guideline is derived based upon exposure modeling using conservative assumptions and home range assignments by CCME (1999). It does not consider selective effects of prey fish species size preferences by piscivorous wildlife or cumulative exposure dosages from other environmental media. The guideline was derived to be protective of the most sensitive piscivorous species potentially exposed in the CCME evaluation.

5.4.3 Avian Species Surveys

Belt transect survey data and opportunistic avian observations confirmed the presence of the belted kingfisher to be utilizing the aquatic habitats of the Drinkwater River and Factory Pond. The presence of the belted kingfisher as well as several other species of herons confirm that piscivorous birds utilize the aquatic resources present. The overall abundance of the belted kingfisher was estimated to be low on-Site and in the reference habitats as this species was only observed as part of the opportunistic observation set and not documented during the transect surveys. No observations of dead belted kingfishers or atypical behaviors in observed individuals were noted during the surveys.

This measurement endpoint was characterized as having a high significance. The surveys did confirm the presence of this species as utilizing the habitats present and confirmed a complete exposure pathway for piscivorous birds.

5.4.4 Uncertainty Assessment

Based upon the use of Site-specific fish tissue concentrations from both riverine and pond habitats, application of species-specific exposure parameters to the Site habitats present, and the confirmation of the species presence in the habitats, uncertainty was considered to be low for this assessment end point. The exposure assessment considered an areal exposure point concentration as the basis for predicting the dosage to this receptor via multiple exposure routes based on the ecology of the belted kingfisher. Exposure areas of riverine and pond habitats remained consistent with the average home range occupied by this receptor in the wild.

The use of literature-based chronic or subchronic NOAELs and LOAELs implies a direct effects comparison and does not consider internal modifying factors affecting the chemical form of the mercury once ingested. Nor does the exposure assessment consider modifying factors such as excretion or limitations on bioavailability in the environment.

5.4.5 Risk Determination for Assessment Endpoint #4

Results of the exposure assessment and risk characterization identified a LOAEL exceedance for reproductive endpoints to the belted kingfisher from methyl mercury. A LOAEL exceedance for exposure in both the river and pond background areas suggest that other sources of mercury to the environment are contributing to the overall exposure at the Site and reference areas. Exposure of this species to methyl mercury from the ingestion of fish prey on the Site were elevated above background. Comparison of methyl mercury concentrations in prey fish, predatory fish and crayfish from the Eastern Channel and Lower Channel of the Drinkwater River, Upper Factory Pond and Lower Factory Pond exceeded the tissue based guidelines for the protection of piscivorous wildlife. Avian surveys confirmed the belted kingfisher to be utilizing the habitats present. Based upon the above lines of evidence, a risk of potential biological harm of reproductive effects from methyl mercury exposure was determined for piscivorous birds in the Eastern Channel Corridor, Lower Drinkwater River Corridor, Lily Pond/Upper Factory Pond and Middle/Lower Factory Pond.

5.5 Assessment Endpoint #5 Protection and Sustainability of Omnivorous Waterfowl Populations Utilizing Factory and Lily Ponds, the Drinkwater River and Marsh Upland Area Wetland Habitats

Two measurement endpoints were used as lines of evidence for characterizing risks to this assessment endpoint. These included: (1) identification of exposure pathways and routes of exposure and comparison of predicted exposure dosages to NOAELs and LOAELs for a representative omnivorous waterfowl species, the mallard; and (2) performance of avian bird surveys to determine any reduction in avian diversity in Site habitats. The lines of evidence are discussed below.

5.5.1 Mallard Exposure Modeling

Exposure of the mallard was based upon the utilization of the river, pond and wetland habitats associated with the Site where benthic macroinvertebrate and aquatic plant populations were observed to be present.

- Aquatic habitats present along the Drinkwater River, Factory Pond and the Marsh Upland Area were found to be conducive for use by the mallard for foraging and nesting.
- Principle exposure routes evaluated were the ingestion of drinking water, dietary ingestion of soft bodied aquatic invertebrates (i.e., aquatic earthworms) and aquatic plants, and incidental ingestion of sediments from the aquatic habitats present.

5.6.1 American Woodcock Exposure Modeling

Exposure of the American woodcock was based upon the utilization of the terrestrial habitats present in the Central and Southern areas of the Site.

- The terrestrial habitats present in the Central and Southern Areas of the Site were found to be conducive for use by the woodcock for foraging and nesting. The presence of soil invertebrates such as earthworms, armored millipedes, sowbugs and slugs was noted in the leaf litter layer and soils of the Central and Southern Areas.
- The principal exposure routes evaluated were the ingestion of drinking water, dietary ingestion of soil invertebrates (i.e., earthworms), and incidental ingestion of surface soils consumed during feeding in the terrestrial habitats present.
- The principal dietary exposure media were surface soils (0 to 0.5 ft. bgs) and surface water. Estimated tissue concentrations for soil invertebrates were determined using soil to soil invertebrate accumulation factors from Sample et al. (1998) or EPA (2003) and surface soil data from each area of concern evaluated.
- The exposure assessment revealed the dietary ingestion pathway contributed the largest percentage of the daily dosage of contaminants for this receptor. The primary exposure routes were dietary ingestion of soil invertebrates and incidental ingestion of surface soils.
- NOAEL based exceedances were noted for aluminum, chromium, lead, and zinc in the reference habitat exposure assessment. A LOAEL HQ of 1.9 for lead was observed in the reference exposure assessment. Exposure dosages for aluminum, chromium and zinc in the Central Commercial Area, Proposed Greenway Area, Marsh Upland Area and Southern Conservation Area were comparable to the exposure dosages observed in the background habitats and were not considered problematic in these areas.
- LOAEL based exceedances were observed for a sensitive reproductive endpoint for lead and selenium above background exposures in the Flood Plain Area. NOAEL based exceedances in excess of the background exposures were also noted for total mercury and methyl mercury in the habitats of the Flood Plain Area.
- A NOAEL and LOAEL exceedance for a sensitive reproductive endpoint was identified for total mercury in the Proposed Greenway Area.
- NOAEL and LOAEL exceedances in excess of background exposures were observed for lead and total mercury in the Marsh Upland Area.
- NOAEL and LOAEL exceedances in excess of background exposures were observed for barium, lead, total mercury and di-n-octylphthalate in the Southern Conservation Area.
- NOAEL and LOAEL exceedances in excess of background exposures were observed for arsenic, barium, chromium, copper, lead, total mercury, selenium and zinc in the Southern Disposal Area.
- In the Cold Waste Area, NOAEL and LOAEL exceedances in excess of background exposures were observed for arsenic, barium, chromium, cobalt, lead, mercury, selenium and zinc. LOAEL HQs > 1 to < 10 were identified for arsenic, chromium, cobalt, copper, mercury and selenium. LOAEL HQs >30 to < 100 were identified for lead and zinc. A LOAEL HQ >200 was identified for barium.

This measurement endpoint was characterized as having a high significance as the exposure assessment included use of Site-specific environmental media data specific to each of the areas of concern evaluated.

The exposure assessment relied upon use of a soil to soil invertebrate accumulation factor that is prone to overestimate tissue concentrations in the soil invertebrate exposure route.

5.6.2 Avian Species Surveys

The presence of the American woodcock was confirmed based upon opportunistic avian observations of this species in the Central Commercial Area. Overall abundance of the American woodcock was estimated to be low as this species was only observed as part of the opportunistic observation data set and not documented as part of the avian belt transect survey. Other species of insectivorous birds including the American robin, Carolina wren, eastern wood peewee, chimney swift, vireo and northern flicker were also observed during belt transect surveys and as opportunistic observations. No observations of dead insectivorous birds or birds displaying atypical behaviors were noted during the surveys. No statistical difference in overall avian diversity was noted between reference and on-Site transect survey.

This measurement endpoint was characterized as having a high significance. The surveys did confirm this species as utilizing the habitats present.

5.6.3 Uncertainty Assessment

For this assessment endpoint, uncertainty in the risk evaluation is considered to be low as the exposure assessment relied upon conservative bioaccumulation factors to predict body burden levels in soil invertebrates. The empirical bioaccumulation factors assume a 100% bioavailability of the contaminant present and a 100% assimilation of the contaminant by both prey and the wildlife receptor. These two assumptions contribute to overestimate the dietary exposure pathway for the receptor evaluated and results in an overestimate of risk in general. The application of species-specific exposure parameters to the on-Site habitats and the confirmation of the species in the habitats indicates that exposure is likely occurring. The exposure assessment considered an areal exposure point concentration on the basis of predicting the dosage to this receptor via multiple exposure routes deemed typical to the ecology of the American woodcock. Areal exposure estimates were assumed to be 1.0 for the areas of concern. Given that the acreage of each area of concern represents a fraction of the home range occupied by the American woodcock, the areal exposure estimate of 1.0 will further contribute to an overestimate of risk.

Finally, the use of literature based chronic or sub-chronic NOAELs and LOAELs imply a direct effects comparison and do not consider internal modifying factors affecting the chemical form of the contaminant once ingested. Such a modifying factor will include excretion of the contaminant or regulation of the contaminant via metabolic pathways in the receptor.

5.6.4 Risk Determination for Assessment Endpoint #6

Results of the exposure assessment and risk characterization identified LOAEL exceedances for reproductive endpoints to the American woodcock in the Flood Plain Area, Proposed Greenway Area, Marsh Upland Area, Southern Conservation Area, Southern Disposal Area and Cold Waste Area. NOAEL exceedances for aluminum, chromium and zinc in all the on-Site areas (except the Southern Disposal Area) were comparable to background areas suggesting that these metals do not present an excess risk at the Site. Exceedance of a NOAEL under the MCP is inferred as an indeterminant risk. Avian observations confirmed the American woodcock and other insectivorous birds to be utilizing the habitats in the Central Commercial Area but transect survey data suggest that this species is in low abundance in all habitats. The Central Commercial Area was determined to present no risk of significant harm to insectivorous birds based upon the comparability of Central Commercial Area exposure dosages to background dosages.

Those areas where exposure dosages exceeded background estimates and resulted in LOAEL HQs > 1.0 were identified as contributing to a risk of potential biological harm for insectivorous birds. The contaminants for each of the areas are summarized as follows:

- Flood Plain Area – Lead and selenium
- Proposed Greenway Area – Total mercury
- Marsh Upland Area – Lead and total mercury
- Southern Conservation Area – Barium, lead, total mercury and di-n-octylphthalate
- Southern Disposal Area – Arsenic, barium, chromium, copper, lead, total mercury, selenium and zinc
- Cold Waste Area – Arsenic, barium, chromium, cobalt, copper, lead, total mercury, selenium and zinc

5.7 Assessment Endpoint #7 Protection and Sustainability of Carnivorous Birds Utilizing the Terrestrial Habitats

Two measurement endpoints were used as lines of evidence in characterizing risks for this assessment endpoint. These included: (1) identification of exposure pathways and routes of exposure and comparison of predicted exposure dosages to NOAELs and LOAELs for a representative carnivorous bird species, the red-tailed hawk; and (2) performance of avian bird surveys to determine any reduction in avian diversity in the terrestrial habitats of the Site. The lines of evidence are discussed below.

5.7.1 Red-tailed Hawk Exposure Based Modeling

Exposure of the red-tailed hawk was based upon the utilization of the terrestrial habitats present on the Site. The evidence of small mammal burrows and runways in the soil litter confirmed the presence of representative prey species for this receptor group.

- The terrestrial habitats present in the Central and Southern Areas of the Site were found to be conducive for use by the red-tailed hawk for foraging. The Northern Area is not considered in the exposure assessment based upon the existing development, which limits the availability of foraging and nesting habitat for this species.
- Principal exposure routes evaluated were the ingestion of drinking water, dietary ingestion of small mammal prey (i.e., white-footed mice, voles, shrews) and incidental ingestion of surface soils during foraging.
- The principal dietary exposure media were surface soils (0-0.5 ft. bgs) and surface water data from the areas evaluated. Estimated contaminant tissue concentrations for small mammals were determined using soil-small mammal bioaccumulation factors from Sample et al. (1998) or methods in EPA (2003).
- The exposure assessment revealed the dietary ingestion pathway contributed the largest percentage of the daily dosage of contaminants for this receptor. The primary exposure route was the dietary ingestion of small mammals.
- NOAEL based exceedances were noted for aluminum and lead in the background exposure assessment for this receptor species.
- Exposure dosages and corresponding NOAEL HQs for aluminum and lead in the Central Commercial Area, Flood Plain Area, Proposed Greenway Area and the Site-wide evaluation were determined to be comparable or slightly elevated to background exposure dosages for both metals. The exposure dosage and NOAEL HQ for aluminum in the Marsh Upland Area

and Southern Disposal Area were equivalent to background exposure and were not considered problematic in these areas.

- NOAEL and LOAEL exceedances for a sensitive reproductive endpoint were observed for lead and total mercury in the Marsh Upland Area surface soils.
- NOAEL and LOAEL exceedances for a sensitive reproductive endpoint were identified for barium, chromium, lead and zinc for this receptor species in the Southern Disposal Area.
- A NOAEL based exceedance for a sensitive reproductive endpoint was identified for selenium for this receptor species in the Southern Disposal Area.

This measurement endpoint was characterized as having a high significance as the exposure assessment included use of Site-specific environmental media data for each area of concern evaluated. The exposure assessment relied upon use of a soil to small mammal accumulation factor that was selected to over-estimate tissue concentrations in the small mammal exposure route. The principle source of this overestimate are the assumptions of 100% bioavailability of contaminants in the soils, a 100% assimilation efficiency by the prey species and selection of the upper confidence level for the bioaccumulation term from the sources used. The exposure modeling assumed an areal foraging factor of 1.0 to all areas evaluated regardless of the size of the individual areas.

5.7.2 Avian Species Surveys

The presence of the red-tailed hawk was confirmed based upon opportunistic avian observations of this species in habitats on the Site. A pair of individuals were observed suggesting a nesting pair was utilizing the Site. Overall abundance of the red-tailed hawk was estimated to be low as this species was only observed as part of the opportunistic observation data set and not documented as part of the avian belt transect surveys. No observations of dead carnivorous bird species or atypical behaviors in observed individuals were noted during the surveys. The surveys revealed no statistical difference in avian diversity across the Site.

This measurement endpoint was characterized as having a high significance since the avian surveys confirmed the presence of this species as utilizing the habitats present.

5.7.3 Uncertainty Assessment

For this assessment endpoint, uncertainty in the risk evaluation is considered to be medium based upon conservative assumptions applied in the risk assessment. The exposure assessment relied upon conservative bioaccumulation factors to predict body burden levels in small mammal prey species. The bioaccumulation factors assume a 100% bioavailability of the contaminant present and a 100% assimilation of the contaminant by both the prey species and the wildlife receptor. These two assumptions act to overestimate the dietary exposure pathway resulting in an overestimate of the exposure dosage and any risk in general. Application of species-specific exposure parameters to the Site habitats present and the confirmation of the species in the habitats affirm that exposure is occurring. The exposure assessment considered an areal exposure point concentration on the basis of predicting the dosage to this receptor via multiple exposure routes deemed typical to the ecology of the red-tailed hawk. Areal exposure estimates were assumed to be 1.0 for each area of concern. The average home range for adult red-tailed hawks was determined to be equivalent to the entire area of the Site. Assessment of the exposure in the individual areas of concern for on-Site soils would overestimate exposure for this species relative to its home range. The exposure assessment on a Site-wide basis revealed exposure and risk equivalent to background conditions. The use of literature based chronic or sub-chronic NOAELs and

LOAELs imply a direct effects comparison and do not consider internal modifying factors affecting the chemical form of the contaminant once ingested.

5.7.4 Risk Determination for Assessment Endpoint #7

Results of the exposure assessment and risk characterization identified LOAEL exceedances for reproductive endpoints to the red-tailed hawk in the Marsh Upland Area and Southern Disposal Area. With the exception of the Marsh Upland Area and Southern Disposal Area, NOAEL exceedances for aluminum and lead in the remaining on-Site areas were comparable to background exposures indicating that these metals do not represent an excess risk at the Site. Exceedance of a NOAEL under the MCP is inferred as an indeterminant risk. A secondary line of evidence must be applied. Avian observations confirmed the red-tailed hawk to be utilizing the habitats present on the Site and no indication of impairment was apparent in the individuals observed. Based upon the Site-wide evaluation, no risk of significant harm to carnivorous birds was determined.

The Southern Disposal Area and Marsh Upland Area where exposure dosages exceeded background estimates and resulted in LOAEL HQs > 1.0 for barium, chromium, lead and zinc were identified as contributing to a risk of potential biological harm for carnivorous birds. The exposure assessments for these individual areas applied an areal use factor of 1.0 resulting in an overestimate of exposure to any contaminants associated with these areas. The Site-wide evaluation presents a more realistic representation for the exposure assessment and risk characterization for this receptor species.

5.8 Assessment Endpoint #8 Protection and Sustainability of Herbivorous Waterfowl Populations in Factory and Lily Ponds, the Drinkwater River Channel and the Marsh Upland Area Wetland

Two measurement endpoints were used as lines of evidence in characterizing risks for this assessment endpoint. These included: (1) identification of exposure pathways and routes and comparison of predicted exposure dosages to NOAELs and LOAELs for a representative herbivorous waterfowl species, the mute swan; and (2) performance of avian surveys to determine the presence of the mute swan and any reduction in avian diversity in the Site habitats. The lines of evidence are discussed below.

5.8.1 Mute Swan Exposure Based Modeling

Exposure of the mute swan was based on the utilization of the aquatic habitats present at the Site.

- Extensive stands of aquatic vegetation were present in the basins of the Drinkwater River and Factory Pond. Benthic macroinvertebrate surveys confirmed the presence of a benthic macroinvertebrate community in the aquatic habitats present. Submergent aquatic vegetation included stands of pondweed, (*Potamogeton* sp.), milfoil (*Myiophyllum* sp.), and coontail (*Ceratophyllum demersum*). Floating leaved aquatic plant species included white water lily (*Nuphar* sp.) and water shield (*Brasenia schreberi*). Abundance of aquatic vegetation was noted to decline in the Lower Drinkwater River Corridor and Eastern Channel Corridor due to light limitation by an enclosed canopy. All the aquatic plant species observed are common in the diet of the mute swan (USEPA, 1993).
- Exposure routes evaluated included the ingestion of drinking water, dietary ingestion of aquatic plants and soft bodied aquatic invertebrates (i.e., aquatic earthworms), and incidental ingestion of surface sediments during feeding in the pond, riverine and wetland environments;

- The principal dietary exposure sources were the tissue data for aquatic earthworms from the sediment bioaccumulation study and predicted tissue concentrations for submergent aquatic plants using sediment data for each habitat evaluated and the sediment-aquatic plant accumulation factors from Jackson and Kalff (1993).
- The exposure assessment revealed the dietary ingestion pathway contributed the largest percentage of the daily dosage of contaminants for this receptor. The primary exposure route was the dietary ingestion of aquatic vegetation.
- No NOAEL based exceedances were noted for any contaminants in the Northern Drinkwater River background exposure assessment. A NOAEL HQ = 2.4 was noted for lead in the Forge Pond background assessment. Lead exposure in the Eastern Channel Corridor and Lower Drinkwater River Corridor was comparable to background exposures.
- A NOAEL and LOAEL exceedance for a sensitive reproductive endpoint was noted for total mercury for this species in the Eastern Channel Corridor and Lower Drinkwater River Corridor assessments.
- NOAEL exceedances for a sensitive reproductive endpoint were noted for aluminum, chromium and lead in excess of background exposures in the habitats of Lily Pond/Upper Factory Pond.
- NOAEL and LOAEL exceedances were noted for total mercury for this species at exposure dosages in excess of the background exposures in the habitats of both Lily Pond/Upper Factory Pond and Middle/Lower Factory Pond.

This measurement endpoint was characterized as having a high significance as the exposure assessment included use of Site-specific tissue data for soft bodied invertebrate prey, aquatic plant specific sediment-plant accumulation factors and application of species specific exposure parameters which were adapted to the ecology of the mute swan for both the riverine and pond habitats.

5.8.2 Avian Species Surveys

The presence of the mute swan was confirmed based upon observation of a pair of mute swans present on both Forge Pond and habitats of Lily/Upper Factory Pond and Lower Factory Pond as part of the opportunistic avian observation data. While the pair of individuals suggested the presence of a breeding population, no cygnets were observed. Overall abundance of the mute swan was estimated to be low as this species was only observed as part of the opportunistic observation data set and not documented as part of the avian belt transect survey. Mute swans are very territorial and aggressively defend breeding and foraging habitat. This behavior includes the harassment of other swan and waterfowl species. Therefore their limited abundance to a single pair of individuals is not unusual. No observations of dead swans or waterfowl or swans displaying atypical behaviors were noted during the surveys.

This measurement endpoint was characterized as having a high significance. The surveys did confirm the presence of this species as utilizing the habitats present.

5.8.3 Uncertainty Assessment

For this assessment endpoint, uncertainty is considered to be medium based upon the use of Site-specific environmental media concentrations from both riverine and pond habitats, application of species specific exposure parameters to the Site habitats present, and the confirmation of the species in the habitats surveyed. The exposure assessment considered an areal exposure point concentration for the basis of predicting the dosage to this receptor via multiple exposure routes deemed typical to the ecology of the mute swan. Exposure across the riverine and pond habitats remained consistent with the average home range occupied by the mute swan in the wild. This method is consistent with the home range for this species as it pertains to the habitats present. The use of literature based chronic or sub-chronic NOAELs and LOAELs implies a direct effects comparison and does not consider internal modifying factors affecting the chemical form of the mercury once ingested nor excretion. These processes can modify the toxicity potential of the mercury ingested.

5.8.4 Risk Determination for Assessment Endpoint #8

Results of the exposure assessment and risk characterization identified a LOAEL exceedance for reproductive endpoints to the mute swan from methyl mercury. A LOAEL exceedance for exposure in both the river and pond background areas suggests that other sources of mercury to the environment are contributing to the overall exposure at the Site and reference areas. However, the exposure of this species to methyl mercury remained elevated above background exposure in the habitats of the Site. Total mercury concentrations in ingested aquatic plants and aquatic earthworms contribute to an exposure dosage in excess of the NOAEL and LOAEL in the Eastern Channel Corridor, Lower Drinkwater River Corridor, Lily Pond/Upper Factory Pond, Middle/Lower Factory Pond, and Marsh Upland Area. Results from the bird surveys confirmed that mute swan utilize the habitats present but transect survey data suggest that this species is in low abundance. Based upon the above lines of evidence, a risk of potential biological harm from total mercury was determined for herbivorous waterfowl in the Eastern Channel Corridor, Lower Drinkwater River Corridor, Lily Pond/Upper Factory Pond, Middle/Lower Factory Pond and Marsh Upland Area.

5.9 Assessment Endpoint #9 Protection and Sustainability of Piscivorous Mammal Populations in the Habitats of Factory and Lily Ponds, the Drinkwater River, and the Marsh Upland Area Wetland

Three measurement endpoints were used as lines of evidence in characterizing risks for this assessment endpoint. These included: (1) evaluation of exposure pathways and exposure routes of exposure and comparison of predicted exposure dosages to NOAELs and LOAELs for a representative piscivorous mammal species, the mink; (2) comparison of prey fish and invertebrate tissue concentrations to CCME (1999) guidelines; and (3) performance of mammal surveys to determine the presence of this species in the Site habitats. The resulting lines of evidence are discussed below.

5.9.1 Mink Exposure Based Modeling

Exposure of the mink was based upon utilization of the river and pond habitats associated with the Site where sustainable fish and aquatic invertebrate populations were present. The Marsh Upland Area was not evaluated as a sustainable fish population.

- Aquatic habitats present along the Drinkwater River and Factory Pond were found to be conducive for use by mink for foraging and as habitat for denning.
- The principal exposure routes evaluated were the ingestion of drinking water, dietary ingestion of aquatic prey (i.e., small fish) and incidental ingestion of surface sediments.
- The exposure assessment revealed the dietary ingestion pathway contributed the largest percentage of the daily dosage of contaminants for this receptor. The primary exposure route was the dietary ingestion of small fish.
- NOAEL and LOAEL HQs >1.0 were noted for aluminum in the exposure assessment for both riverine and pond background areas and all the on-Site aquatic habitats. Aluminum is

among the most abundant elements in the earth's crust. Its toxic potential is wholly related to soluble forms and not to the total aluminum fraction in environmental media (USEPA 2003). Under acidic conditions where the pH<5.5, aluminum is expected to be in sufficient soluble form to cause a toxic effect (USEPA 2003). The pH of the water in the Drinkwater River and Factory Pond was determined to be circum-neutral (pH ≈ 7.0) and not conducive to the solubilization of aluminum into more toxic bioavailable forms. Therefore, aluminum is not anticipated to represent a risk to piscivorous wildlife in these habitats.

- A NOAEL based exceedance for a sensitive reproductive endpoint was noted for methyl mercury for this species in the Northern Drinkwater River background exposure assessment. A LOAEL based exceedance for a sensitive reproductive endpoint was noted for methyl mercury for this species in the pond background exposure assessment. This indicates that ambient exposure to methyl mercury was sufficient to support a risk of potential biological harm to this receptor without exposure to any contamination related to the Site.
- NOAEL and LOAEL based exceedances were noted for methyl mercury for a sensitive reproductive endpoint at exposure dosages in excess of background exposure in the Eastern Channel Corridor, Lower Drinkwater River Corridor, Lily Pond/Upper Factory Pond, and Middle/Lower Factory Pond. The elevated nature of the exposure to methyl mercury in these habitats supplemented the exposures associated with other mercury sources.

This measurement endpoint was characterized as having a high significance. The exposure assessment included use of Site-specific tissue data for prey fish and species specific exposure parameters which were adapted to the ecology of the mink in both the riverine and pond habitats.

5.9.2 Comparison to Canadian Tissue Residue Guidelines for Methyl Mercury for the Protection of Wildlife Consumers of Aquatic Biota

Results of the evaluation for this measurement endpoint revealed the following:

- Forage fish (i.e., bluegill sunfish), predatory fish (i.e., largemouth bass), and large macroinvertebrates (i.e., crayfish) collected from the aquatic habitats of the Drinkwater River and Upper and Lower Factory Ponds contain methyl mercury concentrations in excess of the CCME (1999) 0.033 mg/Kg protective standard.
- Concentration of total mercury and methyl mercury in fish tissues from the Eastern Channel Corridor, Lower Drinkwater River Corridor, Lily Pond/Upper Factory Pond, and Middle/Lower Factory Pond and Upper and Lower Factory Pond were elevated above levels in fish from Massachusetts lakes not impacted by anthropogenic sources (MADEP, 1997).
- Exceedance of the 0.033 mg/Kg standard was also observed in the reference areas of Forge Pond and the upper Drinkwater River outside any potential influence from historical Site operations. This indicates that sources such as atmospheric deposition and point waste water discharges may be contributing to exposure of fish and wildlife to mercury in the Drinkwater River watershed.
- Concentration of total mercury and methyl mercury in fish tissues from Forge Pond and the Upper Drinkwater River reference areas were found to be comparable to levels of these contaminants in fish from Massachusetts lakes (MADEP, 1997) not impacted by anthropogenic sources.

This measurement endpoint was characterized as having a medium significance as the evaluation considered the comparison of measured tissue concentrations to a generic tissue standard. The standard is derived based upon exposure modeling using conservative assumptions and home range assignments. It does not consider selective effects of prey fish size preferences by piscivorous wildlife or cumulative exposure dosages from other environmental media. The standard was derived to be protective of the most sensitive piscivorous species potentially exposed.

5.9.3 Qualitative Mammalian Surveys

Mammal surveys confirmed the presence of the mink to be utilizing the aquatic habitats of Upper and Lower Factory Pond. The presence of the mink confirms that piscivorous mammals do utilize the aquatic resources present at the Site. Evidence of this largely nocturnal species was based upon tracks along the shore of Factory Pond and its overall abundance across the Site was difficult to assess given its nocturnal habits. The abundance of the mink was estimated to be low as this species was only observed as part of the opportunistic observation set and not observed during the transect survey. No observations of dead mink or other piscivorous mammals were noted during the surveys. No evidence of the river otter (*Lutra canadensis*) was observed, which affirms that this species was not associated with the on-Site habitats or reference area habitats.

Mammalian abundance based upon belt transect data revealed a similar assemblage of mammals at all transect locations and habitats sampled. Similar species of mammals were encountered across all habitats with a slightly greater diversity of species being encountered in the habitats present on the Site.

This measurement endpoint was characterized as having a high significance as the surveys considered observations of mammal species which are present on the Site including the mink. The surveys confirmed the presence of this species as utilizing the habitats present.

5.9.4 Uncertainty Assessment

For this assessment endpoint, uncertainty is considered to be low. The use of Site-specific prey fish tissue concentrations from both riverine and pond habitats, application of species specific exposure parameters and the confirmation of the species presence in the habitats provide the basis for the low uncertainty determination. The exposure assessment considered an areal exposure point concentration for the basis of predicting the dosage to this receptor via multiple exposure routes deemed typical given the ecology of the mink. Exposure areas of riverine and pond habitats remained consistent with the average home range occupied by this receptor in the wild. This method is consistent with the home range for this species as it was applied to the habitats present.

The use of literature based chronic or sub-chronic NOAELs and LOAELs implies a direct effects comparison and does not consider internal modifying factors affecting the chemical form of the mercury once ingested.

5.9.5 Risk Determination for Assessment Endpoint #9

Results of the exposure assessment and risk characterization identified a LOAEL exceedance for a reproductive endpoint to the mink from methyl mercury. A LOAEL exceedance in both the river and pond background areas indicates that other sources of mercury to the environment are contributing to the overall exposure at the Site and reference areas. Exposure of this species to methyl mercury from the ingestion of fish prey was elevated above background exposure. Comparison of methyl mercury concentrations in prey fish, predatory fish and crayfish exceeded the CCME tissue guidelines for the protection of piscivorous wildlife. Mammal surveys confirmed that mink are utilizing the habitats present but transect survey data indicated that this species is in low abundance. Based upon the above lines of evidence, a risk of potential biological harm of reproductive effects from methyl mercury exposure was determined for piscivorous mammals in the Eastern Channel Corridor, Lower Drinkwater River Corridor, Lily Pond/Upper Factory Pond, and Middle/Lower Factory Pond.

5.10 Assessment Endpoint #10 Protection and Sustainability of Omnivorous Mammal Populations Occupying the Habitats of Lily and Factory Ponds, the Drinkwater River, and the Marsh Upland Area Wetland

Three measurement endpoints were used as lines of evidence in characterizing risks for this assessment endpoint. These included: (1) evaluation of exposure pathways and exposure routes and comparison of predicted exposure dosages to NOAELs and LOAELs for a representative omnivorous mammalian species, the raccoon; (2) comparison of prey fish and invertebrate tissue concentrations to tissue residue guidelines (CCME, 1998); and (3) performance of qualitative mammalian surveys to determine the presence of this species in Site habitats. The lines of evidence are discussed below.

5.10.1 Raccoon Exposure Based Modeling

Exposure of the raccoon was based upon utilization of the riverine and pond habitats associated with the Site where sustainable fish and aquatic invertebrate populations were present.

- Habitats present along the Drinkwater River and Factory Pond were found to be conducive for use by raccoon for foraging and as habitat for denning.
- Principal exposure routes were identified as the crayfish ingestion route, the forage fish ingestion route, and incidental surface sediment ingestion.
- The exposure assessment revealed that the dietary and incidental ingestion pathways contributed the largest percentage of the daily dosage of contaminants.
- Site-related NOAEL and LOAEL HQs >1.0 were noted for antimony in the exposure assessment for the Eastern Channel Corridor.
- Concentrations of total mercury exceeded the NOAEL, but not LOAEL in the Eastern Channel Corridor.
- Concentrations of methyl mercury exceeded NOAEL but not LOAEL in the Lower Drinkwater River Corridor, Lily Pond/Upper Factory Pond, and Middle/Lower Factory Pond.

This measurement endpoint was characterized as having a high significance as the exposure assessment included use of Site-specific tissue data for prey fish and crayfish, and species-specific exposure parameters which were adapted to the ecology of the raccoon in both the pond and riverine habitats.

5.10.2 Comparison to Canadian Tissue Residue Guidelines for Methyl Mercury for the Protection of Wildlife and Consumers of Aquatic Biota

This line of evidence revealed the following:

- Forage fish (i.e., bluegill sunfish), predatory fish (i.e., largemouth bass), and large macroinvertebrates (i.e., crayfish) from the Drinkwater River and Factory Pond contain methyl mercury concentrations in excess of the 0.033 mg/Kg guidance value.
- Total mercury and methyl mercury concentrations in fish from Forge Pond and the Upper Drinkwater River reference areas were comparable to fish from Massachusetts lakes (MADEP, 1997) not impacted by anthropogenic sources.

- The concentration of total mercury and methyl mercury in fish tissues from the Eastern Channel Corridor, Lower Drinkwater River Corridor, Lily Pond/Upper Factory Pond, and Middle/Lower Factory Pond were elevated above levels in fish from Massachusetts lakes not impacted by anthropogenic sources (MADEP, 1997).
- Crayfish and bluegill sunfish (a representative forage fish species) contained total and methyl mercury concentrations in excess of the 0.033 mg/Kg tissue guideline.
- Exceedance of the 0.033 mg/Kg guideline was also observed in the reference areas of Forge Pond and the upper Drinkwater River outside any potential influence from historical Site operations. Sources such as atmospheric deposition and point waste water discharges are contributing to the exposure of fish and wildlife to mercury in the Drinkwater River watershed.

This measurement endpoint was characterized as having a medium significance as the evaluation considered the comparison of measured tissue concentrations of methyl mercury to a generic tissue standard. The standard is derived based upon exposure modeling using conservative assumptions and home range assignments. It does not consider selective effects of prey fish species size preferences by piscivorous wildlife or cumulative exposure dosages from other environmental media. The standard was derived to be protective of the most sensitive piscivorous species potentially exposed.

5.10.3 Qualitative Mammalian Surveys

Mammal surveys confirmed the presence of the raccoon at the aquatic habitats of the Site. The presence of the raccoon confirms that omnivorous mammals utilize the habitats present. Evidence of this species was based upon sightings during the systematic transect survey in the Forge Pond reference area and on-Site in the northern, central, and southern areas. The abundance of the raccoon was high, as nine separate observations were made during the transect surveys, two in the Forge Pond reference location, two in the northern area, one in the central area, four in the southern area, and none in the western parcel. No observations of dead raccoons or abnormal behavior in the individuals observed were noted during the surveys.

This measurement endpoint was characterized as having a high significance as the surveys included direct observations of raccoons. The surveys confirmed raccoons are utilizing the habitats present and confirmed a complete exposure pathway for omnivorous mammals.

5.10.4 Uncertainty Assessment

For this assessment endpoint, uncertainty is considered to be low because of the use of Site-specific prey fish and crayfish tissue concentrations from on-Site riverine and pond habitats, application of species specific exposure parameters to the Site habitats present and the confirmation of the species' presence. The exposure assessment considered an areal exposure point concentration as the basis for predicting the dosage to this receptor via multiple exposure routes. Areas of riverine and pond habitats evaluated remained consistent with the average home range occupied by this receptor in the wild. This method is consistent with the home range for this species as it pertains to the habitats present.

The use of literature based chronic or sub-chronic NOAELs and LOAELs implies a direct effects comparison and does not consider internal modifying factors affecting the chemical form of the mercury once ingested.

5.10.5 Risk Determination for Assessment Endpoint #10

Results of the exposure assessment and risk characterization identified a LOAEL exceedance for a reproductive endpoint to the raccoon from antimony and methyl mercury in the Lower Drinkwater River Corridor riverine habitat. A NOAEL exceedance for exposure in both the river and pond reference areas suggests that other sources of antimony and mercury to the environment are contributing to the overall exposure at the Site. Exposure of this species to methyl mercury from the ingestion of fish and crayfish was elevated above background exposure dosages. Comparison of methyl mercury concentrations in prey fish and crayfish from the Eastern Channel Corridor, Lower Drinkwater River Corridor, Lily Pond/Upper Factory Pond, and Middle/Lower Factory Pond exceeded the tissue based guidelines for the protection of piscivorous wildlife. Mammalian surveys confirmed the raccoon to be utilizing the habitats present and transect survey data suggest that this species was abundant. Based upon the above lines of evidence, a risk of potential biological harm of reproductive effects from antimony and mercury exposure in the Lower Drinkwater River Corridor, Lily Pond/Upper Factory Pond, and Middle/Lower Factory Pond and from methyl mercury exposure in the riverine and pond on-Site habitats were determined for omnivorous mammals in the aquatic habitats of the Site.

5.11 Assessment Endpoint #11 Protection and Sustainability of Insectivorous Mammal Populations Occupying the Terrestrial Habitats

Two measurement endpoints were used as lines of evidence in characterizing risks for this assessment endpoint. These included: (1) evaluation of exposure pathways and routes of exposure and comparison of predicted exposure dosages to NOAELs and LOAELs for a representative insectivorous mammalian species, the short-tailed shrew; and (2) performance of qualitative mammalian surveys to determine the presence of this species in the Site habitats. The lines of evidence are discussed below.

5.11.1 Short-tailed Shrew Exposure Modeling

Exposure of the short-tailed shrew was based upon utilization of the on-Site terrestrial habitats where soil invertebrates and small mammals were present.

- Terrestrial habitats present were found to be conducive for use by shrew for foraging and as habitat for denning.
- The exposure assessment revealed the dietary ingestion pathway contributed the largest percentage of the daily dosage of contaminants to this receptor. The primary exposure route was via dietary ingestion of terrestrial invertebrates.
- Site-related NOAEL and LOAEL HQs >1.0 were noted for thallium in the exposure assessment for the Proposed Greenway Area terrestrial on-Site habitat.
- Site-related NOAEL and LOAEL HQs >1.0 were noted for antimony, copper, and zinc in the exposure assessment for the Southern Disposal Area terrestrial on-Site habitat.
- The qualitative exposure assessment for the Cold Waste Area identified Site-related LOAEL HQs >1.0-<10 for aluminum, arsenic and zinc. A LOAEL HQ >10 was identified for barium and a LOAEL HQ >150 was identified for antimony in this area.

This measurement endpoint was characterized as having a moderate significance as the exposure assessment included use of species specific exposure parameters which were refined to the ecology of the short-tailed shrew in the habitats present. It also included use of conservative soil to soil invertebrate bioaccumulation factors.

5.12.3 Uncertainty Assessment

For this assessment endpoint, uncertainty in the risk evaluation is considered to be moderate. The use of species-specific exposure parameters to the Site habitats present and the confirmation of the species' presence in the habitats contribute to a moderate estimation of risk. The exposure assessment considered an areal exposure point concentration for the basis of predicting the dosage to this receptor via multiple exposure routes deemed typical to the ecology of the muskrat. Exposure areas of riverine, pond and wetland habitats remained consistent with the average home range occupied by this receptor in the wild. This method is consistent with the home range for this species as it pertains to the habitats present. The use of literature based chronic or sub-chronic NOAELs and LOAELs relies upon a direct effects comparison and does not consider internal modifying factors affecting the chemical form of the contaminant once ingested.

5.12.4 Risk Determination for Assessment Endpoint #12

Results of the exposure assessment and risk characterization identified a Site-related LOAEL exceedance for reproductive endpoints to the muskrat from antimony in the riverine and pond habitats. A Site-related LOAEL exceedance was also identified in the wetland habitat for lead and methyl mercury. Mammalian surveys did not confirm the muskrat to be utilizing the habitats present. Based upon the above lines of evidence, a risk of potential biological harm of reproductive effects from antimony, lead, and methyl mercury exposure was determined for herbivorous mammals in the Eastern Channel Corridor, Lower Drinkwater River, Upper Factory Pond and Marsh Upland Area.

5.13 Assessment Endpoint #13 Protection and Sustainability of Reptile Populations and Communities in Factory and Lily Ponds, the Drinkwater River and the Marsh Upland Area Wetland Habitat

Three lines of evidence were used as measurement endpoints in characterizing risks for this assessment endpoint. These included: (1) transect surveys for terrestrial reptile abundance in the Site and reference habitats; (2) trapping surveys of freshwater turtle populations in the Lower Drinkwater River Corridor, Lily and Factory Ponds; and (3) performance of a health assessment and calculation of an index of condition for freshwater turtle species surveyed. The lines of evidence are discussed below.

5.13.1 Transect Surveys for Terrestrial Reptiles

- Transect surveys performed across the areas of concern in the northern, central, and southern areas revealed the presence of four snake species in Site terrestrial habitats.
- The overall abundance of snake species was similar for the transect surveys on the Site and the reference habitats. The highest diversity of snake species was encountered in the southern transect.
- The most widely dispersed snake species was the eastern garter snake, *Thamnophis sirtalis sirtalis* which was encountered along all transects surveyed.
- A Massachusetts state listed endangered snake species, the black rat snake *(Elaphe obsoleta obsolete)* was encountered in the central portion of the Site.
- No relationship between the relative abundance of terrestrial reptiles and extent of contamination in on-Site soils was apparent.

This measurement endpoint was characterized as having a high significance as it directly measured reptile abundance in the terrestrial habitats present on the Site.

5.13.2 Aquatic Reptile Abundance in the Aquatic Habitats

The evaluation for this measurement endpoint revealed the following:

Two turtle species were documented on the Site: a small omnivorous species, the eastern painted turtle, *Chrysemys picta picta,* and a large carnivorous species, the common snapping turtle, *Chelydra serpentina serpentina.*

- In Forge Pond, common snapping turtles representing multiple age groups were collected. No eastern painted turtles were collected from this habitat. This species was present based upon visual observations of individuals basking on logs and exposed rocks.
- In moving in an upstream direction from Lower Factory Pond to the Lower Drinkwater River, the common snapping turtle displayed a decrease in relative abundance along a gradient of increasing mercury concentration in sediment. Common snapping turtles were either absent or present in very low numbers in areas with the highest mercury concentrations in sediments. This trend in declining snapping turtle abundance has been observed in other habitats with elevated mercury contamination in sediments (Albers et al., 1986). Snapping turtle density and abundance in Lower Factory Pond was comparable to that observed in Forge Pond.
- Predated snapping turtle nesting areas were identified at Lower Factory Pond and Forge Pond. No snapping turtle nesting areas were identified from Upper Factory Pond or the Lower Drinkwater River.
- No trend between the relative abundance of eastern painted turtle abundance and mercury contamination in sediments was apparent.
- Predated turtle nests of a smaller turtle species (i.e., likely the eastern painted turtle) were identified from Lower Factory Pond and Lily/Upper Factory Pond and Forge Pond.

This measurement endpoint was characterized as having a high significance as it directly measured freshwater turtle abundance in Site aquatic habitats and along a contaminated sediment gradient.

5.13.3 Determination of an Index of Condition and Health Assessment of Freshwater Turtles

Indices of condition for the snapping turtles from Forge Pond and Lower Factory Pond were similar. A single individual from Lily Pond also was within the range for snapping turtles from the reference area of Forge Pond. A higher incidence of shell disease, shell rot and metabolic bone disease was observed in the populations of snapping turtles in Middle/Lower Factory Pond. No incidence of shell disease was observed in the common snapping turtles surveyed from Forge Pond. The severity of the shell disease was not as severe as reported from other turtle populations (Lovich et al., 1996).

Incidence of shell disease was observed in the populations of eastern painted turtles surveyed from Lily/Upper Factory Pond or Lower Factory Pond. While a reference population from Forge Pond was not available for comparison, a higher incidence of shell disease was noted in populations from Lily/Upper Factory Pond than in Lower Factory Pond.

This measurement endpoint was characterized as having a high significance as the surveys considered direct observations of turtle populations present along a defined gradient in mercury contamination. The surveys also provided species specific data on the relative health of these populations.

5.13.4 Uncertainty Assessment

For this assessment endpoint, uncertainty is considered to be low. The use of Site-specific data on turtle abundance and relative health of these populations provides a direct means of assessing risk to this receptor group. The indices of condition and health assessment were performed for both on-Site and reference populations allowing for a direct comparison between local populations within the same watershed.

The exposure assessment did not provide a direct link between observed effects in the field to an associated toxicological endpoint. A casual link between literature-based studies and comparison to observed field data was used to characterize risks to turtle populations in Lily/Upper Factory Pond and Lower Factory Pond.

5.13.5 Risk Determination for Assessment Endpoint #13

Results of the terrestrial reptile surveys revealed comparable abundance of reptiles in terrestrial habitats across the Site and the reference habitats. No trend in terrestrial reptile abundance and extent or concentration of contaminants across the Site was apparent. The highest diversity of terrestrial reptiles was observed in the southern area of the Site. The diversity of terrestrial reptiles was comparable or exceeded that observed in the reference habitat. Based upon the above lines of evidence, no risk of biological harm was determined for terrestrial reptile populations in the Site habitats.

For aquatic reptiles, results of the exposure assessment and risk characterization identified a decreasing trend in the populations of the common snapping turtle along a gradient of increasing mercury concentrations in sediments. The observed decline displayed a recovery in Lower Factory Pond to numbers similar to those observed in the reference population. This recovery also showed a higher incidence of disease in the population in Lower Factory Pond. The decline in numbers was noted only for the common snapping turtle. Based upon the above lines of evidence, a risk of biological harm was determined for carnivorous turtles in the Lower Drinkwater River, Lily/Upper Factory Pond and Lower Factory Pond.

5.14 Assessment Endpoint #14 Protection of the Amphibian Community in the Riverine, Pond, and Wetland Habitats

Three measurement endpoints were used as lines of evidence in characterizing risks for this assessment endpoint. These included: (1) comparison of the concentrations of metals present in surface waters to benchmark values protective of amphibious species and to reference station concentrations; (2) performance of qualitative systematic transect surveys to determine the presence of this species in the Site aquatic habitats; and (3) performance of qualitative amphibian call-back surveys to determine the presence of this species in Site aquatic habitats. The lines of evidence are discussed below.

5.14.1 Surface Water Benchmark and Reference Station Comparison

None of the metals screened exceeded the chronic or acute benchmark values for amphibians from the riverine and pond sites sampled.

Concentrations of metals in surface waters were comparable to local conditions and below benchmark values indicating that ambient levels of metals in surface water do not indicate an excessive exposure to amphibious species from historical Site activities.

5.14.2 Qualitative Systematic Transect Surveys

Systematic transect surveys confirmed the presence of eight species of amphibians on the Site. The lowest species abundance observed was in the central area and the highest was in Forge Pond. SWDI values for the five transects ranged from 0 to 0.8 with the lowest diversity occurring in the central area and the highest in the southern area. The western parcel had the lowest number of tree frogs in relation to ranids (zero tree frogs, seven ranids). No frog species were observed in the central area. Overall amphibian abundance was moderate as twenty-nine separate observations were made on-Site during the transect surveys. No observations of dead amphibians were noted during the surveys.

5.14.3 Qualitative Amphibian Call-Back Surveys

The calls of five species of frogs and toads were heard on the Site. No calls were heard in the reference area, the Drinkwater River, or the Lower Drinkwater River. Thus, all calls heard were from Forge Pond and the Marsh Upland Area. Species distribution between ranid and bullfrogs was essentially equal. Upper Forge Pond was the only area where any tree frog calls were heard. Species diversity was lowest in the Marsh Upland Area (0.29) and higher in the Upper (0.45) and Lower (0.48) Ponds.

5.14.4 Uncertainty Assessment

For this assessment endpoint, uncertainty in the risk characterization is considered to be moderate. Comparison of the concentrations of metals in surface waters to benchmark values protective of amphibious species provide a moderate level of certainty. Comparison of on-Site analyte concentrations to reference station concentrations supplements the benchmark screening by determining if an exceedance is Site-related. Amphibians, as a group, are among the least formally studied and understood with regard to sensitivity and susceptibility to contaminants in their environment. How different amphibian species are exposed to contaminants during the various stages of their lives relative to the surface water, sediment or soil is understood than for other vertebrate groups. For this Site, surface water concentrations were measured to be relatively low, well below surface water benchmarks that are protective of amphibian communities. On this basis, the uncertainty about whether there is a potential risk to amphibian communities is considered low. Amphibians for much or part of their lives (possibly while eggs are developing in contact with sediment) would be exposed to the contamination present in the local sediments to some degree, and could receive additional intake from their diet and from food chain uptake. The ability to explicitly model these special periods in an amphibian's life cycle relative to exposure is currently very limited by the lack of available studies that link exposure of this group to sediment bound contamination. Finally, the lack of calls from some areas of the Site during the survey (including no calls from the reference area) provided a less robust measurement endpoint upon which to draw conclusions. Considering these factors, along with the clear counterbalancing result from the surface water concentration screening, the overall level of uncertainty for this aspect of the risk characterization was judged to be moderate.

5.14.5 Risk Determination for Assessment Endpoint #14

Results of the exposure assessment and risk characterization revealed no benchmark or reference station exceedances for concentrations of metals in the riverine or pond habitats on the Site. Qualitative amphibian surveys confirmed the presence of eight species of amphibians on the Site. Comparison of abundance and diversity revealed decreased abundance and species diversity in the central area. The lowest abundance was found in the western parcel where there was also a large number of ranids in relation to tree frogs. Based upon the above lines of evidence, no risk of potential biological harm was determined for amphibians in the central area and western parcel of the Site.

5.15 Assessment Endpoint #15 Protection of Plant, Soil Invertebrate, and Soil Microbial Processes in the Terrestrial Habitat

Three measurement endpoints were used as lines of evidence in characterizing risks for this assessment endpoint. These included: (1) comparison of surface soil analyte concentrations to surface soil benchmark values; (2) comparison of surface soil analyte concentrations to benchmark values protective of terrestrial plants; and (3) comparison of surface soil analyte concentrations to benchmark values protective of soil invertebrates and soil microbial processes. The lines of evidence are discussed below.

5.15.1 Surface Soil Benchmark Screening

Surface soil analyte concentrations were screened against surface soil benchmarks:

- Mean concentrations of cis-1,2-dichloroethene, trichlorethene, toluene, butylbenzylphthalate, antimony, chromium, copper, lead, mercury, nickel, and selenium exceeded benchmark values at one or more of the on-Site locations and were not considered reflective of local conditions (exceeding background concentrations by more than one order of magnitude).
- Exceedances were mainly located in the Southern Disposal Area, the Upper North Area, and the Marsh Upland Area.
- All other analyte concentrations were below the surface soil benchmark values or were comparable to background concentrations.

5.15.2 Terrestrial Plant Benchmark Screening

Surface soil analyte concentrations were compared to terrestrial plant benchmarks:

- Mean concentrations of barium, chromium, copper, lead, mercury, nickel, selenium, silver, and zinc exceeded terrestrial plant benchmark values at one or more of the on-Site locations and were not considered reflective of local conditions (exceeding background concentrations by more than one order of magnitude).
- Exceedances were mainly located in the Southern Disposal Area (eight exceedances) and in the Southern Conservation Area, Marsh Upland Area, and Upper North Area (two exceedances each).
- All other analyte concentrations in surface soils on-Site were below benchmark values protective of terrestrial plants or were comparable to background concentrations.
- No areas of stressed vegetation or areas of barren soil were noted in Site habitats.

5.15.3 Soil Invertebrate and Soil Microbial Process Benchmark Screening

Surface soil analyte concentrations were compared to soil microbial process benchmarks:

- Mean concentrations of antimony, barium, chromium, copper, total mercury, nickel, and zinc exceeded soil invertebrate and soil microbial process benchmark values at one or more of the on-Site locations and were not considered reflective of local conditions (exceeding background concentrations by more than one order of magnitude).
- Exceedances were mainly located in the Southern Disposal Area and in the Southern Conservation Area and Marsh Upland Area.

- All other analyte concentrations in surface soils on-Site were below benchmark values protective of soil invertebrates and soil microbial processes or were comparable to background concentrations.
- Terrestrial invertebrates were present in all habitats surveyed. The relative abundance of the invertebrates present in the leaf litter acts as a prey base for insectivorous wildlife species.

5.15.4 Uncertainty Assessment

For this assessment endpoint, uncertainty in the risk evaluation is considered to be moderate. Comparison of surface soil analyte concentrations to benchmark values protective of soils, terrestrial plants, and soil invertebrates and soil microbial processes alone provides a qualitative evaluation. Comparison of on-Site analyte concentrations to reference station concentrations supplements the benchmark screening by determining if an exceedance is Site-related. The assessment endpoint relies upon comparison of observed concentrations to a single benchmark value that does not consider chemical form, bioavailability or comparability of the plant species used to derive the benchmark.

5.15.5 Risk Determination for Assessment Endpoint #15

Results of the exposure assessment and risk characterization identified Site-related benchmark exceedances especially concentrated in the Southern Disposal Area with a total of 12 exceedances for analytes of the 3 measurement endpoints. Exceedances were also concentrated in the Southern Conservation Area, Upper North Area, and Marsh Upland Area locations. Site-related benchmark exceedances occurred for the surface soil (thirteen exceedances), terrestrial plant (nine exceedances), and soil invertebrate and soil microbial processes (seven exceedances) benchmark screenings. Copper, mercury, nickel, and zinc exceeded all benchmark values in the reference area for all three measurement endpoints and were not considered Site-related. No evidence of stressed vegetation or areas of habitat devoid of soil invertebrates were observed. Based upon the above lines of evidence, low risk of potential biological harm exists for terrestrial plants, soil invertebrates, and soil microbial processes due to elevated concentrations of a number of analytes including copper, mercury, nickel, and zinc in the Southern Disposal Area, Southern Conservation Area, and Marsh Upland Area terrestrial habitats.

6.0 SUMMARY AND CONCLUSIONS OF FIREWORKS SITE STAGE II ENVIRONMENTAL RISK CHARACTERIZATION

A Stage II ERC was performed for the Fireworks Site in Hanover, Massachusetts. The ERC was performed in accordance with the MCP (MADEP, 1996) as part of the Phase II CSA. The following presents an overview of the Site environmental setting and natural resources, the conceptual site model applied, assessment endpoints evaluated, and exposure assessment and risk characterization findings.

6.1 Summary of the Fireworks Site Stage II ERC

6.1.1 Environmental Setting and Natural Resources

The Site property is located within the towns of Hanover and Hanson. The total land area of the Site is approximately 250 acres. The Northern Area represents the most developed portion of the Site with commercial and light industrial land uses currently occupying a major portion of this area. The Northern Area is currently zoned for industrial and commercial land uses and terrestrial habitat for ecological receptors was limited to overgrown, formerly developed areas associated with the former Fireworks facility operations. Approximately 120 acres of land on the Site are zoned as conservation areas and are owned by the Town of Hanover.

Most of the Site has remained in a state of occupational abandonment that has resulted in the dumping of debris by trespassers. Types of chemicals that could be associated with the Site may include explosives, propellants, metals associated with the production of munitions, chemicals from research and development laboratories and miscellaneous chemicals associated with laboratory or Site housekeeping practices. Phase IIB, IIC, and IID investigations sampled the soils, groundwater, sediments and surface waters from the on-Site areas. These sampling events identified elevated concentrations of Site-related contaminants in the environmental media sampled. Elevated concentrations of total mercury were identified in the sediments of the Eastern Channel Corridor of the Drinkwater River, the Lower Drinkwater River Channel (Lower Drinkwater River Corridor) below the Eastern Channel Corridor, Lily/Upper Factory Pond and Middle/Lower Factory Pond.

Waterbodies present on the Site include the channel of the Drinkwater River along the northeast perimeter of the Site, a channel of the Drinkwater River along the northwest perimeter of the Site, the basins of Lily Pond, Upper and Lower Factory Pond and a small tributary, Torrey Brook, which enters along the northeastern perimeter of the Site and discharges into the Drinkwater River.

The Drinkwater River and its impoundments are classified as Class B waters by the MADEP. Class B waters are designated to be suitable habitat for fish and other aquatic life, support suitable habitat for wildlife, and suitable for primary and secondary contact recreation. Class B waters are also designated to be a suitable source for water supply with appropriate treatment, a suitable source for irrigation and other agricultural uses, a suitable source for compatible industrial cooling and process uses, and should have consistently good aesthetic value. The MADFW classifies the Drinkwater River, its tributaries and its impoundments as supporting warm water fisheries.

Wetlands include several smaller palustrine forested areas along the western perimeter and northeastern perimeter of the Site. Two of these isolated wetlands are located in the northern area of the Site and are each less than 1.0 acre in size. Both wetlands are classified as scrub-shrub wetlands on the NWI maps.

A search of the MADFW NHESP database revealed a number of rare species to be documented from the towns of Hanover and Hanson. These included two reptiles of special concern (eastern box turtle, *Terrapene carolina* and spotted turtle, *Clemmys guttata*), one amphibian of special concern (four-toed salamander *Hemidactylium scutatum*), two aquatic invertebrates (eastern pond mussel, *Ligumia nasuta* and New England blue dragonfly, *Enallagma laterale*), three plant species of special of concern (Plymouth gentian, *Sabatia kenndyana*; river arrowhead, *Sagittaria subulatta* var. *subulatta*; and estuary pipewort, *Eriocaulon parkeri*) and one endangered plant species (estuary beggar-ticks, *Bidens hyperborea* var. *colpophila*) and one fish species of special concern (bridle shiner, *Notropis bifrenatus*).

Site-specific studies performed on the Site revealed one endangered species (eastern black ratsnake, *Elaphe obsolete obsolete*), one threatened species (eastern spadefoot toad, *Scaphiopus holbrooki holbrooki*), and one species of special concern (eastern pond mussel, *Ligumia nasuta*) at the Site. No Areas of Critical Environmental Concern or Vernal Ponds have been identified on the Site based upon the MADFW NHESP database. There is a fish consumption advisory for Factory Pond fish as recommended by the Massachusetts Department of Public Health.

6.1.2 Conceptual Site Model and Food Chain Model Development

OHM has been detected in groundwater, surface water, sediments and surface soils in the three areas evaluated within the project boundary where exposure to ecological receptors (including benthic macroinvertebrates, plankton, fish, plants, soil invertebrates, mammals, birds, amphibians, and reptiles) can occur. Exposure pathways for semi-aquatic, aquatic and terrestrial receptors were identified and found to be complete with regard to potential exposure to Site-related OHM.

An ecological CSM was developed for the Site. Exposure routes for ecological receptors included direct contact with or incidental ingestion of contaminated abiotic media or through ingestion of prey that has bioaccumulated Site-related OHM. The environmental media of concern for the terrestrial receptors was surface soils (0-0.5 ft.). The exposure pathways of concern for the freshwater ponds/wetlands were exposure through the direct contact of aquatic life with surface water and sediments, and exposure of higher trophic level species through the ingestion of water, incidental ingestion of soils or sediments and ingestion of prey items that have bioaccumulated contaminants through the food chain. Contact with groundwater was evaluated as part of the surface water pathway using GW-3 standards.

Fifteen assessment endpoints were identified for the Stage II ERC. These assessment endpoints included benthic macroinvertebrate communities, phytoplankton and zooplankton communities, warm water fish communities, piscivorous birds and mammals, insectivorous birds and mammals, omnivorous waterfowl and omnivorous mammals, herbivorous birds and mammals, carnivorous birds, soil invertebrate and terrestrial plant communities, reptiles and amphibians. Each assessment endpoint utilized two to six measurement endpoints as lines of evidence for the risk characterization evaluation. Risks were assessed using a weight of evidence approach that considered individual lines of evidence in a cumulative fashion for assessing the significance and magnitude of risk to the specific endpoint.

The exposure assessment and risk characterization conclusions are summarized below and tabulated in Table B-6-1.

6.2 Conclusions of Exposure Assessment and Risk Characterization

6.2.1 Benthic Communities

Results of the exposure assessment revealed sediment concentrations exceeding MADEP sediment quality criteria in benthic communities and bioaccumulation of metals including mercury and methyl mercury at all locations on-Site. Mobilization of mercury into the food chain was determined to be via infaunal, deposit feeding organisms ingesting contaminated sediments and being consumed by other aquatic species. The highest body burdens of mercury and methyl mercury in infaunal aquatic worms was observed in the Eastern Channel Corridor and Marsh Upland Area. The bioavailability of mercury and other metals in sediments from one area of the Eastern Channel Corridor was observed. The toxic potential for all the sediments evaluated was determined to be low and whole sediment toxicity tests confirmed no toxicity was associated with the sediments evaluated. The benthic community surveys revealed changes in community structure in riverine, pond and wetland habitats. Functional assessment of these communities did not show functional alterations in the benthic communities sampled. Based upon the above lines of evidence, the elevated levels of total mercury and methyl mercury in the sediments of the Eastern Channel Corridor, Lower Drinkwater River and the Marsh Upland Area pose a risk of biological harm to benthic communities present in these habitats.

6.2.2 Freshwater Planktonic Communities

The exposure assessment and risk characterization for planktonic communities in the riverine and pond habitats used three measurement endpoints. The exposure assessment revealed no major exceedances of GW-3 criteria for groundwater discharge to surface water. Minor exceedances of AWQC for carbon disulfide, iron, manganese and silver were observed. However, the observed concentrations of these contaminants were comparable to concentrations observed in reference habitats sampled. No significant exceedances of toxicity reference values for freshwater phytoplankton or zooplankton toxicity in surface waters from the habitats sampled were noted. Based upon the above lines of evidence, no risk of potential biological harm exists for plankton in Site aquatic habitats.

6.2.3 Warm Water Freshwater Fish Communities

The exposure assessment and risk characterization for the warm water fish community endpoint for the riverine and pond habitats evaluated five measurement endpoints. The exposure assessment revealed minor exceedances of surface water concentrations of copper, iron and silver above screening criteria for freshwater fish. Sampling of the fish communities revealed a comparable community structure was present between the on-Site river and pond habitats and the corresponding reference populations. Functional feeding guilds in the fish communities in the Eastern Channel Corridor were slightly skewed towards piscivores when compared to the riverine reference fish community of the Northern Drinkwater River. A slight increase in the occurrence of ulcers, lesions and/or cloudy eyes was observed in fish from the Eastern Channel Corridor, Lower Drinkwater River Corridor and Lily Pond/Upper Factory Pond relative to occurrence of these external condition factors in the reference populations. Body burden concentrations for total mercury in forage fish (i.e., bluegill sunfish) exceeded tissue based NOAELs for behavioral effects from mercury in the river and pond habitats on-Site. Observed concentrations of total mercury in piscivorous fish (i.e., largemouth bass) exceeded tissue based NOAELs and LOAELs for reproductive effects and NOAELs for behavioral effects for representative studies with warm water fish. LOAEL based exceedances were confined to fish from the Eastern Channel Corridor and Lower Drinkwater River Corridor and 7-day toxicity testing with *Pimephales promelas* revealed no significant reductions in survival or growth associated with surface water from the Eastern Channel Corridor, Lower Drinkwater River Corridor, Lily Pond/Upper Factory Pond or the Middle/Lower Factory Pond habitats. Body burden levels of methyl mercury and the data collected on-Site fish community health indicates possible sub-chronic effects support a potential risk of biological harm to predatory fish from bioaccumulation of mercury in the habitats of the Eastern Channel Corridor.

6.2.4 Piscivorous Birds – Belted Kingfisher

The exposure assessment and risk characterization for the piscivorous bird assessment endpoint used three measurement endpoints as lines of evidence. Avian survey data confirmed the presence of the belted kingfisher in the aquatic habitats present on-Site. Other piscivorous bird species observed included black-crowned night herons and great blue herons. Statistical comparison of avian species richness between the reference habitat transect and the transects performed in Site habitats revealed no significant difference in avian diversity present in the habitats surveyed. Results of the exposure assessment and risk characterization identified a LOAEL exceedance for reproductive endpoints to the belted kingfisher from methyl mercury in all aquatic habitats evaluated. LOAEL exceedances for exposure in both the river and pond background areas suggest that other sources of mercury to the environment are contributing to the overall exposure at the Site and reference areas. Exposure of this species to methyl mercury from the ingestion of fish prey on the Site was elevated above background exposure. Based upon the above lines of evidence, a risk of potential biological harm of reproductive effects from methyl mercury exposure was determined for piscivorous birds in the Eastern Channel Corridor, Lower Drinkwater River Corridor, Lily Pond/Upper Factory Pond and Middle/Lower Factory Pond Site habitats.

6.2.5 Omnivorous Waterfowl – Mallard

The exposure assessment and risk characterization for the omnivorous waterfowl assessment endpoint used two measurement endpoints as lines of evidence to assess risks to this assessment endpoint. Avian surveys confirmed the mallard to be utilizing the habitats present but transect survey data suggest that this species is in low abundance in all habitats including the reference habitats. A LOAEL based exceedance was noted for the above lines of evidence indicating a risk of potential biological harm from exposure to total mercury in on-Site sediments for omnivorous waterfowl in the Eastern Channel Corridor, Lower Drinkwater River Corridor and the Marsh Upland Area. Exceedance of the NOAEL for methyl mercury is considered as an indeterminant risk; the presence of the mallard in the habitats evaluated suggests that overall abundance of this species is stable. No significant risk of biological harm was determined for omnivorous waterfowl in the habitats of Lily Pond/Upper Factory Pond and Middle/Lower Factory Pond.

6.2.6 Insectivorous Birds – American Woodcock

The insectivorous bird assessment used two measurement endpoints as lines of evidence for assessing exposure and risk to this assessment endpoint. Avian observations confirmed the American woodcock and other insectivorous birds to be utilizing the habitats in the Central Commercial Area, but transect survey data suggest that this species was in low abundance in all habitats including the reference areas. The Central Commercial Area was determined to present no significant risk of harm to insectivorous birds based upon the comparability of Central Commercial Area exposure dosages to background dosages. Those areas where exposure dosages exceeded background estimates and resulted in LOAEL HQs >1.0 were identified as contributing to a risk of potential biological harm for insectivorous birds. The identified areas and the contaminants for each include Flood Plain Area (lead and selenium); Proposed Greenway Area (total mercury); Marsh Upland Area (lead and total mercury); Southern Conservation Area (barium, lead, total mercury and di-n-octylphthalate); and the Southern Disposal Area (arsenic, barium, chromium, copper, lead, total mercury, selenium and zinc).

6.2.7 Carnivorous Bird – Red-tailed Hawk

The carnivorous bird assessment used two measurement endpoints as lines of evidence for assessing exposure and risk to this assessment endpoint. The primary exposure routes were the small mammal ingestion route or the incidental soil ingestion route. Avian observations confirmed the red-tailed hawk to be utilizing Site habitats. Based upon the Site-wide evaluation, no risk of significant harm to carnivorous birds was determined based upon the comparability of Site-wide exposures to background dosages. The Southern Disposal Area and Marsh Upland Area where exposure dosages exceeded background estimates and resulted in LOAEL HQs > 1.0 for barium, chromium, lead and zinc were identified as contributing to a risk of potential biological harm for carnivorous birds. The exposure assessments for these individual areas applied an areal use factor of 1.0 resulting in an overestimate of exposure to any contaminants associated with these individual areas. The Site-wide evaluation presents a more realistic representation for the exposure assessment and risk characterization for this receptor species.

6.2.8 Herbivorous Waterfowl – Mute Swan

Results of the exposure assessment and risk characterization for the herbivorous waterfowl identified a LOAEL exceedance for reproductive endpoints to the mute swan from total mercury. A LOAEL exceedance for exposure in both the river and pond background areas suggests that other sources of mercury to the environment are also contributing to the overall exposure at the Site and reference areas. Based upon the above lines of evidence, a risk of potential biological harm from methyl mercury exposure was determined for herbivorous waterfowl in the Eastern Channel Corridor, Lower Drinkwater River Corridor, Lily Pond/Upper Factory Pond and Middle/Lower Factory Pond. For the Marsh Upland Area, LOAEL exceedances greater than 1.0 were observed for total mercury, methyl mercury and lead indicating a risk of potential biological harm for herbivorous waterfowl in this habitat.

6.2.9 Piscivorous Mammal – Mink

Results of the exposure assessment and risk characterization for the piscivorous mammal identified a LOAEL exceedance for reproductive endpoints to the mink from methyl mercury. Mammal surveys confirmed the presence of the mink to be utilizing the aquatic habitats of Upper and Lower Factory Pond. The presence of the mink confirms that piscivorous mammals do utilize the aquatic resources present. Results of the exposure assessment and risk characterization identified a LOAEL exceedance for reproductive endpoints to the mink from methyl mercury. The primary exposure route contributing to the exposure to the above contaminant was the small fish ingestion route. A LOAEL exceedance for exposure in both the river and pond background areas suggests that other sources of mercury to the environment are contributing to the overall exposure at the Site and reference areas. Based upon the above lines of evidence, a risk of potential biological harm from methyl mercury exposure was determined for piscivorous mammals in the Eastern Channel Corridor, Lower Drinkwater River Corridor, Lily Pond/Upper Factory Pond and Middle/Lower Factory Pond.

6.2.10 Omnivorous Mammal – Raccoon

Results of the exposure assessment and risk characterization identified a Site-related LOAEL exceedance for reproductive endpoints to the raccoon from antimony and mercury in the Eastern Channel Corridor riverine habitat. The primary exposure route contributing to the exposure to the above contaminants was the crayfish ingestion route and the incidental sediment ingestion route. Mammalian surveys confirmed the raccoon to be utilizing the habitats present and transect survey data suggest that this species is in relatively high abundance. Based upon the above lines of evidence, a risk of potential biological harm of reproductive effects from antimony and mercury exposure in the Eastern Channel Corridor from methyl mercury exposure in the riverine and pond on-Site habitats was determined for omnivorous mammals.

6.2.11 Insectivorous Small Mammals – Short-tailed Shrew

Results of the exposure assessment and risk characterization identified a Site-related LOAEL exceedance for reproductive endpoints to the short-tailed shrew from thallium in the Proposed Greenway Area habitat. Site-related LOAEL exceedances for reproductive endpoints to the short-tailed shrew were also noted for antimony, copper, and zinc in the Southern Disposal Area habitat. The primary exposure route for the short-tailed shrew in both habitats is terrestrial invertebrate ingestion. Mammalian surveys confirmed small mammals to be utilizing the habitats present by indirect observation. Based upon the above lines of evidence, a risk of potential biological harm of reproductive effects from thallium exposure in the Proposed Greenway Area habitat and from antimony, copper, and zinc in the Southern Disposal Area habitat was determined for insectivorous mammals.

6.2.12 Herbivorous Mammal – Muskrat

Results of the exposure assessment and risk characterization identified a Site-related LOAEL exceedance for reproductive endpoints to the muskrat from antimony in the riverine and pond habitats. A Site-related LOAEL exceedance was also identified in the wetland habitat for lead and methyl mercury. The primary exposure route was the aquatic plant ingestion route for all the listed contaminants. Mammalian surveys did not identify the muskrat to be utilizing the habitats present. Based upon the above lines of evidence, a risk of potential biological harm of reproductive effects from antimony, lead, and methyl mercury exposure was determined for herbivorous mammals in the Eastern Channel Corridor, Lower Drinkwater River Corridor, Lily Pond/Upper Factory Pond, Middle/Lower Factory Pond and Marsh Upland Area.

6.2.13 Reptile Communities – Snapping Turtles

The diversity of terrestrial reptiles was comparable to or exceeded that observed in the reference habitat. Based upon the above lines of evidence, no risk of biological harm was determined for terrestrial reptile populations in Site habitats. For aquatic reptiles, results of the exposure assessment and risk characterization identified a decline in the populations of the common snapping turtle along a gradient of increasing mercury concentrations in sediments. A recovery in Lower Factory Pond to numbers similar to those observed in the reference population was observed, though this population showed a higher incidence of disease relative to the reference population. Based upon the above lines of evidence, a risk of biological harm was determined for carnivorous turtles in the Lower Drinkwater River Corridor, Lily Pond/Upper Factory Pond and Middle/Lower Factory Pond.

6.2.14 Amphibian Communities – American Bullfrog

Results of the exposure assessment and risk characterization revealed no benchmark or reference station exceedances for concentrations of metals in the riverine or pond habitats on the Site. Qualitative amphibian surveys confirmed the presence of eight species of amphibians on the Site. Based upon the above lines of evidence, no risk of potential biological harm was determined for amphibians across the Site.

6.2.15 Soil Invertebrate, Terrestrial Plants, and Microbial Communities

Results of the exposure assessment and risk characterization identified a Site-related benchmark exceedance in the Southern Disposal Area, Southern Conservation Area, Upper North Area, and Marsh Upland Area locations. Site-related benchmark exceedances occurred in surface soils for terrestrial plants, soil invertebrates and soil microbial processes benchmark screenings. No evidence of stressed or concentrated areas of dead or dying vegetation were noted during the field surveys performed. Numerous species of soil invertebrates including armored millipedes, sowbugs, grubs, earthworms, termites, ants, coleopterans, spiders and slugs were observed in the leaf litter and beneath debris surveyed during the wildlife transect searches. No evidence of stained soils was observed in any of the areas surveyed. Based upon the above lines of evidence, a low risk of potential biological harm exists for terrestrial plants, soil invertebrates, and soil microbial processes due to elevated concentrations of copper, mercury, nickel, and zinc in the Southern Disposal Area, Southern Conservation Area, Upper North Area, and Marsh Upland Area terrestrial habitats.

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Appendix C
Characterization of Risk of Harm to Safety

TETRA TECH EC, INC.

APPENDIX C

DRAFT
CHARACTERIZATION OF RISK OF HARM TO SAFETY

FIREWORKS I
(FORMER FIREWORKS FACILITY)
HANOVER, MASSACHUSETTS
TIER IA PERMIT #100223
RTN: 4-0090

August 2005

Prepared for

The Fireworks Site Joint Defense Group

Prepared by

Tetra Tech EC, Inc.
133 Federal Street 6th Floor
Boston, Massachusetts 02110

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SGS

Revision	Date	Prepared By	Approved By	Pages Affected
1	8/23/05	R. Marnicio	B. Allen	All

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LIST OF ATTACHMENTS

1.0 REQUIREMENT UNDER THE MCP

Section 40.0960 of 310 CMR (MADEP, 2005), "Characterization of Risk to Safety," specifies that every risk characterization under the Massachusetts Contingency Program (MCP) must include an evaluation of the risk of harm to safety. This involves evaluating the current and reasonably foreseeable conditions at the site relative to their potential impact on safety. These conditions are generally characterized or projected using much of the same information collected for the characterizations of the risk to human health and the environment that relate to the site, the receptors, and the potential exposure pathways. A level of No Significant Risk of harm to safety exists (or has been achieved following some response to mitigate hazards) if the conditions at the site do not currently and will not in the foreseeable future pose a threat of physical harm or bodily injury to people. The focus of an evaluation of the risk of harm to safety for a site under the MCP must be a condition or set of conditions linked causally to the release of oil and/or hazardous material (OHM) for which the site has been scored and permitted for investigation and possible response.

Section 40.0960 of 310 CMR provides examples of the types of conditions that could be considered to pose a threat of physical harm or bodily injury to people. They include:

1) The presence of rusted or corroded drums, open pits, lagoons, or other dangerous structures;
2) Any threat of fire or explosion, including the presence of explosive vapors resulting from a release of OHM; and
3) Any uncontained materials that exhibit corrosivity, reactivity or flammability as described in 310 CMR 40.0347.

The following sections describe the characterization of the risk of harm to safety for the various risk assessment areas of the Fireworks Site (the Site). Section 2 presents a summary of the operations at the former Fireworks facility as they relate to this evaluation. Section 3 presents a survey of the conditions present at the Site that could pose a threat of physical harm or bodily injury to people using or accessing the Site now or in the future. Section 4 identifies which of these conditions are indicated to be linked causally to the release of OHM for which the Site has been scored and permitted for response actions under the MCP. This section includes clear statements as to whether or not a condition of No Significant Risk of harm to safety exists or has been achieved in each risk assessment area. Section 5 provides a summary of the evaluation for the area where a condition of No Significant Risk of harm to safety does not exist relative to the release. Section 6 lists the references used in this report.

2.0 SUMMARY OF FORMER FIREWORKS FACILITY OPERATIONS

The following summary of the historical operations has been compiled from the information contained in previously published and MADEP-approved Site data reports (FWENC, 1997, 1999a, 2000, 2002, and 2004) and discussions with the MADEP Manager (Site Walk 2004, Meeting 2005).

Activities at the Site began as early as 1907 when National Fireworks Manufacturing Corporation began the commercial manufacture of fireworks for civilian use. During World War I, the company produced military munitions under the direction of the War Department. In 1924, National Fireworks Manufacturing Corporation became National Fireworks, Inc. During the 1930s, munitions production began to accelerate at the Site. At the onset of World War II, the Site was devoted exclusively to fulfilling military contracts, initially for the British Government under the Lend-Lease Program and then solely for the U.S. Government. During the war, production facilities operated 24 hours per day, employed 5,000 persons, and were the leading producers of 20-mm antiaircraft shells. After the war, National Fireworks, Inc. continued production of pyrotechnics and munitions and performed research and development on munitions for the U.S. Government. Some civilian fireworks production also continued at the former facility. A number of different companies operated at the Site until it closed around 1970. Following the facility closure, U.S. military personnel came to the Site and destroyed all government owned raw materials and explosives at the Waste Burn and/or Demolition Pit Areas located in the southern portion of the Site.

In general, the development and manufacturing activities at the former facility were performed in the northern third of the Site. Initially, three areas in this northern portion of the Site were investigated because of their prior operations involving fireworks and munitions:

Fox Island Area: The Fox Island Area lies in the northeastern part of the Site in an area including or proximate to former explosives/munitions manufacturing operations. Lead azide, lead thiocyanate, mercury fulminate, various solvents, and explosives were used in the mixing or manufacturing of tracer ammunition, primer compounds, squibs, flare mixes, and other explosives. Fox Island also served as a manufacturing area for land mines.

Building 80 Area (Sixth Street): The Building 80 Area also lies in the northeastern part of the Site, but is south of the Fox Island Area. The Building 80 Area was used for the production of munitions (including possibly land mines, detonators and incendiary grenades); research and development for TNT replacement explosives; degreasing area for fuse housings, and the propellant loading area for 20-mm shells.

Building 307 Area: The Building 307 Area was located at the southern end of the manufacturing area that occupied the northern portion of the Site. This manufacturing area is bounded to the north and west by the Drinkwater River. Building 307 is believed to have been the site of past manufacturing operations, including the machining of HMX explosive, production of flares, primers and detonators, assembly of 20-mm shells, loading of tetryl pellets, and degreasing of projectiles.

Following the initial investigation of these areas, additional subareas in the northern part of the Site also were investigated. These other areas also were indicated to have been used in the process of manufacturing, developing, testing, or production of fireworks and munitions:

- Primer-Detonator Production Area
- Mine Research Area
- Fuse and Flare Manufacture Area
- Mine Research Area
- Mine Explosives Loading Area
- Laboratory
- Relict Structures Area

The middle third of the Site (north-to-south) was the area where raw materials and assembled items were stored prior to use or shipment. The area was maintained to remain somewhat isolated, with unimproved access roads winding through a wooded area. These roads provided access to a series of widely spaced storage magazines and storage areas.

The southern third of the Site was where the primary disposal activity occurred. Two areas, the Waste Burn Pit (in the Southern Disposal Area) and the Demolition Pit (in the Marsh Upland Area) were used to destroy excess and off-specification munitions. The inert remains from these destruction operations were disposed in the Cold Waste Area. Areas used for drum storage or the disposal of drummed waste (the Factory Pond Drum Area) also were located throughout the Southern Conservation Commission Area. These four areas are briefly described below:

Waste Burn Pit: Available information indicates that the Waste Burn Pit in the Southern Disposal Area was used as a disposal/destruction area during pyrotechnics and/or munitions manufacturing. Waste materials, possibly anti-personnel mine manufacturing wastes and off-specification raw materials were apparently destroyed by open combustion. Localized depressions in the ground provide a rough approximation of the location of this area.

Demolition Pit: This area is located in the upland portion of the Marsh Upland Area. This area was used for the detonation of off-specification and excess munitions and materials. Anecdotal accounts indicate that the Demolition Pit and surrounding area may have received waste materials from off-site facilities for disposal in addition to wastes from on-site activities. Many drums and some soils were removed from this area during an EPA-mandated removal action conducted in 1989 (GEC, 1989).

Cold Waste Area: The Cold Waste Area is located in the southwestern portion of the Site abutting the east bank of Factory Pond. Based on available information, the Cold Waste Area previously served as a repository and burial area for metallic ordnance explosive waste that had been fired, discharged, detonated or otherwise spent (e.g., shell casings, metallic debris such as fins, fuse assemblies, firing pins). Historical wastes associated with this area have included unfused training rounds. Evidence of relict fencing (coarse 2-inch square mesh) and a review of older Site maps indicate that the Cold Waste Area previously had been fenced off and isolated. Evidence has been observed that souvenir hunters have excavated portions of the Cold Waste Area and adjacent pond bank looking for metallic ordnance debris. In addition, precipitation and surface run-off have eroded portions of the Cold Waste Area and exposed previously buried materials. The Test Slab (where propellants were tested) and some relict foundations are located adjacent and southeast of the Cold Waste Area.

Factory Pond Drum Area: Much of the Southern Conservation Commission Area is comprised of an area that was identified in Phase IIC as the Factory Pond Drum Area. This area is believed to have been used primarily as a staging area for drum storage (full and/or empty) after conveyance to other disposal areas in the southem portion of the Site. Drums were removed by a private contractor to a former owner between December 1988 and May 1989 (GEC, 1989). Site reconnaissance activity early in the project (FWENC, 1997) documented the presence of residual drum remnants and relict structures in this area.

The southern portion of the Site also was the location of the Former Test Range. The Former Test Range (in the Southern Conservation Commission Area) also was used for testing propellants and firing small arms.

3.0 SURVEY OF CONDITIONS THAT COULD POSE A THREAT OF PHYSICAL HARM OR BODILY INJURY TO PEOPLE AT THE SITE

A variety of conditions now exists at the Site that currently or may conceivably pose a threat of physical harm or bodily injury to people accessing and using the Site. This evaluation of risk of harm to safety first catalogues and briefly describes these conditions. Thereafter, a judgment is made relative to each condition or similar set of conditions as to whether they are related to the release of OHM for which the Site is being investigated under the MCP.

The full set of identified conditions that could pose a threat of physical harm or bodily injury to people at the Site includes:

- Conditions Associated with Potential Ordnance-Related Items;
- Conditions Associated with Facility and Site Maintenance; and
- Conditions Associated with Site Housekeeping.

Each of these types of conditions is discussed below.

3.1 Conditions Associated with Potential Ordnance-Related Items

Potential ordnance-related items have been found in or have been anecdotally linked to certain risk assessment areas of the Site. Ordnance-related items have been found at the site up to the early 1990s (S. Tucker, Pers. Comm., March 2005). Since the TtEC investigation activities began at the Site (in 1997), no additional ordnance-related items have been reported to the Hanover Police or Fire Departments (S. Tucker, Pers. Comm., March 2005). The past discoveries of ordnance-related items in some of the risk assessment areas are summarized by area in the sections below.

3.1.1 Material Found in the Upper North Area (Former Development and Manufacturing Area)

During the Phase IIB investigation activities performed in 2000, the project's unexploded ordnance (UXO) specialist found some widely dispersed items lying on the ground in the Upper North Area that were believed to be inert fuse components. The UXO Specialist determined that these items were inert and did not pose a threat. Consequently, the items were left in place undisturbed.

Prior to soil sampling within the Upper North Area during the Phase IIA, IIC and IID field programs conducted between 1998 and 2003, the locations where ground disturbing activity was to be performed for soil sampling were pre-screened by the project's UXO specialist using a magnetometer. The detection of a magnetic anomaly (indicating the likely presence of metal) would have caused the sampling location to be shifted slightly to a nearby location where no anomaly was detected. No additional ordnance-related items were found during the soil sampling performed within the Upper North Area during these phases of the investigation.

3.1.2 Material Found Near the Marsh Upland Area (Demolition Pit)

As part of historical operations, defective or off-specification materials that could potentially explode were generally taken to the Demolition Pit in the Marsh Upland Area to be de-energized prior to being disposed in the Cold Waste Area. During the Phase I investigation activities performed in 1997, a number of ordnance-related items were found in the vicinity of the Demolition Pit Area or the Former Test Range on the surface of the ground. These included: (1) remnants of a 4-pound Thermite magnesium fire bomb; (2) a 20-mm projectile; (3) a detonator carrier; (4) an expended 20-mm cartridge case; and (5) a number of expended 0.50-caliber rounds. This inert material was collected and stockpiled by the project's UXO specialist, and subsequently removed from the area by the Massachusetts State Police through arrangements with the Hanover Fire Chief.

Some old drums, soils, and other debris were removed from the Demolition Pit Area by a private contractor to a former owner between December 1988 and May 1989 (GEC, 1989).

Prior to soil sampling within the Marsh Upland Area during various phases of the field programs conducted between 1998 and 2003, the locations where ground disturbing activity was to be performed for soil or sediment sampling were pre-screened by the project's UXO specialist using a magnetometer. The detection of a magnetic anomaly (indicating the likely presence of metal) would have caused the sampling location to be shifted slightly to a nearby location where no anomaly was detected. No additional ordnance-related items were found during the soil or sediment sampling performed within the Marsh Upland Area during these phases of the investigation.

3.1.3 Material Found in the Southern Disposal Area (Waste Burn Pit)

Defective or off-specification materials that could be burned were generally taken to the Waste Burn Pit in the Southern Disposal Area to be consumed or destroyed prior to any inert remains being disposed in the Cold Waste Area. During the Phase IIB investigation activities performed in 2000, the project's UXO specialist found three additional items lying on the ground in the Southern Disposal Area. The first item was an empty 2.25-inch rocket warhead that was found in the Factory Pond Drum Area near the Waste Burn Pit. The second item was an expended Bellows squib that was found in the Waste Burn Pit. The third item was another 2.25-inch rocket warhead that appeared to contain some unknown burnt filler. This item was destroyed by a Massachusetts State Police detonation in the Cold Waste Area along with the suspect items found in other locations during this field event.

Prior to soil sampling within the Southern Disposal Area during various phases of the field programs conducted between 1998 and 2003, the locations where ground disturbing activity was to be performed for soil sampling were pre-screened by the project's UXO specialist using a magnetometer. The detection of a magnetic anomaly (indicating the likely presence of metal) would have caused the sampling location to be shifted slightly to a nearby location where no anomaly was detected. No additional ordnance-related items were found during the soil sampling performed within the Southern Disposal Area during these phases of the investigation.

3.1.4 Material Disposed in the Cold Waste Area

The Cold Waste Area was the primary area designated for the disposal of "cold waste," or ordnance-related items that did not contain energetic material or that had been previously de-energized by burning or detonation. As such, materials disposed of in this area were supposed to be inert metal casings or components of the items manufactured and tested at the Fireworks facility. However, if a potentially energetic ordnance-related item was not properly or completely de-energized prior to disposal, it is possible that it still may have been buried or dumped in this area. No subsurface investigation of the Cold Waste Area has been conducted for the purpose of identifying and classifying the nature of the ordnance-related items disposed there (as this area is being evaluated to determine if it meets the definition of a Formerly Utilized Defense Site (FUDS)). Consequently, the Cold Waste Area may still contain some energetic items.

During an Immediate Response Action (IRA) performed in 1999 to re-fence in the Cold Waste Area (FWENC, 1999b) (it had previously been fenced in years ago), four ordnance-related items were uncovered while excavating the holes for the waterside gateposts along the shoreline of Upper Factory Pond. One of these items had the words "Inert Load" stenciled on it. However, an unambiguous visual identification of the items as inert could not be made by the project's UXO specialist. As such, these items were treated as potentially energetic and dangerous, and all work crews were removed from the area. The Hanover Fire Department was notified in accordance with the Cold Waste Area IRA Work Plan. The Hanover Fire Department notified the Massachusetts State Police and a police removal team arrived at the site within a short time to take custody of the items. The gatepost installation and fencing activity was then completed without the discovery of additional items. It was later determined that none of these items had been energetic.

During the Phase IIB investigation activities performed in 2000, the project's UXO specialist found four additional items in the Cold Waste Area inside the fencing. These items were identified to be: (1) the empty remains of a 3-inch projectile; (2) two expended 40-mm cartridge cases; and (3) the case base from a fired 105-mm cartridge. All of these items were found lying on the ground in plain sight. These items were destroyed within the Cold Waste Area by the Massachusetts State Police. None of these items were shown to be energetic.

Prior to soil sampling adjacent to the Cold Waste Area during the Phase IIC field program conducted in 2002, the location where ground disturbing activity was to be performed for sampling was pre-screened by the project's UXO specialist using a magnetometer. The detection of a magnetic anomaly (indicating the likely presence of metal) would have caused the sampling location to be shifted slightly to a nearby location where no anomaly was detected.

A point detonating fuse was found during the limited soil sampling performed within the Cold Waste Area during the Phase IID field investigation in 2003. This item was collected by the UXO specialist and temporarily stockpiled within the fenced Cold Waste Area and was subsequently disposed by the Massachusetts State Police through arrangements with the Hanover Fire Chief.

3.1.5 Material Found in the Shallow Sediments Adjacent to the Cold Waste Area (Lily Pond/Upper Factory Pond Area)

During the IRA performed in 1999 to fence in the Cold Waste Area (see above), some inert ordnance-related items were found in the shallow sediments or saturated soil along the shoreline (see the description of these items in Section 3.1.4 above). These items were exposed when the water level in Upper Factory Pond was lowered to facilitate the installation of the fencing and gates (the gates were incorporated into the fencing to allow the area to later be used as a boat launch during the investigation and remediation activities at the Site). There also were anecdotal accounts of defective or off-specification items being floated out into Factory Pond and sunk (Site Walk, 2004).

In order to determine if there was any indication of a large number of potential ordnance-related items in the sediment near the Cold Waste Area or elsewhere in the ponds, a combined bathymetric and magnetometer survey was performed in Lily Pond and in both the Upper and Lower Factory Pond Areas in October 2003. A summary of this investigation is presented in Attachment A "Technical Memorandum: Geophysical Results for the Fireworks Project Factory Pond Survey" (TtFW, 2004a). Combined magnetometer readings and digital positioning information were collected and used to produce mappings of the probable locations of underwater/under sediment metallic material. Seventy-eight (78) anomaly locations were identified on the basis of the review of these results. These anomaly locations were further evaluated and 27 areas of potential interest were selected for visual inspection using a drop video camera equipped with high intensity lighting. These 27 areas of potential interest were primarily located along the eastern shoreline of Upper Factory Pond adjacent to the Cold Waste Area and at the southern tip of Upper Factory Pond at the former bridge location. A summary of this video inspection is presented in Attachment B "Interoffice Memorandum: Underwater Video Footage" (TtEC, 2004b). The inspection revealed: fencing; a fuel oil tank; part of a car; steel plate; parts of bicycles; a 55-gallon drum;

and some other unidentifiable metal objects. None of the objects visible in the video were identified as ordnance wastes or materials by the UXO specialist that evaluated the footage. As such, it appears that the ordnance-related debris found in the shallow sediment adjacent to the Cold Waste Area had probably been buried at the Cold Waste Area and had become exposed by the erosion of the cover soil along the shoreline. Based on the information collected during the geophysical survey and video inspection activities performed in the ponds, no evidence has yet been found to support the anecdotal claim that ordnance items or debris was dumped directly into the water.

3.1.6 Material Found in the Southern Conservation Commission Area (Former Test Range)

During the Phase IIB investigation activities performed in 2000, the project's UXO specialist found some widely dispersed items lying on the ground at the Former Test Range (located within the Southern Conservation Commission Area) that were believed to be the inert remains of incendiary bomblets. The UXO specialist determined that these items were inert and did not pose a threat. Consequently, the items were left in place undisturbed.

Additionally, it has been anecdotally reported that 105-mm projectiles were fired at the Former Test Range (Site Walk, 2004). No evidence of the firing of such relatively large ordnance has been seen in this area during many reconnaissance walks. Given the composition and configuration of the soil berm back stop at the Former Test Range, it appears very unlikely the 105-mm projectiles could have been fired into it and been effectively contained. Interviews with a number of former facility employees and local residents do not corroborate the use of the Former Test Range in this way. It also has been determined that there was no need to test or fire such items at the Site, since there was an active range in the nearby Middleboro/Halifax area and nearly daily runs were made from the former Fireworks facility to this range for test firing activities (Meeting, 2005). The presence of large caliber projectiles or UXO in this area is considered very unlikely.

3.2 Conditions Associated with Facility and Site Maintenance

The lack of routine, ongoing maintenance on many of the buildings and structures at the former Fireworks facility by subsequent owners has created conditions in some locations that could pose a threat of physical harm or bodily injury to people. Conditions of this type are associated with dilapidated buildings and storage magazines, and with the dam that creates Factory Pond.

3.2.1 Dilapidated Buildings and Storage Magazines

The structural integrity and safety of a number of the remaining original former Fireworks facility buildings and storage magazines has degenerated over the years since the facility ceased operations. Some of these buildings and structures have roofs or walls that appear to be unstable and prone to collapse. Dilapidated buildings that pose a threat of collapse if entered or contacted exist in the northeastern portion of the Upper North Area. Similarly, the former storage magazines in the western portion of the Central Commercial Area are typically collapsed or on the verge of falling in. None of these buildings or structures is currently owned by the Joint Defense Group. The current state of disrepair of these structures developed over the years since the Fireworks facility was closed over thirty years ago.

3.2.2 Structural Integrity of the Factory Pond Dam

The Factory Pond Dam creates the impoundments that are Factory Pond and Lily Pond. The Factory Pond Dam is a stone and concrete-faced earthen embankment structure. The dam is owned jointly by the Towns of Hanover and Hanson, and is maintained by the two Towns under the regulatory oversight of the Massachusetts Department of Conservation and Recreation's Office of Dam Safety. The dam limits water flow below the Site (Lower Factory Pond), and creates a partial barrier to the downstream movement of water, sediment and fish that may contain some level of contamination from former facility operations. Because of the volume of water behind the dam and the characteristics of the area downstream of the dam, Factory Pond Dam has received a rating that places it on the least frequent inspection schedule (i.e., once every 10 years). Factory Pond Dam was last inspected on April 19, 1995. The inspection reiterated the findings of previous reports that "The dam is not properly and regularly maintained. Its condition demands an active program of rehabilitation to ensure its continued service." The Towns hired an engineering firm to design and oversee some interim repairs. These repairs were made to most of the dam rockery and embankment sections in 1996. Some of the repairs included refacing the downstream dam face with grouted rip-rap, replacing missing sections of the concrete cap, reestablishing the transition zones between the spillway and the west and east embankments, adding a 36-inch drain pipe to the primary spillway and clearing the debris from the waterway within 45 feet of the spillway. The dam is due for another inspection this year based on the Office of Dam Safety inspection guidelines. Any failure of this dam could pose a threat of physical harm or bodily injury to people immediately below it or within the flow path of the released flood water. In addition, such a release could result in the migration of contaminated sediment and fish currently contained above the dam to downstream locations. This potential spread of contamination may lead to subsequent health risks to people, if they were to be exposed to it.

3.3 Conditions Associated with Site Housekeeping

Some residual wastes from the former facility operations, as well as the recent dumping of a variety of types of debris and trash have created poor site housekeeping conditions that have the potential to pose a threat of physical harm or bodily injury to people. Access controls do not exist or are not strictly enforced throughout most of the Site, especially in the southern third of the Site (i.e., the Southern Conservation Commission Area, the Southern Disposal Area, and the Marsh Upland Area). This lack of control and oversight has allowed some portions of the Site to continue to be used for recent dumping and disposal.

3.3.1 Dumping of Trash and Debris

These conditions include the presence of rusty drums and empty containers lying on the ground, as well as widespread dumping of household trash, used tires, chemicals, and discarded appliances. Old rusty drums that could cause cuts and abrasions if injudiciously handled are present in certain locations in the Upper North Area. Piles of broken glass that pose similar risks of cuts and bodily injury are present in the Southern Disposal Area. Significant amounts of household trash and waste materials have been dumped at various locations throughout the southern portion of the Site, especially near the Former Test Range Area and in other locations within the Southern Conservation Commission Area next to the dirt access roads. Attempts to lock gates that can be placed to block the access roads in a few locations in the southern portion of the Site have not been very successful duc to the relatively isolated nature of this area and the ease with which unobserved access may be gained (since the area is not routinely patrolled or monitored to discourage dumping). Evidence of indiscriminant dumping, some even occurring overnight during field investigation activities, has been observed. In most cases, the dumped material is easily distinguished by type, amount or appearance as recently deposited. In other cases, the degraded condition of the materials makes their age and origin more difficult to ascribe. The recently disposed waste has included flammable liquids, charges to activate/deploy automobile air bags, rusty metal appliances, and a range of combustible wastes and debris. This material may potentially pose a risk of fire, explosion or chemical burn under certain conditions. Since a (GEC, 1989) removal response was performed in these areas by a private contractor to a former owner between December 1988 and May 1989, it is believed that the vast majority of the waste and debris of this type now present at the Site was deposited there well after the closure of the former Fireworks facility.

3.3.2 Recent Activities at the Former Test Range

The area in front of the soil backstop berm at the Former Test Range in the Southern Conservation Commission Area is currently littered with a variety of trash and considerable evidence of ongoing small arms (e.g., shotgun) firing. Piles of expended shotgun shell casings and beer cans litter the ground, and various appliance carcasses and large debris items that have served as apparent targets for shotgun shooters are riddled with holes. The presence of these materials creates poor footing conditions and opportunities for cuts and abrasions. The shooting activity could also pose a direct threat of physical harm or bodily injury to those doing the firing or potentially those living near or accessing the Site while this activity is being performed.

3.3.3 Other Miscellaneous Safety Hazards

During the surveys performed for the environmental risk characterization, missing sewer line manhole covers were observed at a few locations in the northern portion of the Site. This condition creates a falling or tripping hazard that could lead to serious bodily injury.

4.0 CONDITIONS RELEVANT TO THIS CHARACTERIZATION OF THE RISK OF HARM TO SAFETY UNDER THE MCP

This evaluation of the risk of harm to safety must consider those conditions that could pose a threat of physical harm or bodily injury and that are linked causally to the release of OHM for which the Site has been scored and permitted. In this case, this requirement of causal linkage focuses the characterization on only those safety hazards that were created by the operations of the former Fireworks facility and the disposal/release practices that were employed at the Site during the period of operations and shutdown. As such, the following breakdown separates the previously described set of unsafe or potentially hazardous conditions into those linked to any potential former Fireworks facility release(s) and those unrelated to the operations or shutdown of the former facility:

4.1 Conditions Associated with Potential Ordnance-Related Items

The ordnance-related items that have been found at the Site over the years are linked causally to the release of OHM for which the Site has been scored and permitted. They are summarized as follows:

- Upper North Area (Former Development and Manufacturing Area) – Only inert components have been found in this area. Burial of items in this area is not likely given past operational practices. A condition of No Significant Risk of harm to safety exists in this area relative to the releases in question.

- Southern Conservation Commission Area (including the Former Test Range) – Only inert ordnance-related material has been found in this area. Burial of items in this area is not likely given past operational practices. A condition of No Significant Risk of harm to safety exists in this area relative to the releases in question.

- Marsh Upland Area (Demolition Pit) – Only expended items and inert material have been found in this area. Burial of items in this area is not likely given past operational practices. A condition of No Significant Risk of harm to safety exists in this area relative to the releases in question.

- Southern Disposal Area (Waste Burn Pit) – Only expended items and inert material have been found in this area. Burial of items in this area is not likely given past operational practices. A condition of No Significant Risk of harm to safety exists in this area relative to the releases in question.

- Cold Waste Area – A number of expended and inert items have been found in this area. Burial of items in this area is likely given past operational practices. This area is believed to be the location at the Site with the highest probability of finding ordnance-related debris or a potentially energetic ordnance-related item that was not properly or completely de-energized prior to disposal. No subsurface investigation as to the type and number of potential energetic ordnance-related items has been conducted. A condition of No Significant Risk of harm to safety does not exist in this area relative to the releases in question.

- Lily Pond/Upper Factory Pond Area – A small number of expended and inert items were found in the shallow sediments adjacent to the Cold Waste Area. There is no indication that these items were discarded into the pond. It appears more likely that these items were present at this location due to the erosion of the soil at the edge of the Cold Waste Area which exposed previously buried items and material. A magnetometer and video inspection of the ponds revealed no ordnance-related metal on the surface of the pond bottom in the areas most proximate to past disposal areas and in the depositional areas downstream of these locations. As such, a condition of No Significant Risk of harm to safety exists in this area relative to the releases in question.

- Remaining Risk Assessment Areas – No ordnance-related items have been found in the Lower North Area, the Potential Greenway Area, the Central Commercial Area, and in the other aquatic risk assessment areas that are linked causally to the release of OHM for which the Site has been scored and permitted. As such, a condition of No Significant Risk of harm to safety exists in these areas relative to the releases in question.

4.2 Conditions Associated with Facility and Site Maintenance

The potentially hazardous conditions associated with the current state of repair of the dilapidated buildings in the Upper North Area and the relict storage magazines in the Central Commercial Area developed over the years since the former Fireworks facility was closed and was under the management of property owners that are not parties to the Joint Defense Group. As such, these conditions are not relevant to an evaluation of the risk of harm to safety for this Site relative to the releases defining the Site. The structural integrity of the Factory Pond Dam, while potentially posing a risk of physical injury and bodily harm to individuals in the area and potentially contributing to the spread of contamination that may lead to subsequent health impacts to people due to exposure should the dam fail, is not linked causally to the releases of OHM for which the Site has been scored and permitted. As such, this condition is not relevant to an evaluation of the risk of harm to safety for this Site relative to the releases in question.

4.3 Conditions Associated with Facility and Site Housekeeping

Some potentially hazardous conditions have been created at the Site as the result of the overall level of site housekeeping that has been practiced in many areas over the years. These conditions exist mostly in the Southern Conservation Commission Area, the Southern Disposal Area, and the Marsh Upland Area, and are attributable to: the dumping of trash and debris in the southern third of the Site; the relatively recent activities at the Former Test Range; and some missing sewer line manhole covers. These conditions were created or were developed after the former Fireworks facility was closed and was under the management of property owners that are not parties to the Joint Defense Group. As such, these conditions are not relevant to an evaluation of the risk of harm to safety for this Site relative to the releases in question.

5.0 SUMMARY OF THE CHARACTERIZATION OF THE RISK OF HARM TO SAFETY

Based on this evaluation, only the Cold Waste Area at the Site is indicated to pose a potentially significant risk of harm to safety relative to the hazardous waste releases being investigated. This finding was based on the records of past operation that identify the Cold Waste Area as the primary area designated for the disposal of ordnance-related items that did not contain energetic material or that had been previously de-energized by burning or detonation and on the nature of the ordnance-related items that have been found in this area in the past and during the more recent site investigation work. No subsurface investigation as to the type and number of any potential energetic ordnance-related items present below the surface of the ground has been conducted. Consequently, this area is believed to be the location at the Site with the highest probability of finding any ordnance-related debris or any potentially energetic ordnance-related item that was not properly or completely de-energized prior to disposal. This condition poses a potential risk of physical harm or bodily injury to people in the foreseeable future. This threat is currently being managed by the secure fencing that has been installed around the Cold Waste Area. This fencing is periodically checked and is maintained to provide an effective barrier to incidental access to the area and potential contact with any energetic items that may be present there.

No evidence of ordnance-related material was observed during the underwater video inspection based on the geophysical survey performed and the anomalies judged to be suspect and selected to be visually identified. However, this inspection was performed relative only to the anomalies suspected to be potentially ordnance-related material and relative only to the surface conditions on the bottom of the ponds. No intrusive investigation has been performed in the subsurface sediments in Factory and Lily Ponds. While a condition of No Significant Risk of harm to safety relative to the releases being investigated is indicated by the available information and the possibility of incidental contact with the pond bottom, considerable uncertainty remains relative to conditions below the surface and the potential hazard associated with interaction with the deeper sediment.

6.0 REFERENCES

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Meeting. 2005. Project Status Meeting with MADEP, Held at Tetra Tech FW, Inc. Office in Boston, MA, February 17, 2005.

Site Walk. 2004. Site Walk at the Fireworks Site (Cold Waste Area), Including discussions with J. Hobill and Hanover Fire Chief S. Tucker, November 19, 2004.

Tetra Tech FW, Inc. (TtFW). 2004a. Technical Memorandum – Geophysical Survey Results: Fireworks Project Factory Pond Survey, Hanover, MA, February 2004.

Tetra Tech FW, Inc. (TtFW). 2004b. Interoffice Memorandum – Underwater Video Footage: Fireworks Project, Hanover, MA, August 6, 2004.

Tucker. 2005. Personal communications with Fire Chief S. Tucker of the Hanover Fire Department by Boyd Allen, TtEC, March 10, 2005.

ATTACHMENT A

Technical Memorandum:

Geophysical Results for the Fireworks Project Factory Pond Survey (February 2004)

TECHNICAL MEMORANDUM
GEOPHYSICAL SURVEY RESULTS

FIREWORKS PROJECT
FACTORY POND SURVEY

Fireworks Site
Hanover, Massachusetts

February 2004

Prepared by

Tetra Tech FW, Inc.
133 Federal Street
Boston, MA 02110

frx-807

1.0 INTRODUCTION AND OVERVIEW

This technical memorandum outlines Tetra Tech FW, Inc.'s (TtFW) results for geophysical investigations at the Fireworks Project Site (Fireworks Site). A combined bathymetric and magnetometer survey was performed in Factory Pond. The survey was performed in the area between the southern edge of Lily Pond and the Factory Pond Dam. Survey operations occurred between October 13th and 17th 2003.

1.1 Overall Geophysical Approach/Methods Utilized

A geophysical investigation was carried out at the Fireworks Site to delineate the aerial distribution of ferrous (iron bearing) metallic objects within Factory Pond. A secondary objective was to investigate identified anomalies with an underwater drop camera. A limited five-day field program was completed at the Fireworks Site from October 13th through the 17th. The survey was set up with a measure of flexibility to allow for the collection of the maximum amount of useable data.

2.0 TECHNICAL APPROACH

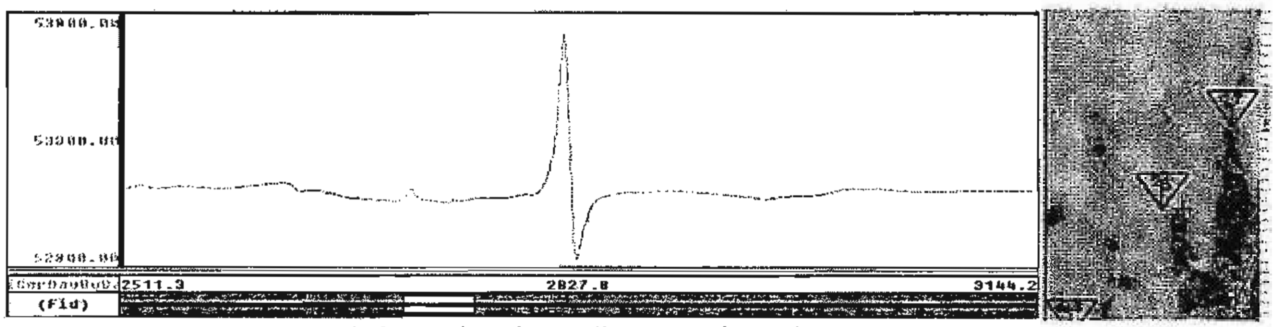
Several geophysical techniques were considered in assessing the most appropriate manner of investigating the Fireworks Site. After review of the anticipated conditions at the Site, magnetometry was selected as the method with the greatest potential to meet the primary project objective of delineating the aerial distribution of ferrous objects. Magnetometry was chosen over Electromagnetic Induction (EMI) because magnetometers are more sensitive at increased distances from targets. Ideally EMI sensors are within 18-24 inches of the ground during data collection. Since water depths were as deep as 6 feet, magnetometry was considered to be the preferred method. Also magnetometry can detect large concentrations of ferrous metal at much greater lateral distances than EMI.

2.1 Magnetometry

Two Marine Magnetics Overhauser Magnetometers were mounted onto a custom built surface towed array at the Fireworks Site. The magnetometers were spaced 10 feet apart laterally. The array was positioned by placing a real-time kinematic (RTK) differential geographic positioning system (DGPS) antenna midway between the magnetometers. A separate DGPS unit was positioned with the bathymetry echo sounder on the survey vessel (RV Quadrature). Coastal Oceanographic's HYPACK® Max hydrographic survey software provided vessel navigation and horizontal positioning for the towed array, calculated the position for each magnetometer and linked it with each magnetometer's reading. Data were collected, processed and interpreted using manufacturer-supplied data collection software, HYPACK® Max, and the GEOSOFT Oasis Montaj® Data Processing and Analysis System.

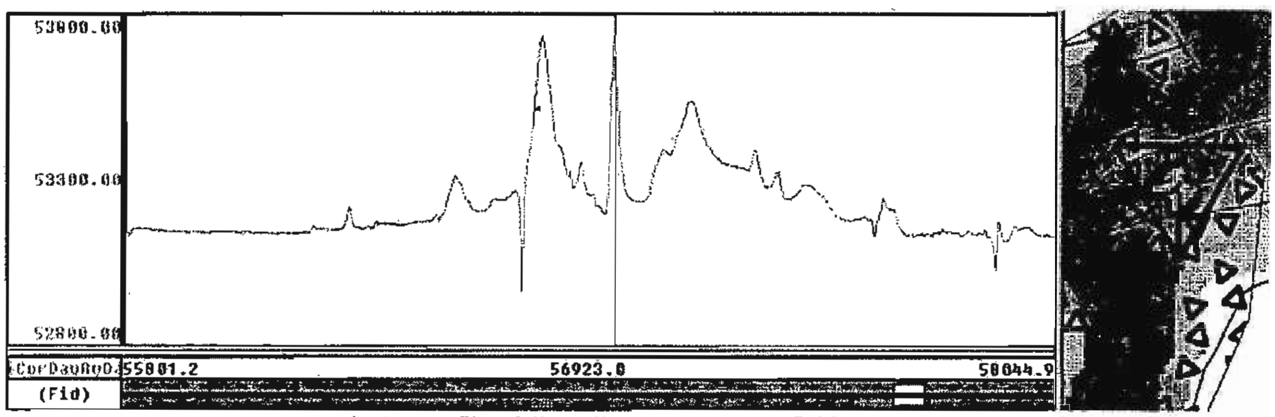
Total field magnetic data were collected by the 2-magnetometer surface towed array during the survey. During the survey a third magnetometer was located on shore, near Factory Pond to serve as a base station and measure the diurnal variation in the total magnetic field. This allowed for calculation of a correction to be applied to the towed magnetometers, eliminating the natural variation in the magnetic field that occurs as the earth rotates, or as solar activity varies. A diurnal correction for each day was calculated by taking the average of the days total field readings at the base station and then subtracting that from each individual total field reading recorded at the base station for the same day. This correction factor (either above "+", or below "–" the average reading) was then subtracted from the towed array magnetometers readings (correlated by the time each reading was taken) to yield a diurnally corrected total field reading. The diurnally corrected total field magnetic data are presented in Figure 1.

Isolated discrete targets often form dipolar anomalies, anomalies that have a paired positive and negative peak above the surrounding or background magnetic field (anomaly # 21 below is a good example).



Anomaly 21, profile of diurnally corrected total field magnetic data

This is not always the case though. Sometimes the anomaly does not have a well-developed dipole, and appears as just one peak, or monopoles (i.e. anomaly # 55).



Anomaly 55, profile of diurnally corrected total field magnetic data

The diurnally corrected total field magnetic data were then used to calculate the analytic signal (also known as reducing the data to the pole) which turns the dipole anomalies into monopoles, and highlights discrete objects (removes long wavelength anomalies). The analytic signal is presented in Figure 2.

Both the total field and analytic signal were used to interpret the data. The analytic signal was useful in picking out individual targets within the areas of "concentrated subsurface anomalies". The interpretations are presented as individual overlays on Figures 1 and 2 respectively, as well as on Figure 3 without any of the magnetic data.

A group of 78 targets (numbered 0-77) are marked on the maps (Figures 1-3). These targets range in size from extremely large, like target # 26 (which is just one object along the eastern shore of Upper Factory Pond within an area of concentrated subsurface anomalies) to smaller size targets such as #19 or #20.

2.2 Drop Camera

An underwater drop camera was used in an attempt to visually inspect selected locations where discrete magnetic targets were detected. Multiple locations were investigated, but the camera's four external lights were not of sufficient power to discern more than vague shadows in water depths greater than 6 inches due to the extremely dark water in Factory Pond.

3.0 CONCLUSIONS

There are many areas that contain ferrous objects within Factory Pond. The largest concentration is along the eastern shore of Upper Factory Pond near the two areas of concern. This extremely large negative anomaly suggests that there are a large amount of ferrous objects in the area, which could potentially continue onto shore. (This could be reflected as one lobe of a larger dipole anomaly that continues on . shore.) It appears that ferrous items may have been placed in the pond in the vicinity of the two areas of interest. Once past the constriction between Upper and Middle Factory Pond there are fewer anomalies within the property line than there are in Upper Factory Pond. There is a small area of "concentrated subsurface anomalies" extending across Middle Factory Pond near the southern end of the property but there is not nearly as much ferrous material present there, compared to other areas of "concentrated subsurface anomalies". There are also two linear features that could potentially be able crossings near residential areas in Middle and Lower Factory Pond outside the property line.

Anomalies are scattered throughout Factory Pond that have a signature consistent with either single items or a group of items, as well as larger anomalies that could potentially be abandoned process piping. Many of these anomalies appear to be at or near the pond sediment/water interface. A selection of these anomalies could be reacquired based on their DGPS position and then precisely located with a long reach hand-held metal detector for inspection with a drop camera, with sufficiently bright lights. These tasks could be easily performed from a small boat, as was used for the survey.

APPENDIX – Instrument Theory and Operation

Magnetics

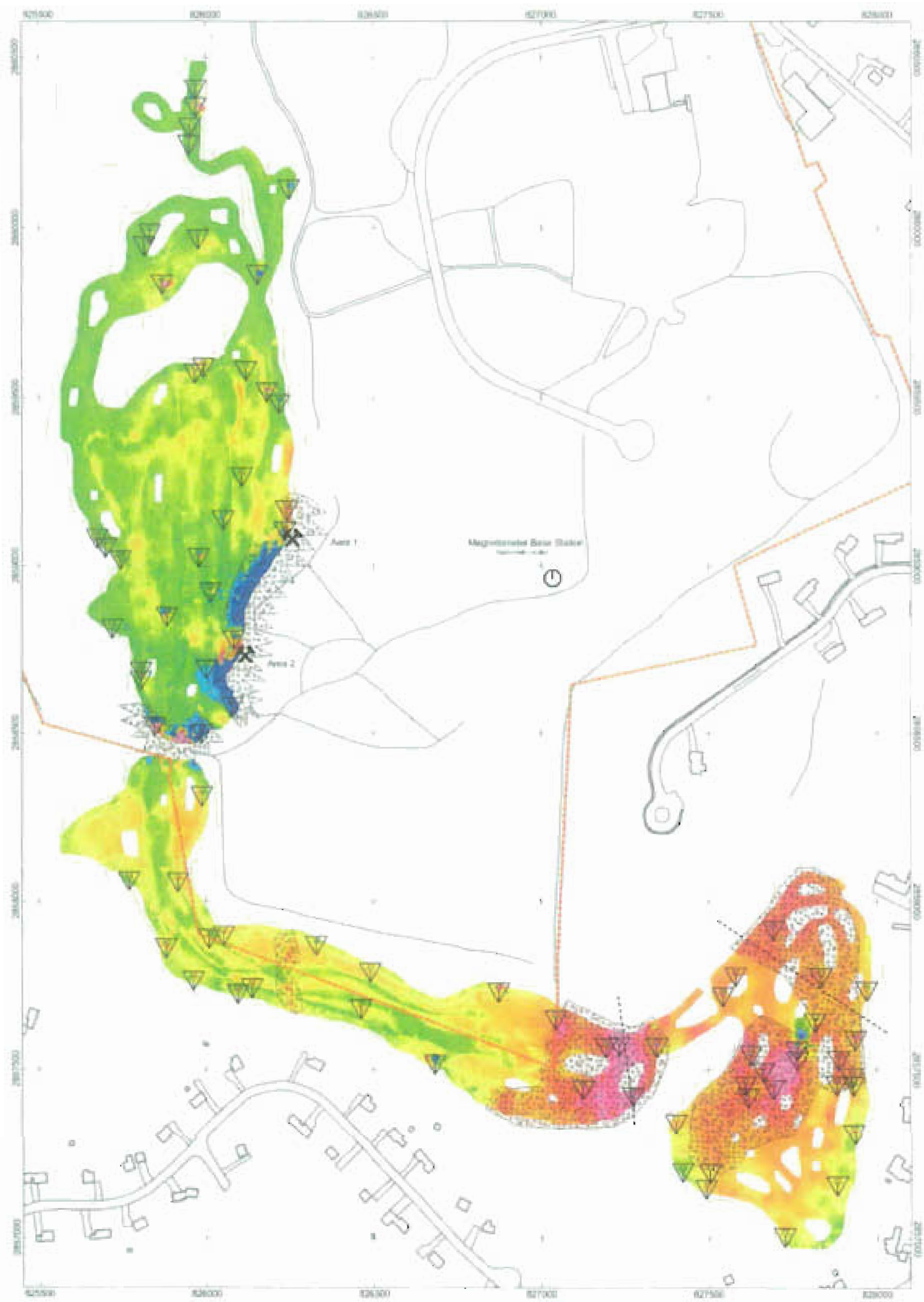
The degree to which a material can be magnetized by the magnetic field of the earth is determined by the material's magnetic susceptibility. Every material possesses an inherent magnetic susceptibility, and magnetic anomalies are the result of the magnetic susceptibility contrast between different materials. Ferromagnetic materials typically consist of iron or steel and possess high magnetic susceptibility. Slag and scrap metal typically contain ferromagnetic portions. These materials generally have high magnetic susceptibilities and locally distort the magnetic field, producing magnetic anomalies. If these anomalies are sufficiently large, they may be detected with field magnetometers. If the source of the anomaly is far enough away from the magnetometer, the anomaly can be expressed as a dipole magnetic field and the dipole magnetic moment dominates.

Principles of Operation

The geophysical technique of magnetometry measures spatial variations in the Earth's ambient magnetic field. Ground-based magnetic surveys are conducted using a magnetometer to measure the magnetic field at one or more constant heights above the ground surface. Magnetic data are generally acquired over a predetermined grid at a line and station interval consistent with the anticipated characteristics of the target. These data provide a spatial distribution of the magnetic field over the surveyed area. In general, when the magnetic field from a single sensor is considered, the instrument reading is referred to as the total magnetic field. When the ratio of the magnetic field between two sensors at different separations is considered, the analysis is referred to as the gradient of the magnetic field (typically as either the vertical or horizontal gradient).

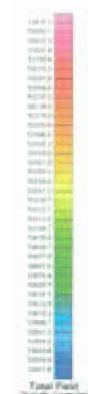
Instrumentation

The best magnetometer available for ferrous target detection in shallow to deep water (greater than 10 feet) is a unit that utilizes the Overhauser effect. An Overhauser magnetometer is completely omni-directional (no change in readings with respect to the orientation of the Earth's magnetic field), has the highest absolute accuracy (0.2 nT [nannoTesla], with a counter sensitivity of 0.001 nT) and repeatability (0.01 nT between sensors) of any magnetometer currently available. It is temperature independent (data recorded at -40°C will be identical to data recorded at +60°C), and has no heading error (successive survey lines taken in opposite directions will match up perfectly, due to the omni directionality of the unit). To remove diurnal variations in the earth's magnetic field from the field data, a third magnetometer was utilized as a base station during the magnetometer survey.



Legend

- Area of Concentrated Subsurface Anomalies
- Area of Interest
- Selected Targets
- Potential Crossings (Pipes / Utilities)
- Property Line



Scale 1:2400

Figure 1

Fireworks Project
Hanover, Massachusetts

Total Field Magnetics Data
Diurnally Corrected

TtFW Geophysics

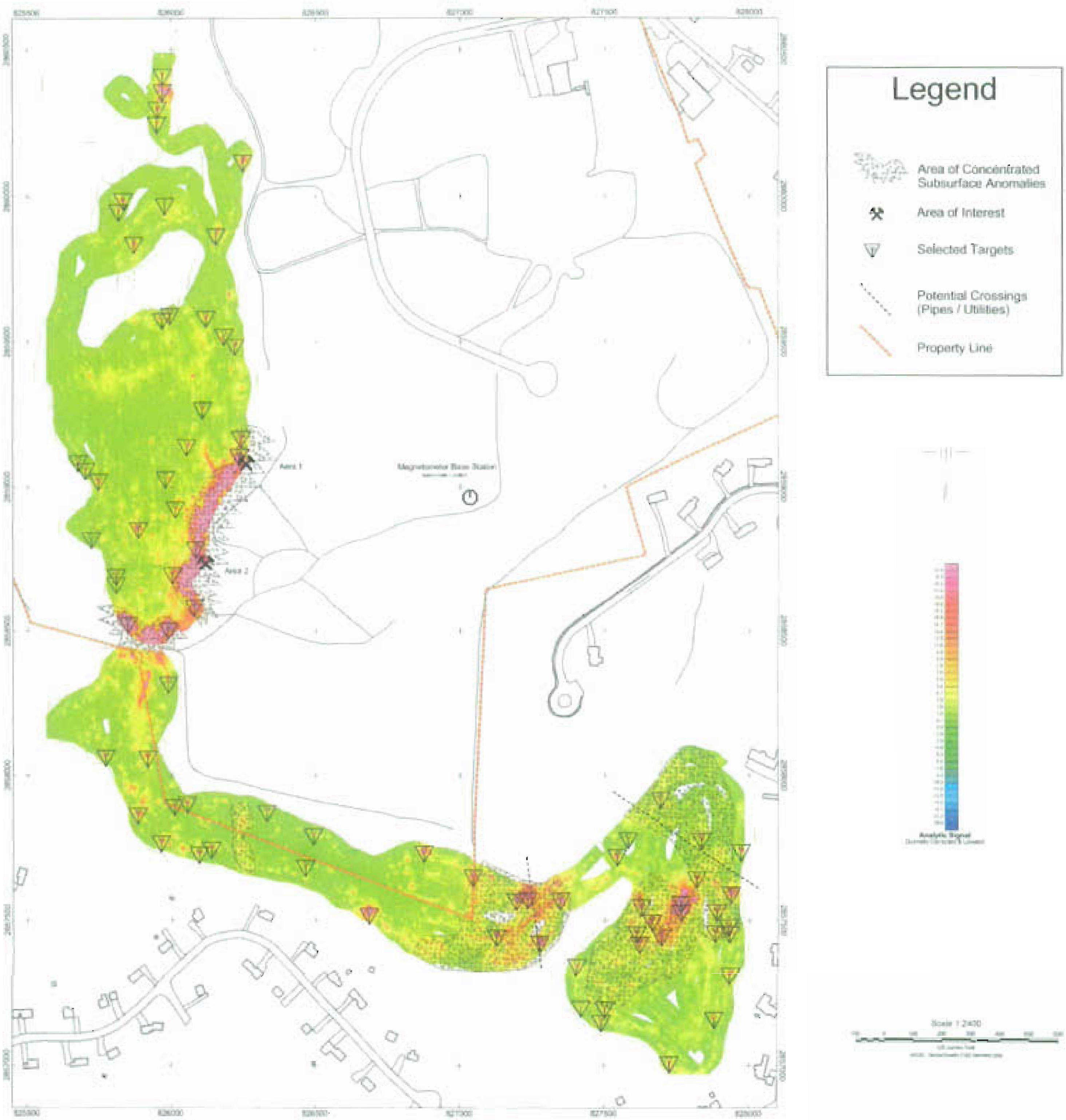


Figure 2

Fireworks Project
Hanover, Massachusetts

Analytic Signal Magnetics Data
Diurnally Corrected, Reduced to Pole

TIFW Geophysics

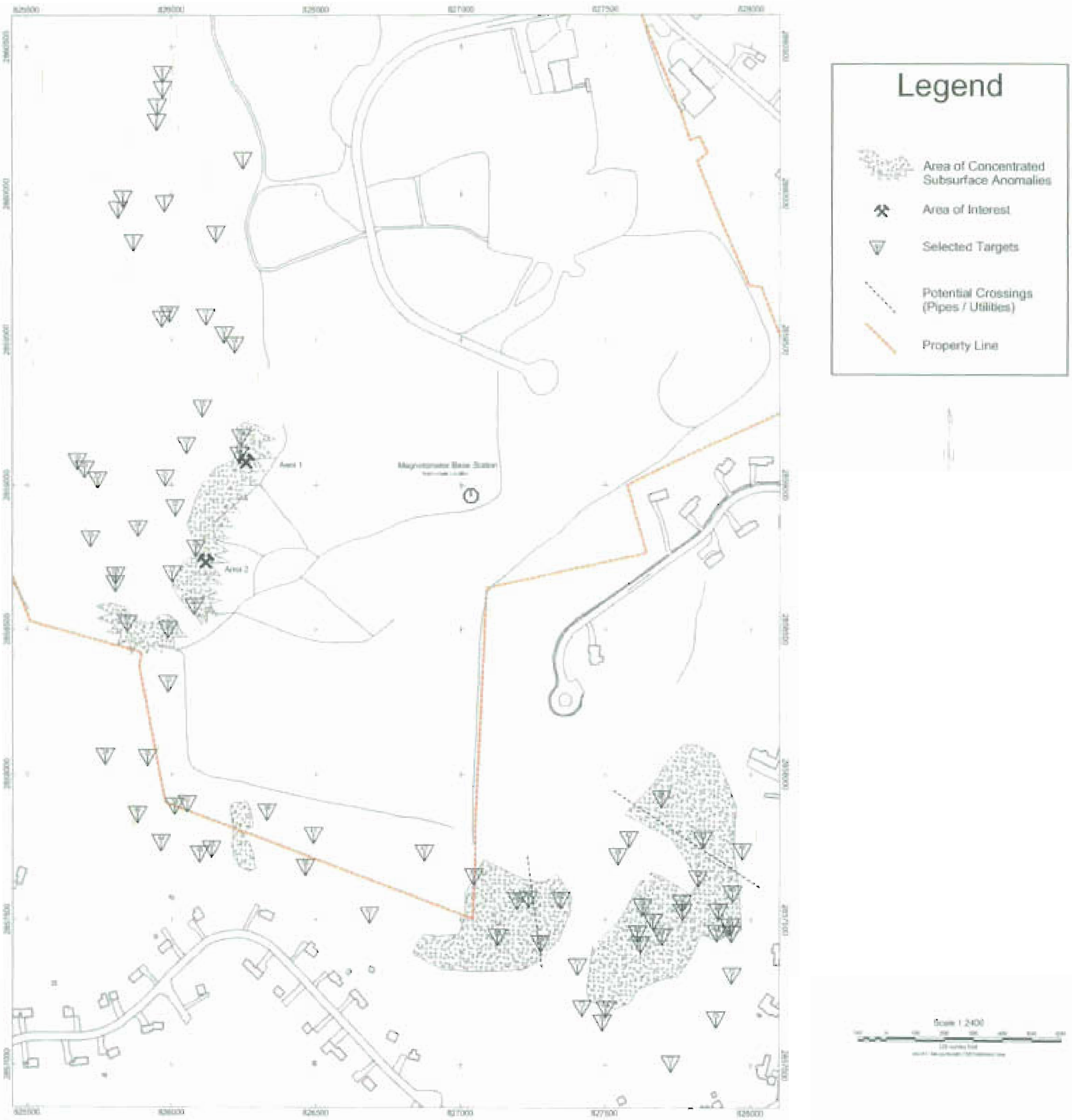


Figure 3

Fireworks Project
Hanover, Massachusetts

Interpretation of Magnetics Data

TtFW Geophysics

ATTACHMENT B

Interoffice Memorandum:

Underwater Video Footage
(August 2004)

TETRA TECH FW, INC.

Interoffice Memorandum

TO: Distribution
FROM: Boyd Allen
DATE: 6 August 04
REF. #: frx-843
SUBJECT: Underwater Video Footage

Enclosed please find a copy of the film footage shot with the underwater camera at various locations in Factory Pond that were identified as areas of interest based on magnetic anomalies recorded during the Fall 2003 geophysical program. I have also included a listing of the targets and a map of the locations keyed to the Target ID number.

A member of our UXO team has reviewed the footage and did not discern any ordnance items or debris clearly indicative of ordnance items in the films. You will see car parts, a bicycle, the back end of a VW bug, home heating oil tank and miscellaneous metal. In some locations the vegetation or sediments are so thick that any metallic object(s) are obscured.

The footage is not destined to win any awards, lacks a musical score that can get airplay, and need not be viewed in its entirety. The lack of any visibly identifiable ordnance wastes and the demonstrated variety of metal found on the pond floor is good information to have and will be used by Ron Marnicio in the current Phase II safety evaluation.

Distribution:
R. Jones
E. Mason
M. O'Brien
M. Goldstein

Enc: DVD of Underwater Camera Footage
Underwater Camera Target Listing
Underwater Camera Location Map

cc: R. Donati
R. Marnicio

File: FRX 2.1.2
FRX 26.2

Target Data Sheet			Revise Date:	07/15/04	
Fireworks Site Project 2329					
Target ID	Video ID	Comment	Mag_Anom Visible	Northing	Easting
2	2	video 2 boat launch fence	NA	2858583.3	826111.0
3	3		NO	2859042.4	825986.5
4	4	fence post	YES	2858510.1	825928.5
5	5	tank (fuel?) with hole (50-250 gallon)	YES	2858503.9	825941.4
6	6	unknown circular object	YES	2858493.6	825916.7
7	7	VW Beetle adjacent to bridge	YES	2858463.8	825917.3
8	8		NO	2858717.5	826058.9
9	9	small metallic object seen	NO	2858694.7	826048.4
10	10		NO	2858678.3	826047.4
11	11	visible small round object unable to identify	YES	2858767.3	826102.0
12	12,13	video files 12 and 13	NO	2858737.0	826084.9
13	14	highly vegetated	NO	2859105.4	826258.7
14	15	steel plate with a small hole noted	YES	2859177.4	826240.9
15	16	possible bike frame and lumber	YES	2860364.5	825974.4
16	17	dense vegetation	NO	2857885.5	826332.7
17	18		NO	2857798.3	826488.7
18	19	unidentified objects	YES	2858312.7	825932.3
19	20		NO	2857863.5	826255.5
20	21		NO	2859142.6	826049.3
21	22	depositional bar	NO	2859874.5	826151.2
22	0	125-2502 photo 55 gallon drum above water; no video	YES	2859875.1	826081.4
23	23		NO	2859028.5	825979.7
24	24		NO	2858528.9	825848.3
25	25	bike and VW pedal	YES	2858486.9	825901.5
26	26	VW back end	YES	2858467.9	825916.4
27	27	unknown large metal object	YES	2858462.4	825913.7
Note:	None of the objects in the video footage were identified as ordnance wastes or materials by in-house UXO experts at TTFW.				

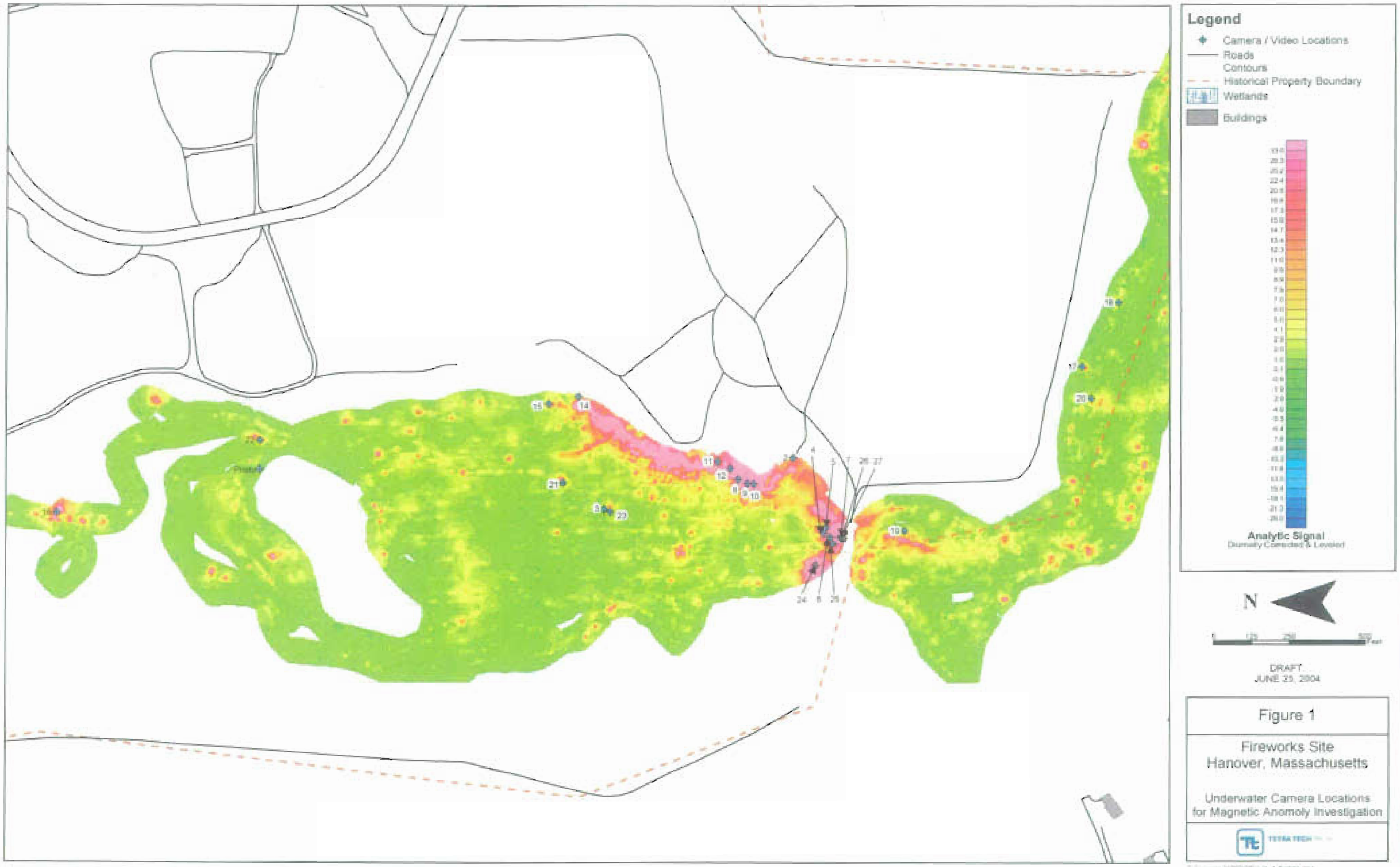


Figure 1

Fireworks Site
Hanover, Massachusetts

Underwater Camera Locations
for Magnetic Anomoly Investigation

TETRA TECH

SCANNED

FOSTER WHEELER ENVIRONMENTAL CORPORATION

PHASE IIC SITE INVESTIGATION
DATA REPORT

FIREWORKS I
(FORMER FIREWORKS FACILITY)
HANOVER, MA
TIER 1A PERMIT #100233
RTN: 4-0090

RECEIVED
NOV - 1 2002
D.E.P.
SOUTHEAST REGION

October 2002

Prepared for:

The Fireworks Site Cooperating Parties

Prepared by:

Foster Wheeler Environmental Corporation
133 Federal Street
Boston, Massachusetts 02110

Revision	Date	Prepared By	Approved By	Pages Affected
1	10/30/02	M. Greenberg/K. Craigie	B. Allen	All

OT02-050
10/30/02

FOSTER WHEELER ENVIRONMENTAL CORPORATION

October 30, 2002
OT02-151

Mr. Jonathan Hobill
Bureau of Waste Site Cleanup
Massachusetts Department of Environmental Protection
Southeast Regional Office
20 Riverside Drive
Lakeville, MA 02347

Subject: FIREWORKS I SITE, HANOVER, MA, RTN #4-0090, TIER 1A PERMIT #100233
PHASE IIC SITE INVESTIGATION DATA REPORT (REV. 1)

Dear Mr. Hobill:

On behalf of the Fireworks Site Cooperating Parties and in partial fulfillment of the requirements at 310 CMR 40.0835, Foster Wheeler Environmental Corporation (Foster Wheeler) is submitting this Phase IIC Site Investigation Data Report for the Fireworks I Site, Tier 1A Permit Number 100233, Release Tracking Number 4-0090. Included within the report are suggestions for the next phase of work which I look forward to continuing to discuss with you and Mr. Angus in the upcoming weeks. The LSP of Record overseeing the Phase IIC investigation was Mr. Robert Donati (License No. 5878).

Foster Wheeler's submission of these documents does not constitute an acknowledgment of liability by any or all of the Cooperating Parties, and each of the Cooperating Parties reserves its rights to dispute such liability in the future. Furthermore, these documents contain no admissions of any kind, and should not be construed to contain any admissions.

If you have any questions, please call me at (617) 457-8253.

Sincerely,

Boyd Allen III, CPG
Project Manager

Enclosure: OT02-150

cc: R. Jones
J. Grachuk
M. Goldstein
M. O'Brien
R. Donati
T. Angus
Hanover Board of Health
Hanson Board of Health

File: FRX 21.7
FRX 2.1.2