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Risk Characterization for Future Training Scenarios at the Massachusetts Military Reservation (MMR)

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ABSTRACT:

This study was conducted to evaluate potential human and ecological health risks associated with emission of pyrotechnic compounds during future training exercises at the Massachusetts Military Reservation. Air dispersion modeling was used to determine air concentrations and deposition rates for emissions. Annual average and spatially averaged air concentrations and deposition rates were used to perform the risk assessments. The Army Risk Assessment Modeling System (ARAMS) was used to conduct the human health risk assessment, which evaluated a site visitor or trespasser exposed to air and soil using air concentrations and deposition rates from the air dispersion modeling. ARAMS was also used to evaluate the time for deposited compounds to reach groundwater and the peak concentration upon contact with the water table. Of the 24 compounds evaluated, only Cr(VI), with an incremental cancer risk of 2.4×10^{-6}, posed a potential concern for human health with the maximum exposure and effect through the air inhalation pathway/route. None of the compounds are suspected to cause a groundwater problem. Computed soil concentrations were compared to soil screening toxicity benchmarks for the ecological risk assessment for the purpose of retaining or eliminating chemicals from the assessment. Toluene and hexachlorobenzene were the only compounds that exceeded the soil toxicity benchmarks. However, because of the slight exceedence and its nonbio-accumulating properties, toluene is not considered to be a chemical of potential concern. Although hexachlorobenzene exceeded the toxicity benchmark, uncertainties and conservative assumptions associated with the modeled soil concentrations and conservative soil benchmarks should be recognized.

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Preface

This report describes the application of models and risk assessment methods to evaluate potential human and ecological health risks associated with future training activities at the Massachusetts Military Reservation (MMR). Drs. Mansour Zakikhani and Mark S. Dortch, Water Quality and Contaminant Modeling Branch (WQCMB), Environmental Processes and Engineering Division (EPED), Environmental Laboratory (EL), U.S. Army Engineer Research and Development Center (ERDC), Vicksburg, MS, conducted the portion of the study that used the Army Risk Assessment Modeling System (ARAMS) for the groundwater assessment and human risk assessment. Mr. Stafford Coakley, U.S. Army Center for Health Promotion and Preventive Medicine (CHPPM), conducted the air dispersion modeling, and Ms. Melanie Hawkins, CHPPM, conducted the ecological risk assessment.

Drs. Zakikhani and Dortch prepared the main body of this report dealing with the ARAMS application, Mr. Coakley prepared Appendix A on Air Dispersion Modeling, and Ms. Hawkins prepared Appendix B on Ecological Assessment. Appendixes A and B document key components of this study. This material was located in these appendixes for convenience during report preparation and does not in any way suggest that these components were not paramount to the entire study effort. A report of the ARAMS application was drafted first, and it was much easier to attach the other two study components as appendixes.

The U.S. Army National Guard Bureau funded this study. The ARAMS application was conducted under the general supervision of Dr. Dortch, Chief, WQCMB, and Dr. Richard E. Price, Chief, EPED. The air dispersion modeling and ecological assessment were conducted under the general supervision of Mr. Dennis Druck, CHPPM.

Drs. Zakikhani and Dortch express thanks to Messrs. Jeffrey Gerald, WQCMB, and Jonathon Lizardi, summer student from the University of Puerto Rico, for valuable contributions toward the ARAMS application.

Mr. Gerald and Dr. Dennis Brandon, WQCMB, reviewed the report. Dr. Elizabeth Fleming was Acting Director, EL.

COL James R. Rowan, EN, was Commander and Executive Director of ERDC. Dr. James R. Houston was Director.

1   Introduction

Background

The Massachusetts Military Reservation (MMR) has been used for a variety of military training and munitions related activities throughout the 1900s. As a result of these operations, the U.S. Environmental Protection Agency (USEPA) has issued Administrative Orders under the Safe Drinking Water Act to the National Guard Bureau (NGB) at MMR asserting that military operations have contaminated and/or threaten to contaminate the groundwater of Cape Cod.

During the 1980s, much attention was given to environmental issues both nationwide and on Cape Cod. At that time, groundwater contamination was first discovered flowing off the southern portion of MMR. The groundwater plumes emanated from areas of previous activity mainly associated with those conducted at the former Otis Air Force Base (now Otis Air National Guard Base) located in the southern 7,000 acres of the base. The discovery of off-base contamination led to increased community interest in the existing environmental cleanup program at MMR. As interest and activity grew at MMR, citizens and local community organizations began to look at other activities taking place at MMR and voiced concern about the effects of historic and current training activities in the northern 14,700 acres.

The U.S. Army NGB requested the U.S. Army Center for Health Promotion and Preventive Medicine (CHPPM) to conduct a screening-level human and ecological health risk assessment as related to munitions emissions for future training activities at MMR to screen compounds that could pose a potential hazard. As a result, the CHPPM requested the U.S. Army Engineer Research and Development Center (ERDC) to assist in the effort by conducting the human health risk assessment and subsurface chemical fate modeling using the Army Risk Assessment Modeling System (ARAMS). CHPPM conducted the air dispersion modeling and the ecological risk assessment. The air dispersion modeling provided air concentrations and deposition rates for emission compounds during future training exercises. These air concentrations and deposition rates were used in ARAMS to model potential human health risks and the subsurface fate/transport of emission compounds. Average soil concentrations computed by ARAMS were utilized in the ecological assessment.

The main body of this report covers the ARAMS application, Appendix A describes the air dispersion modeling, and Appendix B provides details of the

ecological assessment. The organization of this report was for convenience and is not related to the role of the three study components.

Objective

The overall objective of this study was to assess potential human and ecological health impacts/risks at MMR as associated with exposure to emission compounds released during future training scenarios. An additional objective was to determine which compounds could pose the greatest potential hazard. To achieve these objectives, study components conducted were:

    a.   Air dispersion modeling

    b.   Human health assessment and subsurface fate/transport modeling using ARAMS

    c.   Ecological health assessment.

Scope of Work

The original Scope of Work called for evaluating approximately 200 chemicals with ARAMS. However, because of funding constraints, only 24 chemicals from the original list were included in the analysis. These chemicals were carefully selected so that at least one from each class of chemicals was considered in the analysis. The remaining chemicals on the list are being evaluated in a follow-on study funded by the Army Environmental Center.

CHPPM conducted atmospheric dispersion (i.e., transport) and deposition modeling to predict air concentrations and land deposition rates of chemicals as a result of future training scenarios (Appendix A). Results of these simulations were provided to ERDC for use as initial and boundary conditions of the chemicals for the ARAMS modeling. Average soil concentrations computed with ARAMS were utilized in the ecological health assessment (Appendix B).

2   Site Description

Massachusetts Military Reservation, a military training facility, is located on the upper western portion of Cape Cod, immediately south of the Cape Cod Canal in Barnstable County, Massachusetts (Figure 1). MMR includes parts of the towns of Bourne, Mashpee, and Sandwich and abuts the town of Falmouth. MMR covers nearly 8,498,3980 m^2 (21,000 acres) — approximately 32.8 $mile^2$ (30 sq miles).
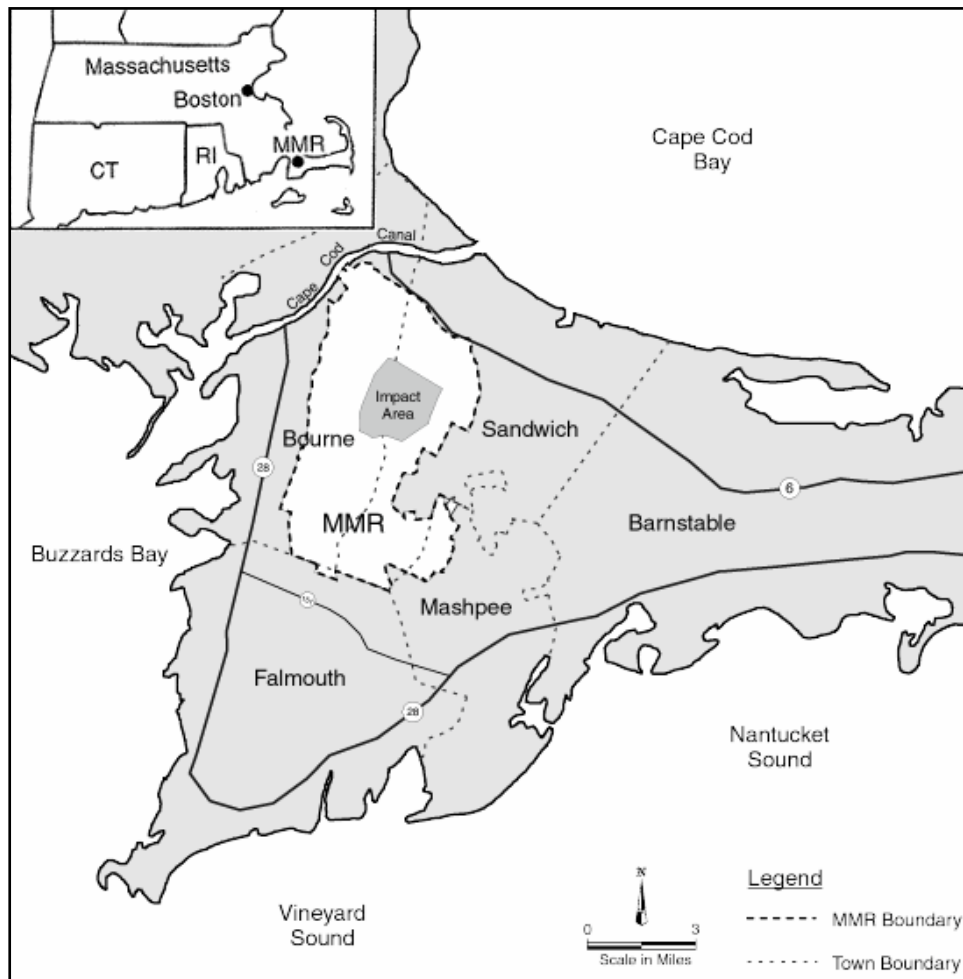
Figure 1.   Map of MMR and vicinity (source: *http://www.mmr.org/irp/about/descrip.htm*)

MMR is located over the recharge area of the Sagamore Lens, the sole-source aquifer supplying drinking water for the western part of Cape Cod, known as the Upper Cape. The Sagamore Lens is a large, 91-m- (300-ft-) thick layer of groundwater. In general, soils in the vicinity of MMR are sandy and permeable and permit rapid groundwater movement (0.305 to 0.61 m (1 to 2 ft) per day). The Sagamore Lens is recharged, or replenished, by rainwater that seeps through the sandy soil into the aquifer.

Portions of MMR have been used for military purposes since 1911. Since 1935, the base has been used for Army training and maneuvers, military aircraft operations, maintenance, and support. The northern portion of the MMR, known as Camp Edwards, is used for the training of National Guard and law enforcement personnel from the New England area. The northern portion spans approximately 59,490,900 sq m (14,700 acres), with an impact area of 8,903,400 sq m (2,200 acres) at its center. The impact area (Figure 1) was used as a target for artillery and mortar firing and constitutes the study site for this study.

3   Modeling Approach

The U.S. Department of Defense and the Army follow risk assessment procedures to determine safe exposure concentrations and safe cleanup target levels for military relevant chemicals (MRCs) and to evaluate remediation alternatives to provide the most cost-effective approach to reach target levels. As part of the Army's Installation Restoration Research Program, the ERDC is developing ARAMS, a computer-based, integrated information delivery, modeling, and assessment system for estimating human and ecological health impacts/risks associated with exposure to MRCs and other compounds. ARAMS allows for multimedia and multipathway exposure assessment (*http://www.wes.army.mil/el/arams/*).

Specifically, the ARAMS modeling had the following components for this study:

a.   Modeling to predict potential human health risk from air and soil exposure associated with a site visitor entering the MMR.

b.   Modeling of subsurface fate/transport processes to predict the movement of chemicals through the vadose zone to quantify the time required for these chemicals to migrate from the soil surface to the groundwater table and the concentration at the water table.

Description of ARAMS

ARAMS (*http://www.wes.army.mil/el/arams/arams.html*) is based on the widely accepted risk paradigm, where exposure and effects assessments are integrated to characterize risk. ARAMS determines exposure by considering source zone release, multimedia fate/transport, exposure pathways, and receptor intake. ARAMS is being developed in phases (Dortch 2001), where Version 1.0 was released in June 2002 (Dortch 2001, Dortch and Gerald 2002, Dortch and Johnson 2002). The phased development and delivery enables users to access the product, while more advanced features and updates are added to future versions. Version 1.0 (Dortch 2001, Dortch and Gerald 2002, Dortch and Johnson 2002) features simplified models for fate/transport adequate for screening-level studies. Screening-level models are those that can be conducted rather quickly with limited data at low cost using conservative assumptions, whereas comprehensive assessments require more time, cost, and data but should provide more definitive information. Version 2.0, yet to be published, will feature more comprehensive

fate/transport and effects models. ARAMS version 1.0 (Dortch 2001, Dortch and Gerald 2002, and Dortch and Johnson 2002) was used for this study.

The module linkage framework of ARAMS is the Framework for Risk Analysis in Multimedia Environmental Systems (FRAMES) developed by the Pacific Northwest National Laboratory (PNNL) of the U.S. Department of Energy (DOE) in cooperation with the EPA (Whelan et al. 1997). FRAMES serves as an object-oriented conceptual site model where objects are used to denote different pathways and stages of analysis. Objects or icons represent the primary exposure media, air, land or soil, surface water, vadose zone, and groundwater. Similarly, there are objects representing the sources of contamination, the intermediate exposure pathways, uptake, and health impact assessment. The Multimedia Environmental Pollutant Assessment System (MEPAS) (Buck et al. 1995) is integrated into ARAMS/FRAMES and provides a variety of models for risk assessment. MEPAS provides much of the screening-level fate/transport modeling needed for ARAMS, including models for describing sources of contamination and fate/transport in air, streams, vadose zone, and groundwater. Additionally, MEPAS includes models for intermediate exposure pathways to humans, multimedia human intake routes, and human health impacts. The MEPAS fate/transport models are typically simplified mathematical models with analytical solutions. Other screening-level models for surface water and the vadose zone have been added as modeling options during the ARAMS development. MEPAS version 4.1 was used for this study.

Modeling Scenarios and Methods

Average (temporally and spatially) air concentrations and deposition rates obtained from the air dispersion modeling were used as input conditions for ARAMS. Since the averages for the entire range were used, spatial location was not a variable, thus spatial aspects could be ignored, and single point models could be used. This section describes the two modeling scenarios that were conducted and the methods used for each of the two scenarios, as well as an overview of the air modeling conducted by CHPPM to provide input for the two scenarios.

Conceptual site model

Two independent modeling scenarios, one for human health impacts and one for migration of chemicals through the vadose zone, were conducted and evaluated. Each scenario was described with a conceptual site model shown in Figure 2.

Physical and chemical properties are defined within the Chemical Database object (labeled Chemicals of Concern), which is linked to each of the other objects. The left-hand side of Figure 2 is the vadose zone migration/groundwater analysis. The analysis starts with the source of contamination, which for this case was the Known Source Module (labeled Source – Air Deposition). The source term feeds into a vadose zone model, which feeds into the saturated aquifer

model. MEPAS vadose zone and aquifer models were used for these two objects. The aquifer model was required in this study merely to provide an end point for chemicals to reach the groundwater table. Likewise, the Exposure Pathways object was linked to the aquifer model only to describe the point of interest in the aquifer. Since the time to reach the groundwater table and concentrations at the water table were of primary interest, rather than concentrations at points downstream in the aquifer, the exposure receptor location was placed at the location of initial water table contact of chemicals migrating through the vadose zone.
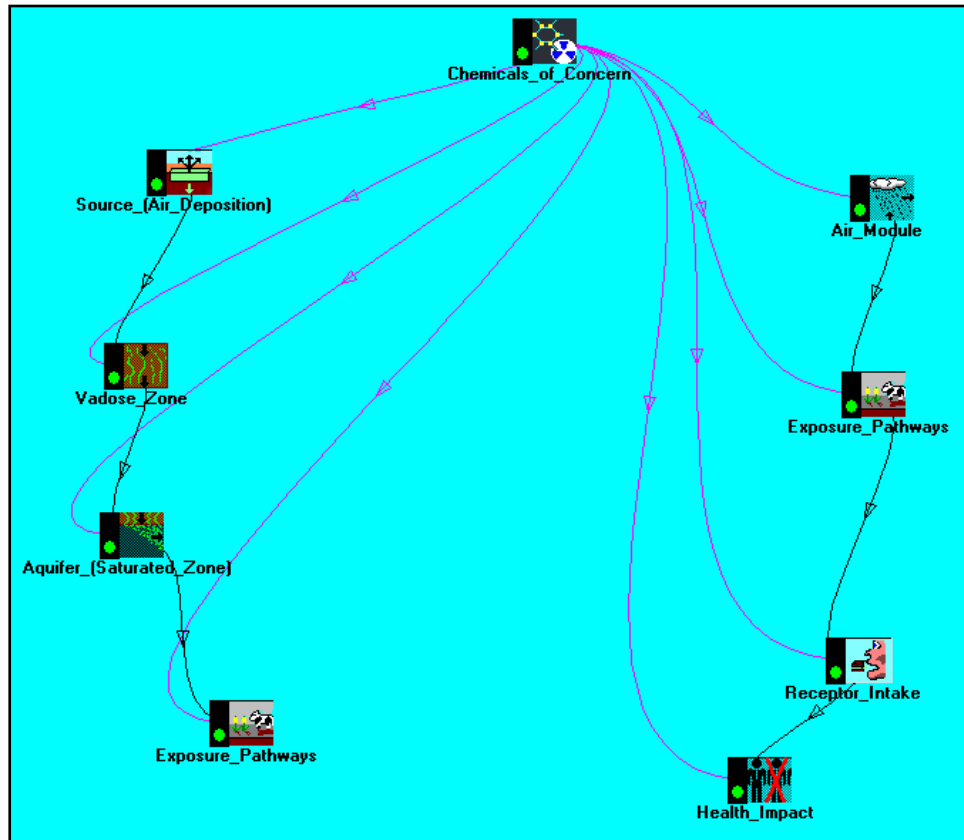
Figure 2.   ARAMS/FRAMES conceptual site model

The right-hand side of Figure 2 is the human health impact analysis. This analysis starts with the air object where the Known Air (concentrations/ deposition) Module was used. Air concentrations and deposition rates from the CHPPM air model were used for the ARAMS Known Air Module. The MEPAS Human Exposure Pathways Module was used to describe the pathways from media to receptor, and the MEPAS Human Receptor Intake Module was used to describe the intake routes for the receptor. Output from the exposure object is exposure concentration (mg/kg for soil and mg/m^3 for air). Output from the receptor object is chemical dose (mg/kg/day), which is used in the MEPAS Human Health Impacts Module along with toxicity benchmarks to compute incremental carcinogenic risks and noncarcinogenic hazard index (HI).

Air dispersion modeling

CHPPM computed temporally and spatially varying air concentrations and deposition rates (fluxes) for a list of important chemicals that could be released from training activities. The latest version of the EPA Industrial Source Complex Short Term (ISCST3) model was used to model emissions from each munition type (Appendix A). This model is a steady-state Gaussian plume model that uses emission source data, meteorological data, and receptor locations to determine wet and dry depositions and air concentrations, while conserving mass using plume depletion. Plume depletion algorithms account for the mass of plume lost in the area between the receptor being analyzed and the source. The ISCST3 model was chosen specifically because of its ability to handle inputs of multiple sources as well as to estimate dry deposition and wet deposition values for each source and receptor combination for each hour of meteorological data. Though the model assumes continuous operations, it can calculate concentrations and depositions for a period as short as 1 hr.

The air model was run for a 4-year period using historical meteorology. The modeling scenario was based on anticipated future training for the National Guard. Weekend training was assumed during the Fall, Winter, and Spring, while week-long training was assumed for the Summer. Realistic (based on Bang Box data) emission rates were used for the air modeling. The output for the 4 years was processed to yield annual average air concentrations ($\mu g/m^3$) and deposition rates ($g/m^2/yr$) for each chemical and for each receptor location. A regularly spaced grid of 250 m was used for the site to define 2,457 receptor locations for reporting the annual average air concentrations and deposition rates. For the ARAMS analyses, the spatial average for all receptor locations was used for the annual average deposition rates and air concentrations for each chemical. Chapter 4 presents the input load values in terms of gas and particle total deposition (wet and dry) and gas and particle air concentration that were provided by CHPPM and used in the analyses.

Human health analysis

This section describes the exposure pathways and models for conducting the human health analysis.

Exposure Pathways. Future training can result in chemicals potentially moving from air to soil through deposition. Thus, air and soil are the fate/ transport media and initial exposure pathways. The MMR human receptor consisted of an adult individual moving around or within the site as a visitor or trespasser. It was assumed that the receptor used no domestic water from wells potentially contaminated by the site. The receptor also did not recreate in site surface waters, consume agricultural products from the site, nor consume any fish and wildlife from the site, although it is possible to consider all of these exposure pathways with ARAMS. Therefore, the exposure routes were air inhalation, soil dermal contact, soil ingestion, and resuspended soil inhalation.

Air concentrations and soil fluxes can be provided directly to ARAMS through several modules that allow entering measured or known data. The options for entering known concentrations/fluxes are to:

a. Use the known atmospheric output (ATO) module of the air fate/transport object for specifying air concentrations and depositional flux rates;

b. Use the known soil concentrations spreadsheet component of the source module along with the ATO component for air concentrations;

c. Use the exposure pathways in food or other media module of the exposure object.

The first option internally computes soil concentrations from depositional rates, and ATO output is linked to the exposure module where soil resuspension can be taken into account. Additionally, soil leaching and decay can be accounted for within the exposure module when computing soil concentrations. The second option would require externally computing soil concentrations from depositional fluxes. Neglecting leaching, decay, or volatilization, this conversion can be done in a spreadsheet outside of ARAMS from the following relation:

$$C_{si} = \int_0^{\tau} \frac{1000 \, L_i}{\rho_b} \frac{dt}{h} \tag{1}$$

where

C_{si} = time-varying soil concentration for chemical *i*, mg/kg

τ = time integration period, days

1,000 = units conversion for mg/g

L_i = time-varying loading rate of chemical *i* to the soil, g/m^2/day

t = time, days

ρ_b = soil bulk density, kg/m^3

h = surficial, mixed soil layer thickness, m

The third option of using the EPF module allows one to enter directly the exposure concentrations in various media including food and environmental media, i.e., air, water, and soil. However, use of this option would require computing soil resuspension externally and providing these values to the EPF component. Any of these three input options can work, but the first option is the most straightforward, thus, it was used for this study. Since this study was conducted, a new object was added, called User Defined, which can be used to enter known or measured concentrations and/or fluxes for all media, thus simplifying use of the system.

The Conceptual Site Model (CSM) for the modeling approach used for this study is shown in the right-hand side of Figure 2. Air concentrations and depositional rates were entered in the Air Module. Output (air concentrations and

depositional fluxes) from this module fed into the Exposure Pathways Module, and output (exposure concentrations in air and soil) from the Exposure Pathways Module fed into the human Receptor Intake Module. Output (body doses) from the Receptor Module fed into the human Health Impacts Module. Each of these modules is described in the following text along with input parameters as well as the dosage calculations.

Air Module. Known air concentrations and depositional flux for the gas phase and up to three particulate phases can be entered as time series data within the ATO Module. Wet, dry, or total deposition can be entered for depositional flux. For this study, total depositional flux was used, and only one particulate phase was considered. However, several chemicals that were evaluated can exist in both particulate and gas phase, thus, both phases were considered for air concentrations and depositional flux. As explained above, the spatial average of the time-averaged (i.e., annual average) deposition rates and air concentrations were used. Two sets of air concentrations and deposition rates were input for each chemical, one at time 0.0 and one at some years later, e.g., 300 years, depending on the length of the simulation. The concentrations and deposition rates were set to be constant over time.

Exposure Module. The various exposure routes to be considered are speci- fied in this module, and for this study these included air inhalation, resuspended soil inhalation, soil ingestion, and soil dermal contact. Parameters dealing with exposure, soil leaching, and soil resuspension must also be specified. Since this module accepts depositional fluxes and computes soil concentrations for soil ingestion, inhalation, and dermal contact, surficial soil properties must also be specified. All parameters required for this module and the values used are listed in Table 1. Site data were used to set as many parameters as possible, such as soil bulk density, while others (e.g., soil thickness for leaching) were assumed.

In addition to leaching as a loss pathway in the soil, it is possible for chemical decay in the soil. The chemical database contains values for decay in soil estimated from volatilization. Thus, if a half-life value is in the database for a chemical, a first-order decay based on the half-life was applied in the model. These half-life values are listed for each chemical in Chapter 4.

Receptor Module. User input parameters for the Receptor Module are: individual's body weight (set at 70 kg); exposure duration set at 30 years; age at the start and end of the exposure duration (ages must be input but are not presently used except to distinguish output for different receptor characteristics); air and soil inhalation parameters (Table 2); and soil ingestion and dermal contact parameters (Table 3). Values for the parameters in Tables 2 and 3 were agreed upon in collaboration with CHPPM. In addition to these parameters, gastrointestinal (GI) absorption fraction and dermal soil absorption fraction are required and are provided via the physicochemical properties database as discussed in Chapter 4.

Table 1
Exposure Module Parameters

Parameter	Value
Exposure duration	30 years
Time to start exposure	0
Maximum time for reporting results	See note 1
Number of time points for reporting results	See note 2
Surficial soil thickness receiving deposition	4 cm
Bulk density for surficial soil receiving deposition	1.5 g/cm^3 (see note 3)
X and Y coordinates of exposure site	See note 4
Soil leach option	Calculated from infiltration, soil properties, and K_d
Surficial soil sorption distribution coefficient for leaching, k_d	See note 5
Surficial soil thickness for leaching	7.6 cm (assumed)
Surficial soil moisture content fraction for leaching	0.3 (see note 3)
Surficial soil bulk density for leaching	1.5 g/cm^3 (see note 3)
Total infiltration rate for leaching	76.2 cm/yr (see note 3)
Atmospheric resuspension factor for soil	1 x 10^{-7} m^{-1} (MEPAS model default value)

1 Variable and depended on chemical characteristics. Models were run until a maximum exposure concentration was reached.
2 Depended on maximum time for reporting results, but enough detail to determine maximum exposure concentration.
3 Average or typical for MMR site data (AMEC 2001 and *http://www.mmr.org*)
4 Not required.
5 Depended on chemical-specific properties (Chapter 4).

Table 2
Air and Soil Inhalation Parameters

Parameter	Value
Inhalation rate for contaminated air	20 m^3/day
Inhalation rate for resuspended contaminated soil	20 m^3/day
Annual frequency factor (fraction of year) for contaminated air inhalation[1]	0.0114
Annual frequency factor (fraction of year) for resuspended soil inhalation[1]	0.0114

[1] Based upon 50 days per year for 2 hr per day.

Table 3
Soil Ingestion and Dermal Contact Parameters

Parameter	Value
Skin thickness (not required unless water contact is considered)	0.001 cm
Exposed skin area	3,300 cm^2
Soil adherence factor	0.2 mg/cm^2
Soil dermal contact frequency	1 event/day
Annual dermal contact frequency factor (fraction of year)[1]	0.0114
Soil ingestion rate	0.1 g/day
Annual soil ingestion frequency factor (fraction of year)[1]	0.0114

[1] Based upon 50 visits per year for 2 hr per day.

The equations used to compute daily doses are described below for each exposure route. The daily dose method, rather than the air concentration method, was used for the air inhalation impact analysis. The average daily dose resulting from air inhalation is calculated in the Receptor Module from the relation

$$D_{ai} \ = \ C_{ai} \ U_a \ F_a \ \frac{ED}{BW \ \ AT} \tag{2}$$

where

D_{ai} = average daily inhalation dose from chemical i for the air pathway, mg/kg/day

C_{ai} = average concentration over the exposure duration of chemical i in air at point of inhalation, mg/m^3

U_a = air inhalation rate during exposure, m^3/day

F_a = fraction of year that inhalation exposure occurs, dimensionless

ED = exposure duration, 1 year

BW = body weight of individuals exposed, kg

AT = averaging time for exposure, 1 year

It should be noted that time-varying concentrations are integrated over the exposure period to obtain the average concentration during exposure used in Equation 2. Thus, the average daily dose is a single number for the exposure duration. However, the average daily dose can vary over time. For example, consider the case where the concentrations are varying over time (e.g., every year), the exposure duration is 30 years, and the time for analysis extends over 210 years with the number of time points for viewing results set to 21. For this case, dose will vary with time and will be computed and output every 10 years. The value at time zero will be based upon the 30-year-average concentrations integrated over years 0 to 30. The value for dose at year 10 will be based upon the 30-year-average concentrations integrated over years 10 to 40, and so on. Thus, time-varying doses and health impacts can be computed, but they are based upon the integral of exposure concentrations over the exposure duration following the reporting time. The averaging time (AT) for noncarcinogenic chemicals is set to the exposure duration, and the averaging time for carcinogenic chemicals is fixed at 70 years.

The average daily dose resulting from inhalation of resuspended contaminated soil is calculated in the Receptor Module from the relation

$$D_{ri} \ = \ SAF_i \ U_r \ RF \left[\frac{F_r \ ED}{BW \ \ AT} \right] \tag{3}$$

where

D_{ri} = average daily inhalation dose from chemical i from soil resuspension, mg/kg/day

SAF_i = soil unit deposition and accumulation for chemical i for the current exposure duration, mg/m^2

U_r = air inhalation rate of resuspended soil during exposure, m^3/day

RF = soil resuspension factor, m^{-1}

F_r = fraction of year that resuspended soil inhalation exposure occurs, dimensionless

The soil deposition and accumulation factor is used to account for the accumulation of chemicals in soil over multiple years. This factor accounts for the previous years' deposition and accumulation to evaluate an average soil concentration over the exposure duration. This factor is evaluated as the time integral of the solution for the deposition and decay differential equation averaged over the exposure period, which can be computed from

$$\frac{d\ C_{si}}{d\ t}\ =\ DP_{si}\ -\ C_{si}\ \lambda_{si} \tag{4}$$

and

$$SAF_i\ =\ \frac{\int_0^{365.25\ ED} C_{si}\ d\ t}{365.25\ ED} \tag{5}$$

where

DP_{si} = average deposition rate over the exposure duration of chemical i to soil at point of resuspension and inhalation, mg/m^2/day

C_{si} = soil accumulation of chemical i per unit area as a function of time, mg/m^2

λ_{si} = environmental degradation and decay constant for chemical i in surface soil, day^{-1}

The average daily dose resulting from soil ingestion is calculated from the relation

$$D_{si}\ =\ 10^{-6}\ SAF_i\ U_s\ F_s\ \left[\frac{ED}{h\ \rho_b\ BW\ AT}\right] \tag{6}$$

where

D_{si} = average daily dose for chemical i from the ingestion of soil, mg/kg/day

10^{-6} = conversion factor, m^3/cm^3

U_s = ingestion rate of soil, g/day

F_s = fraction of year that soil ingestion exposure occurs, dimensionless

h = thickness of soil layer that deposited chemical is uniformly distributed within, m

ρ_b = bulk density of soil that deposited chemical is distributed within, g/cm^3

All other terms have been previously defined.

The daily average dose from soil dermal contact is computed from

$$D_{di} \;=\; 10^{-6} \;\; 10^{-3} \;\; SAF_i \left[\frac{F_d \;\; FE_d \;\; AD \;\; A_d \;\; AB_{di}}{h \;\; \rho_b \;\; f_{li}} \right] \left[\frac{ED}{BW \;\; AT} \right] \qquad (7)$$

where

D_{di} = average daily dose for chemical i from dermal contact with soil, mg/kg/day

10^{-6} = conversion factor, m^3/cm^3

10^{-3} = conversion factor, g/mg

F_d = fraction of year that soil dermal contact occurs, dimensionless

FE_d = soil contact event frequency, events/day

AD = adherence factor for contact with soil or sediment, mg/cm^2 skin

A_d = area of skin contacted by soil (exposed skin area), cm^2

AB_{di} = fraction of chemical i on skin that is absorbed into the body during one soil or sediment contact event (dermal absorption fraction), fraction/event

f_{li} = fraction of chemical i absorbed in passing through the GI tract following ingestion (GI absorption fraction), mg absorbed/mg ingested

All other variables in Equation 7 have been explained previously. The dermal absorption fraction and the GI absorption fraction are defined in the chemical-specific properties database (Chapter 4).

Health Impacts Module. No other parameters must be defined for the analysis. Output from the Receptor Module (doses) is used with either the cancer slope factors (for carcinogens) or the reference doses (for noncarcinogens) to determine either the incremental lifetime cancer risk or the hazard index, respectively. Cancer risk is determined by multiplying dose times the slope factor, and hazard index is obtained by dividing the dose by the reference dose. Both metrics apply to an individual, and cancer risk represents lifetime risks, whereas hazard index is averaged over the exposure duration. However, as

explained earlier, health impacts can vary over time, but they are based upon a sliding, time-integration of exposure concentrations and doses that are experienced over the exposure duration. Although a constant air concentration and depositional flux over time were used in these analyses, the results are time varying since the soil concentrations can change over time as a result of chemical buildup and loss from deposition and leaching. Highly adsorptive chemicals exhibit a much greater time dependency.

Vadose zone analysis

Model description. The MEPAS groundwater models analytically solve the one-dimensional advective, three-dimensional dispersive equation for solute movement through a porous medium with a unidirectional, constant flow velocity with degradation/decay,

$$\frac{\partial C}{\partial t} + (\frac{u}{R_{f1}})(\frac{\partial C}{\partial x}) = (\frac{D_x}{R_{f1}})(\frac{\partial^2 C}{\partial x^2}) + (\frac{D_y}{R_{f1}})(\frac{\partial^2 C}{\partial y^2}) + (\frac{D_z}{R_{f1}})(\frac{\partial^2 C}{\partial z^2}) - \lambda C \qquad (8)$$

where

$$R_{f1} = 1 + \frac{\beta_d}{n_e} K_d \ \text{ (Saturated Zone)} \qquad (9)$$

or,

$$R_{f1} = 1 + \frac{\beta_d}{\Theta} K_d \,\text{(Vadose Zone)} \qquad (10)$$

and

$$\Theta = n \left[\frac{K(\Theta)}{K_s} \right]^b \ \text{(Vadose Zone)} \qquad (11)$$

and

$$D = \alpha \ u \ + \ D_{mol} \qquad (12)$$

where

C = dissolved concentration (mg/L)

u = pore-water velocity (cm s^{-1})

R_{fl} = retardation factor (dimensionless)

β_d = bulk density (g cm^{-3})

K_d = equilibrium partition (or distribution) coefficient (mL g^{-1})

$D_{x,y,z}$ = dispersion coefficients in the x, y, and z directions, respectively (cm^2 s^{-1})

λ = degradation / decay rate (sec^{-1})

n_e = effective porosity (fraction)

n = total porosity (fraction)

Θ = moisture content (fraction)

$K(\Theta)$ = hydraulic conductivity (cm s^{-1})

K_s = saturated hydraulic conductivity (cm s^{-1})

α = dispersivity in x, y, and z direction (cm)

b = an empirically based parameter that is a function of soil type

If the infiltration rate is less than the saturated hydraulic conductivity, $K(\Theta)$ is set to the infiltration rate. If the infiltration rate is equal to or greater than the saturated hydraulic conductivity, $K(\Theta)$ is set to the saturated hydraulic conductivity. The moisture content calculated from Equation 11 is not allowed to be less than the specified field capacity. Thus, the moisture content varies between the field capacity and saturation, or total porosity, n.

In the vadose zone, Equation 8 is oriented and solved with the flow axis, i.e., the x-axis, in the vertical direction. For the vadose zone, lateral components of dispersion are assumed zero. In the saturated aquifer, Equation 8 is oriented and solved with the flow axis (x-axis) in the longitudinal direction along the principal groundwater flow direction, and all three dispersion components are included. Model setup involved specifying site conditions as described in Chapter 2 with values discussed in Chapter 4. The degradation or decay was assumed to be zero for both the vadose zone and saturated aquifer modeling.

Fate/Transport Pathways. The source zone was idealized as a unit area of 1 m × 1 m. The source object used the Known Source Module. Input to the Known Source Module consisted of water and chemical fluxes (m^3/yr and g/yr, respectively) moving from the surficial soil horizon into the vadose zone. These flux rates were obtained by taking the infiltration rate (76.2 cm/yr) and air deposition rates for each chemical (g/m^2/yr) obtained from the CHPPM air modeling and multiplying by the unit source area of 1.0 m^2. Output from the source object was water flux (volume/time) and mass flux (mass/time), which fed into the MEPAS Vadose Zone model. Output flux (mass/time) from the Vadose Zone model fed into the MEPAS Aquifer model, which was used to obtain concentrations in the aquifer at the location of the receptor. The output from the Exposure object was concentration versus time at the aquifer receptor location, which was specified as 1.0 m downstream from the point of vadose zone interception and at the top of the water table. The concentration time series yielded the time for the contamination to reach the water table, which was the

main information of interest for screening chemicals of concern. The receptor location could have been placed farther downstream anywhere in the aquifer to yield potential concentrations at desired locations had this been an objective of the study.

4   Input Data

Hydrogeologic Data

Several parameters from the site hydrogeologic characterization data were needed for the simulations. Some of these data were obtained from a site characterization report prepared by AMEC, Earth & Environmental, Inc. (AMEC 2001) and some from the web site on MMR project (*www.mmr.org*). The thickness of unsaturated zone layer is one of the input parameters used for the vadose (subsurface) simulation. The thickness of the vadose zone was estimated from Figure 3 (Figures 2 through 5, AMEC 2001). Figure 3 shows that the vadose zone thickness varies from 40 to 120 ft with an average of 90 ft in the study area (the impact area). Other hydrogeological input parameters used in the subsurface calculations were obtained either from the AMEC report, earlier subsurface modeling work using the Groundwater Modeling System (GMS) by ERDC, or from the above web site. Table 4 provides a summary of the data that were used in the simulations.

Dispersion

A large-scale tracer test (Garabedian et al. 1991) in sand and gravel of Cape Cod, Massachusetts, indicated longitudinal, transverse, and vertical dispersivities of 96 cm, 1.8 cm and 0.15 cm, respectively, with reference to the principal flow directions. These data were included in the ARAMS/FRAMES simulations as indicated in Table 4.

Sorption Partitioning

The chemicals evaluated in this study are listed in Table 5. The partition coefficient, K_d, for each organic chemical was calculated using K_{ow}, f_{oc}, and the equation defined by Karickhoff et al. (1979),

$$K_d = 0.6 \; f_{oc} \; K_{ow} \tag{13}$$
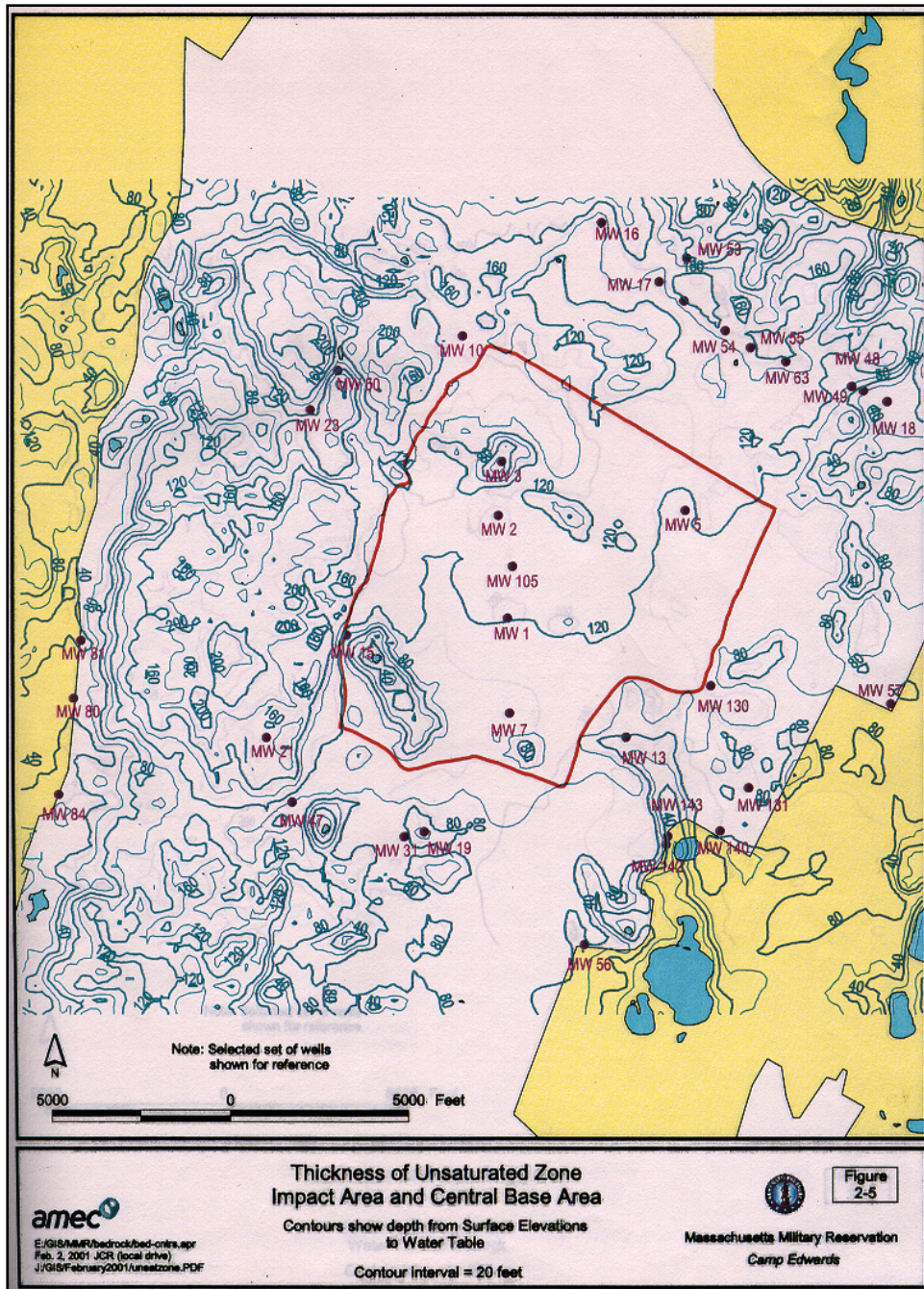
Figure 3.   Thickness of unsaturated zone (permission to reprint granted by AMEC (2001))

where

K_{ow} = octonol to water partitioning coefficient

f_{oc} = fraction of organic carbon of the soil

Barber et al. (1988) measured the organic carbon content of MMR aquifer materials and used foc = 0.001 in their transport calculations. MEPAS requires

the percentage of organic matter (fom) for use in soil composition. The relationship between foc and fom is given as:

$$f_{oc} = f_{om} / 172.4 \qquad\qquad (14)$$

Table 4 Input Parameters for Subsurface Pathway	
Parameter	**Value**
Source (flow data)	
Natural recharge rate	0.762 m/yr
Vadose Zone (hydrogeologic data)	
Thickness	27 m (90 ft)
Soil composition	Sandy Clay Loam[1]
Percentage of organic matter	0.17
Saturated hydraulic conductivity	3,337.56 m/yr
Dry bulk density	1.6 g/cm^3
Total porosity	39.8 %
Vertical dispersivity	0.96 m
Saturated Zone (hydrogeologic data)	
Thickness	24 m (80 ft)
Soil composition	Sandy Clay Loam[1]
Percentage of organic matter	0.17
Dry bulk density	1.6 g/cm^3
Total porosity	39.8 %
Effective porosity	30 %
Darcy velocity	100 cm/day
Horizontal dispersivity	0.96 m
Lateral dispersivity	0.018 m
Vertical dispersivity	0.0015 m
[1] Soil composition available in MEPAS that is closest to the site soil composition.	

Table 5 provides the calculated K_d and K_{ow} for each organic chemical obtained from Risk Assessment Information System (RAIS) database (*http://risk.lsd.ornl.gov/cgi-bin/tox/TOX_select?select=nrad*). For inorganic chemicals such as cadmium, the suggested RAIS or EPA (1999) K_d values were used.

Table 5
Adsorption Coefficient of the Chemicals

Chemical	CAS #[1]	K_d (L/kg)	K_{ow} (L/Kg)	Reference for K_d or K_{ow}
Arsenic, inorganic	7440-38-2	29	N/A	RAIS
Benzene	71-43-2	0.09	141.25	RAIS
Cadmium (Diet)	7440-43-9	226.70	N/A	EPA
Carbon tetrachloride	56-23-5	0.33	524.80	RAIS
Chloroform	67-66-3	0.0575	91.20	RAIS
Chromium VI (particulates)	18540-29-9	19	N/A	RAIS
Ethylbenzene	100-41-4	0.8899	1,412.53	RAIS
Lead and compounds	7439-92-1	900.00	N/A	RAIS
Methylene chloride	75-09-2	0.0112	17.80	RAIS
Nitrobenzene	98-95-3	0.0436	69.18	RAIS
Tetrachloroethylene	127-18-4	0.2508	398.11	RAIS
Toluene	108-88-3	0.3086	489.78	RAIS
Trichloroethylene	79-01-6	0.1228	194.98	RAIS
Dichloroethylene, 1,2-trans-	156-60-5	0.02	30.20	RAIS
2-Butanone	78-93-3	0.0012	1.91	RAIS
Benzaldehyde	100-52-7	0.02	30.20	RAIS
TCDD, 2,3,7,8-	1746-01-6	2,750	4,365,158	RAIS
Furan	110-00-9	0.0446	70.80	RAIS
Carbon disulfide	75-15-0	0.09	144.54	RAIS
Naphthalene	91-20-3	1.4769	2,344	RAIS
Phenanthrene	85-01-8	22.353	35,481	RAIS
Trimethylbenzene (mixed Isomers)	25551-13-7	1.5825	2,511	RAIS
Hexachlorobenzene	118-74-1	185.93	295,120	RAIS
Di-n-octylphthalate	117-84-0	998,482	1.58E+09	RAIS

[1] Chemical Abstracts Service Number

Decay Rates

The human exposure pathways model uses soil concentrations to provide the exposure concentrations for soil dermal contact, ingestion, and inhalation (from resuspended soil). The soil concentrations are computed by the human exposure pathways model and can change with time as a result of deposition, leaching, and decay. Soil and chemical loss because of wind and water erosion are not considered. As discussed in Chapter 3, decay is assumed to be a first-order process based on half-life, where the decay rate, λ, is computed from $\dfrac{ln\,2}{t_{1/2}}$,

where $t_{1/2}$ is the half-life. Soil half-life values provided in the chemical database were estimated based on calculated volatilization rates. The soil half-life values provided in the database and used by the model are indicated in Table 6.

Table 6		
Surface Soil Half-lives		
Chemical	**CAS #**	**Half life, days**
Arsenic, inorganic	7440-38-2	No decay
Benzene	71-43-2	1.28E+01
Cadmium (diet)	7440-43-9	No decay
Carbon tetrachloride	56-23-5	124
Chloroform	67-66-3	7.54E+00
Chromium VI (particulates)	18540-29-9	No decay
Ethylbenzene	100-41-4	1.66E+02
Lead and chemicals	7439-92-1	No decay
Methylene chloride	75-09-2	5.0E+01
Nitrobenzene	98-95-3	7.55E+03
Tetrachloroethylene	127-18-4	6.05E+01
Toluene	108-88-3	2.67E+02
Trichloroethylene	79-01-6	1.94E+01
Dichloroethylene, 1,2-trans-	156-60-5	No decay
2-Butanone	78-93-3	8.42E+02
Benzaldehyde	100-52-7	No decay
TCDD, 2,3,7,8-	1746-01-6	No decay
Furan	110-00-9	2.06E+00
Carbon disulfide	75-15-0	3.41E+00
Naphthalene	91-20-3	1.29E+04
Phenanthrene	85-01-8	1.570E+06
Trimethylbenzene (mixed Isomers)	25551-13-7	8.36E+02
Hexachlorobenzene	118-74-1	9.05E+07
Di-n-octylphthalate	117-84-0	6.69E+06

Toxicological and Exposure Data

The risk calculations require basic input toxicological data from the FRAMES database. For the chemicals used in this study, the current FRAMES database did not contain all the required data. In the absence of data, no toxicological benchmark is assumed, and there is no health risk computed. Therefore, for this study, if toxicological data were missing, the RAIS database (*http://risk.lsd.ornl.gov/cgi-bin/tox/TOX_select?select=nrad*) was used to obtain the benchmark if available in RAIS, and these values were input in the FRAMES project database. Table 7 shows the toxicological data that were used in the assessment taken from FRAMES and RAIS. The FRAMES database was modified to use the values obtained from RAIS. The MEPAS health impacts model uses the oral reference dose and cancer slope factor along with the GI absorption fraction to calculate dermal reference values per USEPA guidance. Dermal reference dose is obtained by multiplying the oral reference dose by the GI absorption fraction, and dermal cancer slope factor is obtained by dividing the oral slope by the GI absorption fraction. Likewise, the dermal toxicity values in RAIS were calculated in the same fashion. The GI absorption fractions shown in Table 7 were used for these calculations in MEPAS.

Table 7
Toxicological Properties from FRAMES and RAIS Databases Used in the Analysis

Chemical	CAS #	Absorption Fraction, Dermal	GI Absorption Fraction	Inhalation RfD – Chronic mg/kg-day	Oral RfD – Chronic mg/kg-day	Inhalation SF (mg/kg-day)$^{-1}$	Oral SF (mg/kg-day)$^{-1}$
Arsenic, Inorganic	7440382	0.001	0.41		3.00E-04	1.50E+01	1.50E+00
Benzene	71432	0.01	0.97	1.70E-03	4.00E-03	2.90E-02	2.90E-02
Cadmium (Diet)	7440439	0.001	0.01	5.71E-05	5.00E-04	6.30E+00	
Carbon Tetrachloride	56235	0.01	0.65	7.00E-04	7.00E-04	5.30E-02	1.30E-01
Chloroform	67663	0.01	0.20	2.77E-02	1.00E-02	8.10E-02	6.10E-03
Chromium VI (particulates)	18540299	0.001	0.02	5.70E-06	5.00E-03	4.10E+01	
Ethylbenzene	100414	0.01	0.97	2.90E-01	1.00E-01	3.85E-03	
Lead and compounds	7439921	0.001	0.15	4.30E-04	1.40E-03		
Methylene Chloride	75092	0.01	0.95	8.57E-01	6.00E-02	1.60E-03	7.50E-03
Nitrobenzene	98953	0.01	0.97	1.43E-03	5.00E-04		
Tetrachloroethylene	127184	0.01	1.0	7.70E-02	1.00E-02	1.80E-03	5.00E-02
Toluene	108883	0.01	0.80	1.10E-01	2.00E-01		
Trichloroethylene	79016	0.01	0.15			1.30E-02	1.10E-02
Dichloroethylene, 1,2-trans-	156605	0.01	1.0	2.00E-02	2.00E-02		
2-Butanone	78933	0.01	0.8	2.90E-01	6.00E-01		
Benzaldehyde	100527	0.01	0.80	1.00E-01	1.00E-01		
TCDD, 2,3,7,8-	1746016	0.03	0.50			1.50E+05	1.50E+05
Furan	110009	0.01	0.80	1.00E-03	1.00E-03		
Carbon Disulfide	75150	0.25	0.63	2.00E-01	1.00E-01		
Naphthalene	91203	0.01	0.80	2.86E-03	4.00E-02		
Phenanthrene	85018	0.13	0.73	3.00E-02	3.00E-02		
Benzene, Trimethyl (Trimethylbenzene (mixed Isomers)	25551137	0.01	0.97	8.80E-01	5.00E-05		
Hexachlorobenzene	118741	0.01	0.50	8.00E-04	8.00E-04	1.60E+00	1.60E+00
Octyl Phthalate, di-N-	117840	0.01	0.90	2.00E-02	2.00E-02	1.40E-02	1.40E-02

RfC = noncarcinogenic reference concentration RfD = noncarcinogenic reference dose	SF = cancer slope factor		Data from RAIS Database
			Data were not available

The area of skin exposed during soil contact events and soil adherence factor for soil contact for outdoor worker are 3,300 cm^2 and 0.2 mg/cm^2, respectively (USEPA 2001). Annual frequency factor for soil dermal contact assuming 50 days and 2 hr per day during 365 days per year is:

$$\frac{50}{365} \times \frac{2}{24} = 0.0114 \qquad (15)$$

The soil dermal absorption fraction is also required from the database as indicated in Table 7.

Initial and Boundary Load Conditions

CHPPM provided the air concentrations and deposition rates, which were used as input to ARAMS/FRAMES. The data set consisted of location-specific data and spatially averaged data. For location-specific data, the coordinate locations of the point of interest in X-direction (UTM, meters), Y-direction (UTM, meters), and Z-direction (meters) were provided. Other parameters provided included: Pc, the average annual particulate concentration in air (ug/m^3); Pdd, the average annual deposition rate resulting from dry deposition/ gravitational settling of particulates (g/m^2/yr); Pwd, the average annual deposition rate resulting from wet deposition (rain and snow) of particulates (g/m^2/yr); Vc, the average annual vapor concentration in air (ug/m^3); Vwd, the average annual deposition rate of vapors because of rain and snow (g/m^2/yr); VF, the vapor fraction of each chemical; PF, particle fraction of each chemical; and Ermax, maximum/worst case emission rate out of all five pyrotechnic categories. The spatially averaged data consisted of the Pc, Pdd, Pwd, Vc, and Vwd values only.

The selected chemicals can be in gas, particle, or both forms. The load data were kept constant throughout the simulation. Total deposition rates were used. Figure 4 shows, as an example, the input screen of the air module of ARAMS for hexachlorobenzene. Table 8 provides the complete list of air concentration and deposition data used in this study. The deposition rates and air concentrations were held constant for 100 years, then set to zero after year 100, and a total simulation time of 300 or more years was used as discussed in Chapter 5.
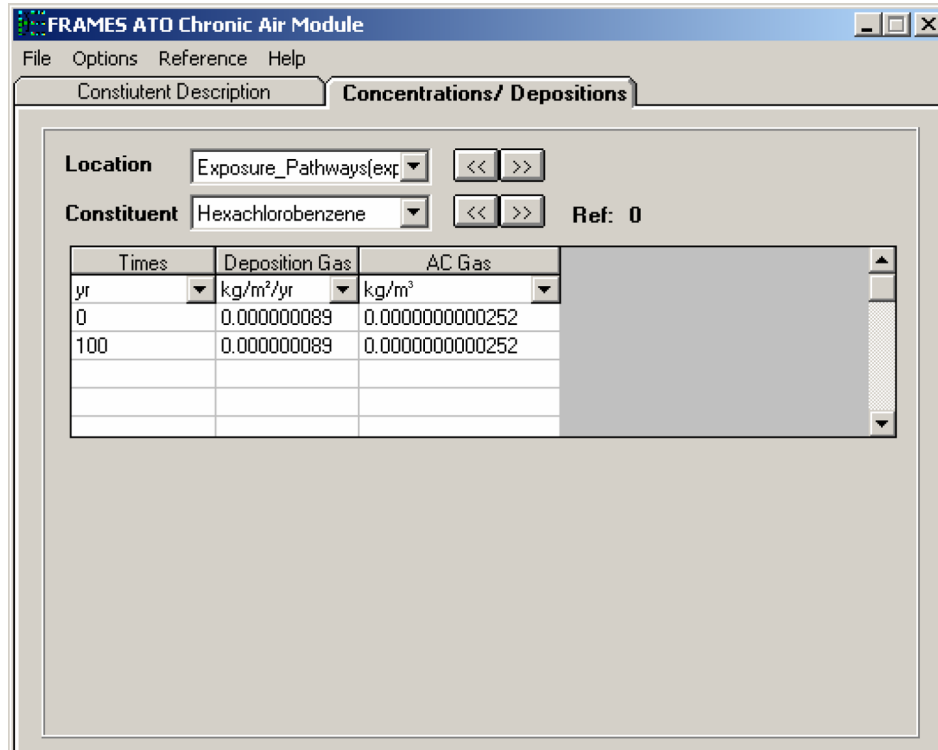
Figure 4.   Input load data for hexachlorobenzene

Table 8
Input Load Data

ID	Chemical	CAS#	Deposition Rate Gas (kg/m^2/yr)	Deposition Rate Particle (kg/m^2/yr)	Air Concentration Gas (kg/m^3)	Air Concentration Particle (kg/m^3)
1	Arsenic	7440-38-2	---	7.436E-07	---	8.416E-012
2	Benzene	71-43-2	4.018E-05	---	1.137E-08	---
3	Cadmium	7440-43-9	---	1.707E-07	---	1.932E-12
4	Carbon tetrachloride	56-23-5	1.731E-06	---	4.898E-10	---
5	Chloroform	67-66-3	1.400E-08	---	3.963E-12	---
6	Chromium	18540-29-9	---	3.595E-06	---	4.068E-11
7	Ethylbenzene	100-41-4	3.886E-05	---	1.099E-08	---
8	Lead	7439-92-1	---	4.576E-06	---	5.179E-11
9	Methylene chloride	75-09-2	3.500E-07	---	9.900E-11	---
10	Nitrobenzene	98-95-3	4.354E-10	---	1.232E-13	---
11	Tetrachloroethylene	127-18-4	2.217E-06	---	6.273E-10	---
12	Toluene	108-88-3	1.017E-04	---	2.878E-08	---
13	Trichloroethylene	79-01-6	1.500E-08	---	4.243E-12	---
14	1,2-Dichloroethylene trans	156-60-5	3.473E-09	---	9.827E-13	---
15	2-Butanone	78-93-3	4.250E-07	---	1.203E-10	---
16	Benzaldehyde	100-52-7	1.800E-06	---	5.093E-10	---
17	Dioxin TEQ	1746-01-6	2.457E-13	---	6.951E-17	---
18	Furan	110-00-9	1.107E-08	---	3.134E-12	---
19	Carbon Disulfide	75-15-0	1.057E-06	---	2.992E-10	---
20	Naphthalene	91-20-3	3.026E-06	---	8.563E-10	---
21	Phenanthrene	85-01-8	1.524E-08	---	4.313E-12	---
22	Trimethylbenzene (mixed isomers)	25551-13-7	2.981E-05	---	8.436E-09	---
23	Hexachlorobenzene	118-74-1	8.907E-08	---	2.520E-11	---
24	Di-n-octylphthalate	117-84-0	1.320E-08	3.232E-08	3.730E-12	3.660E-13
--- Not applicable						

5   Results

As in all risk assessments, human health risk was evaluated in terms of cancer and noncancer effects. Incremental cancer risks were estimated as a probability, or chance, that a person would develop cancer over his or her lifetime as a result of exposure to the chemicals at the site. For example, a risk of "one in one million" means that if one million people were exposed to the contamination at MMR for 30 years, at most one additional case of cancer would be expected to occur over lifetime as a result of their exposure. Noncancer hazard potential (hazard index, HI) is presented as a ratio of the predicted exposure compared to a safe level. Aggregate exposures yielding an HI less than 1.0 will likely not result in adverse noncancer health effects. However, an HI value greater than 1.0 does not necessarily suggest a likelihood of adverse effects. Furthermore, the HI cannot be translated to a probability that adverse effects will occur and is not likely to be proportional to risk. For example, a respiratory HI greater than 1.0 can be best described as indicating that a potential may exist for adverse irritation to the respiratory system. The noncarcinogenic and carcinogenic risks were estimated according to the route of exposure, i.e., dermal, inhalation, and ingestion.

The air concentrations and deposition rates provided by CHPPM were used as input to ARAMS to predict potential health risk from air and soil exposure to visitors or trespassers entering the MMR. In addition, we completed a screening-level modeling of the subsurface fate/transport processes to predict the movement of chemicals through the vadose zone and into the groundwater. The subsurface calculations determined travel time of the peak concentration to reach the water table for each chemical. Twenty-four (24) chemicals were selected for this study.

The soil concentration of a chemical changes with time because of continual loading, leaching, and decay (based on volatilization only) but may eventually reach a steady-state value as a result of the constant deposition rate over time. The concentrations of some chemicals in the soil and subsurface reach steady-state values quickly within a short period (e.g., 1 year) and others with high sorption partition coefficients take a long time (e.g., 1,000 years or more). The soil concentrations and risk values indicated as "initial" in the tables are those expected after 1 year of pollutant deposition. The "final" soil concentrations and risk values in the tables are the values calculated after 70 years of simulation. The deposition rates (and air concentrations) were held constant for 100 years, then set to zero after year 100, and a total simulation time of 300 years was used for most chemicals. For chemicals with very high K_d such as inorganic chemicals, a much longer period of time was required for peak concentrations to

reach steady-state or to reach the water table. For these cases, longer runs were made (up to 10,000 years), but the final soil concentrations and health effects in the tables are those calculated at the end of year 70, and these values may be different from the final steady-state values.

The ARAMS output can be shown in graphical or text form. Figure 5 shows, as an example, a summary table of risks for dichloroethylene. The simulation results from all summary tables are organized in Tables 9 through 12. Table 9 provides a summary of hazard indices and risks associated with inhalation of the chemicals only from the air pathway. Table 10 provides a summary of risks and hazard indices expected for the chemicals from inhalation, ingestion, or dermal contact of contaminated soil. Table 11 provides the combined hazard indices and risks expected from both air and soil pathways. Table 12 shows the peak concentration (at water table interception) and the associated travel times to the groundwater, and EPA Maximum Contaminant Level (MCL). The values in Tables 9,10, and 11 are marked with different colors to differentiate the significance of the numbers. The zero values (0.00E+00) indicate that a health benchmark was not available or not applicable for calculation of risk and is indicated with yellow color. For example, in Table 9, the value of carcinogenic risk for the first chemical in the list (1,2-Dichloroethylen trans) is given as 0.00E+00, which indicates the input data for this calculation were not applicable since no carcinogenic reference values are available. The red color for HI or risk indicates that HI is greater than 1.0 or carcinogenic risk is greater than 10^{-6}. Table 9 shows that only one chemical is shaded red, chromium, which has carcinogenic risk value slightly greater than 10^{-6} for the air pathway. In regard to the soil pathway, the risk calculations in Table 10 show none of the selected chemicals pose problems. Table 11 lists the total noncarcinogenic, HI, and carcinogenic risk from all routes of exposure combined for soil and air. If we consider the total risks (Table 11), only one chemical, chromium, has a carcinogenic risk slightly greater than 1.E-06. Table 12 presents the initial (after 1 year) and final (after 70 years) soil concentrations for each chemical.

As shown in Table 13, none of the chemicals have peak concentrations higher than the MCL. For dioxin, di-n-octylphthalate, and lead, which have very high K_d values, the peak concentrations were not calculated because they require very long simulation times, i.e., greater than 10,000 years, to reach the peak. The calculated results indicate that, during a reasonable time, these chemicals do not reach the groundwater and, hence do not pose any threat. The travel time of the peak concentration is calculated to be from as low as 36 years for methylene chloride to as high as 9.97E+03 years for cadmium. The minimum peak concentration is 1.11E-08 mg/L for hexachlorobenzene and the maximum peak concentration is 3.37E-03 mg/L for toluene, which is much less than the EPA MCL for toluene. In regard to groundwater, ARAMS also provides the breakthrough curves of the concentrations at the water table. As an example, Figure 6 shows concentration versus time for benzene at the water table (note the benzene peak concentration is less than MCL). It should be noted that the groundwater concentration is immediately at the contact point of the vadose zone flux. Thus, this concentration will be greatly reduced at locations down gradient due to dilution and dispersion.

Summary of Risks/Hazard/Dose

Location Name: exp10	Constituent: 1,2-Dichloroethylene trans
Exposure Medium: Air	Time Point (yr): 0.00 Exposure duration: 30.00 yr
Exposure Location: (0 , 0) km	Chemical Risk Target Organ: all sites
Age Group: 20 to 50	

☐ Show Totals Only

Exposure Route and Pathway	Noncarcinogenic HI	Carcinogenic Risk (all sites)
TOTAL	**1.61E-07**	**0.0E+00**
Ingestion (total)	2.2E-13	0.0E+00
Soil	2.2E-13	0.0E+00
Dermal (total)	1.45E-14	0.0E+00
Soil	1.45E-14	0.0E+00
Inhalation (total)	1.61E-07	0.0E+00
Air	1.61E-07	0.0E+00
Soil	5.35E-13	0.0E+00

Figure 5.   Output of Health-Impact module of FRAMES with Summary of Risk/Hazard

Table 9
Summary of Hazard Indices and Risks for Each Chemical (air pathway)

	Chemical Name	Noncarcinogenic HI		Carcinogenic Risk	
		Initial	Final	Initial	Final
1	1,2-Dichloroethylene trans	1.610E-07	1.610E-07	0.00E+00	0.00E+00
2	2,3,7,8TCDD DIOXIN	0.00E+00	0.00E+00	1.460E-08	1.460E-08
3	2-butanone	1.350E-06	1.350E-06	0.00E+00	0.00E+00
4	Arsenic	0.00E+00	0.00E+00	1.770E-07	1.770E-07
5	Benzaldehyde	1.660E-05	1.660E-05	0.00E+00	0.00E+00
6	Benzene	2.190E-02	2.190E-02	4.610E-07	4.610E-07
7	Cadmium	1.100E-04	1.100E-04	1.700E-08	1.700E-08
8	Carbon disulfide	4.880E-06	4.880E-06	0.00E+00	0.00E+00
9	Carbon tetrachloride	2.290E-03	2.290E-03	3.630E-08	3.630E-08
10	Chloroform	4.660E-07	4.660E-07	4.490E-10	4.490E-10
11	Chromium VI	2.330E-02	2.330E-02	2.330E-06	2.330E-06
12	Di-n-octylphthalate	6.700E-07	6.700E-07	8.020E-11	8.020E-11
13	Ethyl benzene	1.240E-04	1.240E-04	5.930E-08	5.930E-08
14	Furan	1.020E-05	1.020E-05	0.00E+00	0.00E+00
15	Hexachlorobenzene	1.030E-04	1.030E-04	5.630E-08	5.630E-08
16	Lead	3.930E-04	3.930E-04	0.00E+00	0.00E+00
17	Methylene chloride	3.770E-07	3.770E-07	2.210E-10	2.210E-10
18	Naphthalene	9.760E-04	9.760E-04	0.00E+00	0.00E+00
19	Nitrobenzene	2.800E-07	2.800E-07	0.00E+00	0.00E+00
20	Phenanthrene	4.700E-07	4.700E-07	0.00E+00	0.00E+00
21	Tetrachloroethylene	2.660E-05	2.660E-05	1.580E-09	1.580E-09
22	Toluene	8.540E-04	8.540E-04	0.00E+00	0.00E+00
23	Trichloroethylene	1.210E-06	1.210E-06	7.710E-11	7.710E-11
24	Trimethylbenzene (mixed isomers)	3.130E-05	3.130E-05	0.00E+00	0.00E+00
Hi > 1 or Risk > 1.E-06					
Hi < 1 or Risk < 1.E-06					
Unavailable or non-applicable Benchmark					

Table 10
Summary of Hazard Indices and Risks for Each Chemical (soil pathway)

Chemical Name	Noncarcinogenic HI						Carcinogenic Risk					
	Ingestion		Dermal		Inhalation		Ingestion		Dermal		Inhalation	
	Initial	Final	Initial	Final	Initial	Final	Initial	Final	Initial	Final	Initial	Final
1,2-Dichloroethylene trans	2.20E-13	2.20E-13	1.45E-14	1.45E-14	5.35E-13	5.35E-13	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
2,3,7,8TCDD DIOXIN	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.10E-11	1.64E-10	1.23E-11	6.48E-11	7.56E-11	3.99E-10
2-butanone	2.83E-12	2.83E-12	2.33E-13	2.33E-13	1.43E-11	1.43E-11	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Arsenic	1.31E-06	1.55E-06	2.11E-08	2.50E-08	0.00E+00	0.00E+00	2.52E-10	2.99E-10	4.06E-12	4.79E-12	6.15E-09	7.29E-09
Benzaldehyde	7.98E-11	7.98E-11	6.59E-12	6.59E-12	1.95E-10	1.95E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Benzene	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.82E-07	1.82E-07	1.58E-12	1.58E-12	1.07E-13	1.08E-13	3.86E-12	3.86E-12
Cadmium	5.30E-07	1.50E-06	3.50E-07	9.88E-07	1.13E-05	3.19E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.75E-09	4.93E-09
Carbon disulfide	1.46E-11	1.46E-11	3.84E-11	3.84E-11	1.78E-11	1.78E-11	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Carbon tetrachloride	2.340E-08	2.34E-08	2.37E-09	2.37E-09	5.70E-08	5.70E-08	9.11E-13	9.13E-13	9.26E-14	9.28E-14	9.06E-13	9.06E-13
Chloroform	3.17E-12	3.17E-12	1.05E-12	1.05E-12	2.79E-12	2.79E-12	8.30E-17	8.30E-17	2.73E-17	2.73E-17	2.68E-15	2.68E-15
Chromium VI	2.64E-07	2.94E-07	8.73E-08	9.73E-08	5.67E-04	6.30E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.66E-08	6.31E-08
Di-n-octylphthalate	3.240E-09	1.84E-08	2.38E-10	1.34E-09	7.90E-09	4.47E-08	3.89E-13	2.20E-12	2.85E-14	1.62E-13	9.48E-11	5.36E-12
Ethyl benzene	7.07E-09	7.10E-09	4.81E-10	4.84E-10	5.93E-09	5.97E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.85E-12	2.86E-12
Furan	9.91E-12	9.91E-12	8.17E-13	8.17E-13	2.42E-11	2.42E-11	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Hexachlorobenzene	1.64E-07	4.16E-07	2.16E-08	5.50E-08	4.00E-07	1.02E-06	8.99E-11	2.29E-10	1.19E-11	3.01E-11	2.19E-10	5.57E-10
Lead	6.13E-06	2.80E-05	2.70E-07	1.23E-06	4.86E-05	2.23E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Methylene chloride	2.13E-11	2.13E-11	1.48E-12	1.48E-12	3.64E-12	3.65E-12	4.12E-15	4.12E-15	2.86E-16	2.87E-16	2.14E-15	2.14E-15
Naphthalene	2.65E-09	2.67E-09	2.19E-10	2.22E-10	9.09E-08	9.16E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Nitrobenzene	4.30E-12	4.30E-12	2.93E-13	2.93E-13	3.66E-12	3.66E-12	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Phenanthrene	2.15E-10	2.44E-10	2.53E-10	2.87E-10	5.23E-10	5.97E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Tetrachloroethylene	1.61E-09	1.61E-09	1.06E-10	1.06E-10	5.09E-10	5.100E-10	3.450E-13	3.450E-13	2.28E-14	2.28E-14	3.02E-14	3.02E-14
Toluene	4.92E-09	4.93E-09	4.06E-10	4.07E-10	2.18E-08	2.19E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Trichloroethylene	2.01E-10	2.02E-10	8.87E-11	8.87E-11	1.29E-11	1.29E-11	2.85E-16	2.85E-16	1.25E-16	1.25E-16	8.20E-16	8.22E-16
Trimethylbenzene (mixed isomers)	2.06E-05	2.08E-05	1.40E-06	1.41E-06	2.85E-09	2.89E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

HI > 1 or Risk > 1.E-06	
HI < 1 or Risk < 1.E-06	
Unavailable Benchmark	

Table 11
Total Hazard Indices and Risks for Each Chemical (air & soil pathway)

	Chemical Name	Noncarcinogenic HI		Carcinogenic Risk	
		Initial	Final	Initial	Final
1	1,2-Dichloroethylene trans	1.610E-07	1.610E-07	0.0E+00	0.0E+00
2	2,3,7,8TCDD DIOXIN	0.0E+00	0.0E+00	1.472E-08	1.523E-08
3	2-butanone	1.350E-06	1.350E-06	0.0E+00	0.0E+00
4	Arsenic	1.331E-06	1.575E-06	1.834E-07	1.846E-07
5	Benzaldehyde	1.660E-05	1.660E-05	0.0E+00	0.0E+00
6	Benzene	2.190E-02	2.19E-02	4.610E-07	4.610E-07
7	Cadmium	1.222E-04	1.444E-04	1.875E-08	2.193E-08
8	Carbon disulfide	4.880E-06	4.880E-06	0.0E+00	0.0E+00
9	Carbon tetrachloride	2.290E-03	2.290E-03	3.630E-08	3.630E-08
10	Chloroform	4.660E-07	4.660E-07	4.490E-10	4.490E-10
11	Chromium VI	2.387E-02	2.393E-02	2.387E-06	2.393E-06
12	Di-n-octylphthalate	6.814E-07	7.344E-07	8.157E-11	8.792E-11
13	Ethyl benzene	1.24E-04	1.24E-04	5.93E-08	5.93E-08
14	Furan	1.02E-05	1.02E-05	0.0E+00	0.0E+00
15	Hexachlorobenzene	1.036E-04	1.045E-04	5.662E-08	5.712E-08
16	Lead	6.452E-04	4.480E-04	0.0E+00	0.0E+00
17	Methylene chloride	3.770E-07	3.770E-07	2.210E-10	2.210E-10
18	Naphthalene	9.761E-04	9.761E-04	0.0E+00	0.0E+00
19	Nitrobenzene	2.800E-07	2.800E-07	0.0E+00	0.0E+00
20	Phenanthrene	4.710E-07	4.711E-07	0.0E+00	0.0E+00
21	Tetrachloroethylene	2.660E-05	2.660E-05	1.580E-09	1.580E-09
22	Toluene	8.540E-04	8.540E-04	0.0E+00	0.0E+00
23	Trichloroethylene	1.210E-06	1.210E-06	7.710E-11	7.710E-01
24	Trimethylbenzene (mixed isomers)	5.330E-05	5.531E-05	0.0E+00	0.0E+00
Hi > 1 and Risk > 1.E-06					
Hi < 1 and Risk < 1.E-06					
Unavailable Benchmark					

**Table 12
Soil Concentration (mg/kg)**

Chemical	CAS #	Initial	Final
Arsenic, Inorganic	7440-38-2	0.0241	0.0285
Benzene	71-43-2	0.008	0.008
Cadmium (Diet)	7440-43-9	0.016	0.046
Carbon Tetrachloride	56-23-5	0.001	0.001
Chloroform	67-66-3	1.940E-06	1.940E-06
Chromium VI (particulates)	18540-29-9	0.081	0.090
Ethylbenzene	100-41-4	0.046	0.046
Lead and compounds	7439-92-1	0.526	2.406
Methylene Chloride	75-09-2	7.861E-05	7.861E-05
Nitrobenzene	98-95-3	1.318E-07	1.318E-07
Tetrachloroethylene	127-18-4	9.872E-04	9.872E-04
Toluene	108-88-3	0.061	0.061
Trichloroethylene	79-01-6	3.707E-06	3.707E-06
Dichloroethylene, 1,2-trans-	156-60-5	2.699E-07	2.699E-07
2-Butanone	78-93-3	1.043E-04	1.043E-04
Benzaldehyde	100-52-7	4.902E-04	4.902E-04
TCDD, 2,3,7,8-	1746-01-6	2.959E-08	1.558E-07
Furan	110-00-9	6.077E-07	6.077E-07
Carbon Disulfide	75-15-0	8.985E-05	8.985E-05
Naphthalene	91-20-3	6.583E-03	6.583E-03
Phenanthrene	85-01-8	3.954E-04	4.494E-04
Trimethylbenzene (mixed Isomers)	25551-13-7	6.374E-02	6.374E-02
Hexachlorobenzene	118-74-1	8.039E-03	2.043E-02
Di-n-octylphthalate	117-84-0	3.972E-03	2.248E-02

Table 13
Summary of Subsurface Peak Concentration and Travel Time

Chemical Name	Time, yr	Peak Concentration, mg/L[1]	MCL, mg/L
1,2-Dichloroethylene trans	7.03E+01	1.148E-07	0.1
2,3,7,8TCDD DIOXIN	[2]	[2]	3.00E-08
2-butanone	4.83E+01	1.404E-05	[3]
Arsenic	1.62E+03	2.279E-06	0.05
Benzaldehyde	7.03E+01	5.950E-05	[3]
Benzene	4.09E+01	1.328E-03	0.005
Cadmium	9.97E+03	5.123E-08	0.005
Carbon disulfide	4.09E+01	3.502E-05	[3]
Carbon tetrachloride	8.66E+01	5.717E-05	0.005
Chloroform	9.63E+01	4.626E-07	0.1
Chromium VI	1.07E+03	1.670E-05	0.1 (total)
Di-n-octylphthalate	[2]	[2]	[3]
Ethyl benzene	1.25E+02	1.278E-03	0.7
Furan	5.56E+01	3.657E-07	[3]
Hexachlorobenzene	9.94E+03	4.282E-08	0.001
Lead	[2]	[2]	0.015
Methylene chloride	3.57E+01	1.157E-05	0.005
Naphthalene	1.54E+02	9.543E-05	[3]
Nitrobenzene	3.79E+01	1.438E-08	[3]
Phenanthrene	1.26E+03	6.028E-08	[3]
Tetrachloroethylene	6.06E+01	7.335E-05	0.005
Toluene	7.48E+01	3.371E-03	1
Trichloroethylene	7.45E+01	4.957E-07	0.005
Trimethylbenzene (mixed isomers)	1.50E+02	9.213E-04	[3]

[1] Peak concentration at the location of contact with water table, mg/L.
[2] Chemical peak concentration had not reached water table after 10,000 years.
[3] Not available.
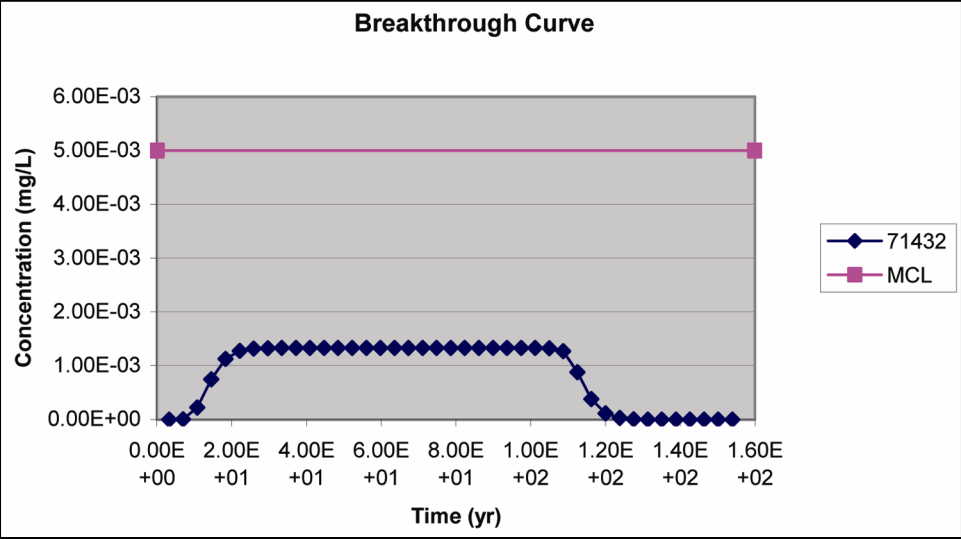
Figure 6.   Time-series of benzene concentration at water table and MCL (0.005 mg/L) for benzene

6   Summary and Conclusions

The potential human health risks associated with exposure to chemicals resulting from future military training at MMR were evaluated. Two independent modeling scenarios, one for human health impacts and one for migration of chemicals through the vadose zone, were utilized in this study. CHPPM provided air concentrations and deposition rates (fluxes) for a list of important chemicals that could be released from future training activities. EPA's ISCST3 air fate/transport model was used (Appendix A). The air model was run for a 4-year period using historical meteorology. The modeling scenario was based on anticipated future training for the National Guard. Weekend training was assumed during the Fall, Winter, and Spring, while weeklong training was assumed for the Summer.

Future training can result in chemicals potentially moving from air to soil through deposition. Thus, air and soil are the exposure media. The MMR human receptor consisted of an adult individual moving around or within the site as a trespasser or visitor. It was assumed that the receptor used no domestic water from wells potentially contaminated by the site. The receptor did not recreate in site surface waters, consume agricultural products from the site, nor consume any fish and wildlife from the site. Therefore, the exposure routes were air inhalation, soil dermal contact, soil ingestion, and resuspended soil inhalation. Twenty-four (24) chemicals were selected from a list of approximately 200 chemicals of potential interest with at least one (1) chemical from each class represented by the complete list of chemicals. The spatially averaged values of annual average deposition rates and air concentrations computed over the site by the air model were used for ARAMS input. Losses resulting from runoff at the site were ignored, but leaching and volatilization losses from soil were included. The calculated risks are based on exposure frequency of 2 hr/day, and 50 days/year, for 30 years exposure duration, and for 100 years of continual training activities and chemical loadings.

With regard to the soil pathway, none of the chemicals posed health concerns, since the calculated risk was less than the acceptable risk of 10^{-6} used by the USEPA, and hazard indices were less than 1.0. For the air pathway, only one chemical, Cr(VI), showed a potential concern, where the cancer risk was 2.4×10^{-6}.

Air deposition to soil can also result in chemicals migrating from soil through the vadose zone to groundwater. For the groundwater analysis, none of the chemicals have peak concentrations higher than the MCL upon initial contact

with the water table. Groundwater that is further down gradient from the point of water table impact will have even lower concentrations because of dilution and dispersion. For Dioxin, di-n-octylphthalate, and lead, which have very high K_d values, the peak concentrations were not calculated because they required very long simulation times (greater than 10,000 years) to reach the water table. The travel time of the peak concentration was calculated to range from as low as 36 years for methylene chloride to as high as 9,970 years for cadmium. The minimum peak concentration was 1.11E-08 mg/L for hexachlorobenzene, and the maximum peak concentration was 3.37E-03 mg/L for toluene, which was still much less than the USEPA MCL for toluene of 1.0 mg/L.

It is emphasized that these results are based on the highly conservative assumption used in the application of emission factors to obtain compound-specific air concentrations and deposition rates (CDRs). As explained in Appendix A, continuous emissions for each munitions type and for each training event were assumed, thus, resulting in a total mass released that is greater than would be expected, which translates into greater, but more conservative, exposure and risks.

Overall, the chemicals to be released during future training activities at MMR that were evaluated in this study should not pose any human health concerns to site trespassers or visitors. Likewise, migration of these chemicals through the vadose zone to groundwater is not expected to be a future problem. Although only 24 of the chemicals of interest resulting from future training exercises were evaluated in this study, the remaining chemicals on the list can be fairly readily evaluated (and are being evaluated) now that the models are in place. The primary effort in evaluating the remaining chemicals is ensuring that the best available chemical-specific parameter values are in the ARAMS database, which requires cross-checking values against other sources of parameter values.

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Appendix A
Air Dispersion Modeling

Introduction

Air concentration and surface deposition rates from emissions related to pyrotechnics training activities depends upon many factors including:

a. Meteorology

b. Location and frequency of the training

c. Amount and type of pyrotechnics used

d. Specific combustion products formed from pyrotechnics use

Air dispersion modeling was used to predict air concentrations and deposition rates resulting from proposed future training operations at the Massachusetts Military Reservation (MMR). These operations were defined using doctrinal/training manuals, site-specific training data, and historical meteorology, as well as specific emissions characterization data. The following sections discuss these factors in more detail.

Training Scenarios

The training information at the MMR was obtained from MMR training personnel (References 1 and 2)[1] and Army training manuals (Reference 3). Information obtained included location of training, schedule of training, and the numbers and types of pyrotechnics used during training scenarios. The type of training conducted varies depending on the military unit, length of the training event, and the particular training mission(s). Typical units training at MMR include Light and Mechanized Infantry, Engineers, and Military Police. Training sessions take place either over a weekend or a 2-week period and include a variety of mission types (e.g., executing an ambush, defending a position, performing a tactical road march).

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[1] References are listed at the end of Appendix A.

Training Locations

The MMR training area is subdivided into several small areas having alphanumeric designations. The areas include small arms ranges, demolition training areas, and various training objectives. Units select areas to train on a first-come/first-served basis throughout the training ranges. Certain areas are off limits for training, such as the Precision Acquisition Vehicle Entry-Phased Array Warning System (PAVE-PAWS) site used by the U.S. Air Force for satellite tracking, the Impact Area, and a portion of Area B9. The range control personnel at MMR identified several areas that are highly used for training because of their location and terrain. Area BA-4 (north of the Ammunition Supply Point), Area B-8 (near the intersection of Wood Road and Canalview Road), and Area B-11 (near the intersection of Cat Road and Jefferson Road) are used heavily for training (Reference 2). Area C15 has preferred ambush sites along Spruce Swamp Road and a highly used trench line system. Area C16 provides a hilltop that is a preferred objective for training. Areas A1, A2, and BA3 are restricted from pyrotechnics use (Figure A1).

Training Schedules

Reserve units train one weekend per month in addition to a 2-week Annual Training (AT) period. Weekend training at MMR occurs year round, while AT occurs primarily between June and August. During an AT, 10 to 12 companies (up to 2,000 soldiers) may be present at MMR at one time. During a weekend training event, up to 1,500 soldiers may be expected. Training occurs during both day and night hours. Training activities are ceased only in the event of lightning or wind speeds greater than 40 miles per hour (Reference 1).

The activities at each AT event depend on the specific mission(s) for which the troops are being trained. However, most training events follow a general pattern. The first and last day of AT are scheduled as travel days, which leaves 12 training days. The first 3 days on post are typically spent in the cantonment area, walking through the tree lines, and setting up bases. Daytime patrols are then run, with nighttime patrols occurring around day 6. Full operations are performed through day 9. Days 10 and 11 are commonly used for final weapon qualifications. Day 12 is used to clean up and move out (Reference 1).

Pyrotechnics Use

The ban on pyrotechnics was initiated at MMR in 1997 and prevents the use of the signal flares, illumination rounds, and simulators, all of which are desired for signaling troop movement and providing realism to training. The MMR training at the time of this report consists of the use of blanks throughout the training area, as well as "green" .50 caliber plastic ammo at the A and SAW training ranges in MMR. In addition, the small arms ranges are limited to tungsten rounds. Demolition training with shape charges and the firing of artillery has not occurred since 1997.
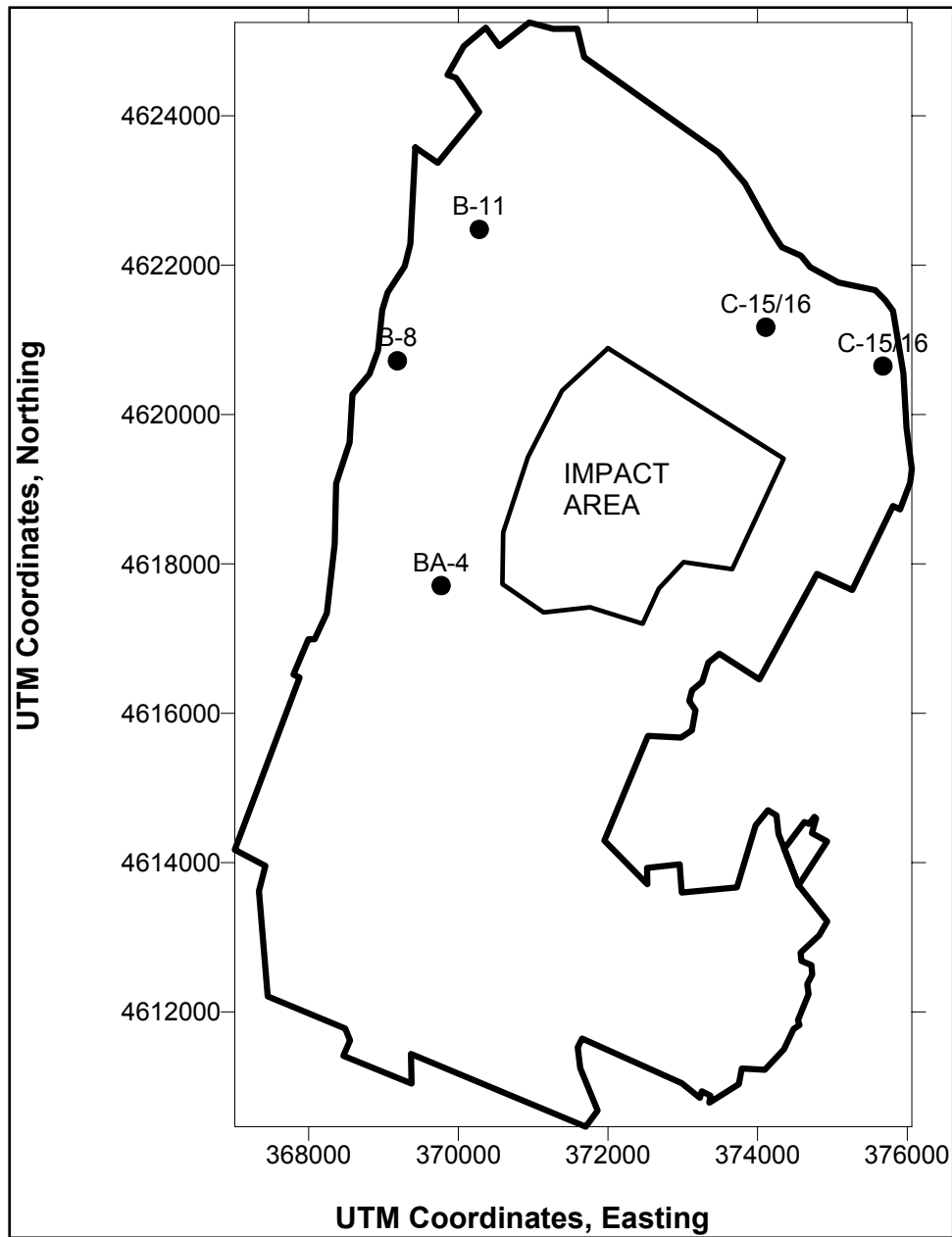
Figure A1. Training/Source locations evaluated at MMR

   To maintain readiness, training with pyrotechnics at MMR is desirable. This
study evaluates several types of pyrotechnic items that are often used at training
ranges to properly train for military missions (Table A1). The units training at
MMR that would potentially use the largest amounts of these items include the
Mechanized Infantry, Light Infantry, Military Police, and Engineers. Most of the
pyrotechnics listed in Table A1 are used throughout training exercises. The items
are listed by Department of Defense Identification Code (DODIC), military
designation, and common name.

Table A1
Pyrotechnics Evaluated in Modeling Study

DODIC	Designation	Pyrotechnics Name
L596	M110	Simulator, Flash Artillery
L601	M116A1	Simulator Hand Grenade
L594	M115A2	Simulator Ground Burst
L598	M117	Booby Trap Flash
L599	M118	Booby Trap Illumination
L600	M119	Booby Trap Whistle
L311		Red Parachute Signal Flare
L314		Green Star Cluster Signal Flare
L305		Green Parachute Signal Flare
L312		White Parachute Signal Flare
L306	M158	Red Star Cluster Signal Illumination
L307	M159	White Star Cluster Signal Illumination
L495		Surface Trip Flare
G940		Green Smoke Grenade
G945		Yellow Smoke Grenade
G930		High Concentration (HC) Smoke Grenade
G950	M18	Red Smoke Grenade
G955		Violet Smoke Grenade

As a general rule, flares are used only at night and smokes are used mainly during the day. Special permission from range control must be obtained to use red-colored pyrotechnics, including flares and smokes, because of the proximity to waters patrolled by the Coast Guard. Pyrotechnics use is restricted during dry conditions because of the potential for fire. Conditions are classified according to a "burn index" which incorporates such factors as number of days since precipitation, temperature, and humidity (Reference 4). The Camp Edwards Regulation 385-63 (Reference 5) provides guidelines for the use of all ammunition according to the burn index (Table A2).

Table A2
Fire-Related Restrictions

Burn Index	Restriction
0-8	No restrictions.
9-18	No restrictions.
19-28	No white phosphorus ammunition. Illumination rounds must be fired at maximum ordnance.
29-38	No illumination rounds, tracer ammunition, trip flares, parachute flares, and star clusters
39-49	Smoke, CS, and simulators may be used in nonvegetated areas
50 and above	Only blank or ball ammunition may be used.

Compound-Specific Emission Rates

Bang Box testing

To determine the types and amounts of emissions from selected pyrotechnics, the U.S. Army Environmental Center (USAEC) is conducting testing at Aberdeen Proving Ground, Maryland, and Dugway Proving Ground, Utah (Reference 6). Samples of the emissions resulting from pyrotechnics testing in the Bang Box were analyzed for more than 350 compounds. The pyrotechnics evaluated in this study (Table A1) have all been evaluated in a Bang Box study.

Emissions characterization

Table A3 provides a list of the compounds that have been detected during the testing of each type of pyrotechnics evaluated in this study. As a further characterization of emissions, an emission factor was calculated for each compound every time it was detected in a valid sample (Reference 6). These emission factors are the basis for determining compound-specific emission rates to calculate compound-specific air concentration and surface deposition rates.

Determination of compound-specific emission rates

For each pyrotechnics type, the Bang Box studies provided the following information: the net explosive weight (NEW) of the item, the compounds analyzed, and the total mass of each compound emitted per munition (in pounds per item). The emission factor for each compound (i.e., total mass of each compound emitted per item) and the duration of release of the respective pyrotechnic was used to develop an emission rate per item. The release duration is the amount of time between the initial activation of the pyrotechnics and the point at which the pyrotechnics stops releasing compounds into the air. The release duration was obtained from military training manuals (Reference 6). The substance emission rate per item (ER_1) for each substance was calculated using the equation below:

$$ER_1 = \frac{M \cdot CV}{t} \tag{A1}$$

where

ER_1 = emission rate for one item (g/(item*sec))

M = total mass of substance emitted per item (lb/item)

CV = conversion factor (453.59 g/lb)

t = release duration in seconds as obtained from training manuals (Reference 4)

The compound-specific emission rates for each pyrotechnic were calculated using Equation A1 and are provided in Table A4. Because these pyrotechnics can be used in numerous combinations and times, the maximum emission rate from

each pyrotechnic category was used as a worst-case release scenario for this study. These emission rates were based on the maximum representative emission rate regardless of a specific pyrotechnic.

Table A3
List of SOPCs Evaluated for the Emissions Testing

1,1,1,2-Tetrachloroethane	2,3,4-Trimethylpentane	2-Thiophenecarboxaldehyde	Benzo(b)fluoranthene
1,1,1-Trichloroethane	2,3-Butanedione	3-Chloropropene	Benzo(e)pyrene
1,1,2,2-Tetrachloroethane	2,3-Dihydro-1-methyl-1H-indene	3-Ethylhexane	Benzo(g,h,i)perylene
1,1,2-Trichloroethane	2,3-Dimethylbutane	3-Heptanone	Benzo(k)fluoranthene
1,1-Dichloro-2-propanone	2,3-Dimethylhexane	3-Methyl-1-butene	Benzofuran
1,1-Dichloroethane	2,3-Dimethylpentane	3-Methyl-2-butanone	Benzoic acid
1,1-Dichloroethene	2,3-Pentanedione	3-Methylfuran	Benzonitrile
1,2,3-Trichloropropane	2,4,5-Trichlorophenol	3-Methylhexane	Benzyl alcohol
1,2,4-Trichlorobenzene	2,4,6-Trichlorophenol	3-Methylpentane	Benzyl Chloride
1,2,4-Trimethylbenzene	2,4,6-Trinitrotoluene	3-Methylphenol	Beryllium
1,2-Dibromoethane	2,4-Dichlorophenol	3-Methylthiophene	Bis(2-chloroethoxy)methane
1,2-Dichloro-2-methylpropane	2,4-Dimethylhexane	3-Nitroaniline	Bis(2-chloroethyl)ether
1,2-Dichloro-3-methylbenzene	2,4-Dimethylpentane	3-Nitrotoluene	Bis(2-chloroisopropyl)ether
1,2-Dichlorobenzene	2,4-Dimethylphenol	3-Pentanone	Bis(2-ethylhexyl)phthalate
1,2-Dichlorobutane	2,4-Dinitrophenol	4,6-Dinitro-2-methylphenol	Bromobenzene
1,2-Dichloroethane	2,4-Dinitrotoluene	4-Amino-2,6-Dinitrotoluene	Bromodichloromethane
1,2-Dichloroethene	2,5-Dimethylbenzaldehyde	4-Bromophenyl-phenylether	Bromoform
1,2-Dichloropropane	2,5-Dimethylfuran	4-Chloro-3-methylphenol	Bromomethane
1,3,5-Trimethylbenzene	2,5-Dimethylhexane	4-Chloroaniline	Butanal
1,3,5-Trinitrobenzene	2,6-Dinitrotoluene	4-Chlorophenyl-phenylether	Butyl Acetate
1,3-Butadiene	234678-HXCDF	4-Ethyltoluene	Butylbenzylphthalate
1,3-Dichlorobenzene	23478-PECDF	4-Methyl-1-pentene	Cadmium
1,3-Dinitrobenzene	2378-TCDF	4-Methyl-2-Pentanone	Calcium
1,4-Dichlorobenzene	2-Amino-4,6-Dinitrotoluene	4-Methylbenzonitrile	Carbon Dioxide
1,4-Dioxane	2-Bromo-1-chloropropane	4-Methylphenol	Carbon Disulfide
1234678-HPCDD	2-Butanone	4-Nitroaniline	Carbon Monoxide (CO)
1234678-HPCDF	2-Butoxyethanol	4-Nitrophenol	Carbon Tetrachloride
1234789-HPCDF	2-Butyne	4-Nitrotoluene	Carbonyl Sulfide
123478-HXCDD	2-Chloronaphthalene	5-Methyl-2-furaldehyde	Chlorobenzene
123478-HXCDF	2-Chlorophenol	6-Methyl-2-heptanone	Chlorodifluoromethane
123678-HXCDD	2-Furaldehyde	6-Methyl-5-hepten-2-one	Chloroethane
123678-HXCDF	2-Heptanone	Acenaphthene	Chloroform
123789-HXCDD	2-Hexanone	Acenaphthylene	Chloromethane
123789-HXCDF	2-Methyl-1-butene	Acetaldehyde	Chromium
12378-PECDD	2-Methyl-1-pentene	Acetic Acid	Chrysene
12378-PECDF	2-Methyl-2-butene	Acetone	Cis 1,3-Dichloro-1-propene
1-Acetoxyacetone	2-Methyl-2-pentene	Acetonitrile	Cis-1,2-Dichloroethene
1-Bromo-2-chloroethane	2-Methylfuran	Acetophenone	Cis-2-Butene
1-Butanol	2-Methylheptane	Acrolein	Cis-2-Hexene
1-Butene	2-Methylhexane	Acrylonitrile	Cis-2-Pentene
1-Chloro-2-methylbenzene	2-Methylnaphthalene	Alpha Methyl Styrene	Cis-butene
1-Chloro-3-methylbenzene	2-Methylpentane	Aluminum	Cobalt

(Continued)

Table A3 (Concluded)

1-Chloro-4-ethylbenzene	Acetylene	Ammonia (NH3)	Copper
1-Chlorobutane	2-Methylphenol	Anthracene	Crotonaldehyde
1-Hexene	2-Methylthiophene	Antimony	Cumene
1-Hydroxy-2-propanone	2-Nitroaniline	Arsenic	Cyclohexane
1-Penten-3-one	2-Nitrophenol	Barium	Cyclohexanone
1-Pentene	2-Nitrotoluene	Benzaldehyde	Cyclopentane
2,2,4-Trimethylhexane	2-Octanone	Benzene	Cyclopentanone
2,2-Dimethylbutane	2-Pentanone	Benzo(a)anthracene	Cyclopentene
2,2-Dimethylpropane	2-Propanol	Benzo(a)pyrene	Decanal
Dibenz(a,h)anthracene	Hexane	N-Decane	Propanenitrile
Dibenzofuran	HMX	Nickel	Propene
Dibromochloromethane	Hydrogen bromide	Nitric Acid	Propyne
Dibromomethane	Hydrogen chloride	Nitrobenzene	P-Xylene
Dichloroacetonitrile	Hydrogen Cyanide	Nitroglycerine	Pyrene
Dichlorodifluoromethane	Hydrogen fluoride	Nitromethane	RDX
Diethylphthalate	Indane	N-nitrosodimethylamine	Sec-Butylbenzene
Dimethyldisulfide	Indeno(1,2,3-cd)pyrene	N-nitroso-di-n-propylamine	Selenium
Dimethylphthalate	Isobutane	N-nitrosodiphenylamine(1)	Silver
Di-n-butylphthalate	Isobutene	N-Nonane	Styrene
Di-n-octylphthalate	Isooctane	Nonanal	Sulfur Dioxide (SO2)
Dioxin TEQ	Isopentane	N-Propylbenzene	Sulfuric Acid
Diphenylamine	Isophorone	O,m,p-Tolualdehyde	Tert-Butyl Alcohol
D-Limonene	Isoprene	OCDD	Tetrachloroethene
Ethane	Isothiocyanatomethane	OCDF	Tetrahydrofuran
Ethanol	Isovaleraldehyde	Octanal	Tetryl
Ethyl Acetate	Lead	Octane	Thallium
Ethyl Acrylate	Magnesium	O-Ethyltoluene	Thiophene
Ethyl Methacrylate	Manganese	Oxides of Nitrogen (NOx)	Toluene
Ethylbenzene	Mercury	O-Xylene	Total Suspended Particulate
Ethylene	Methacrolein	Particulate Cyanide	Trans-1,2-Dichloroethene
Fluoranthene	Methane	Particulate Matter <10 microns	Trans-1,3-Dichloropropene
Fluorene	Methyl Acrylate	Particulate Matter <2.5 microns	Trans-2-Butenal
Formaldehyde	Methyl Iodide	Pentachloro-1-propene	Trans-2-Butene
Freon 113	Methyl Methacrylate	Pentachlorophenol	Trans-2-Hexene
Freon 114	Methylcyclohexane	Pentaerythritoltetranitrate	Trans-2-Pentene
Furan	Methylcyclopentane	Pentanal	Trans-3-Penten-2-one
Heptanal	Methylene Chloride	Pentane	Trichloroacetonitrile
Heptane	Methylnitrite	Phenanthrene	Trichloroethylene
Hexachlorobenzene	M-Ethyltoluene	Phenol	Trichlorofluoromethane
Hexachlorobutadiene	Methyl-vinyl Ketone	Phenylacetylene	Vanadium
Hexachlorocyclopentadiene	MTBE	Phosphoric acid	Vinyl Acetate
Hexachloroethane	M-Xylene	Propanal	Vinyl Chloride
Hexachloropropene	Naphthalene	Propane	Zinc
Hexanal	N-Butane		

Table A4
Substance-Specific Emission Rates for Each Pyrotechnic

SOPC	CAS#	Vapor Fraction, %	Particle Fraction, %	Maximum Emission Rate, g/s
1,1,2,2-Tetrachloroethane	79-34-5	100.00	0.00	1.67E-06
Freon 113	76-13-1	100.00	0.00	1.65E-05
1,1,2-Trichloroethane	79-00-5	100.00	0.00	4.58E-06
1,1-Dichloro-2-propanone	513-88-2	100.00	0.00	1.68E-05
1,1-Dichloroethane	75-34-3	100.00	0.00	1.94E-06
1,2,3-Trichloropropane	96-18-4	100.00	0.00	1.41E-05
1,2,4-Trichlorobenzene	120-82-1	100.00	0.00	1.22E-06
1,2,4-Trimethylbenzene	95-63-6	100.00	0.00	3.47E-01
1,2-Dichloro-2-methylpropane	594-37-6	100.00	0.00	9.24E-05
1,2-Dichloro-3-methylbenzene	32768-54-0	100.00	0.00	1.45E-05
1,2-Dichlorobenzene	95-50-1	100.00	0.00	1.93E-05
1,2-Dichlorobutane	616-21-7	100.00	0.00	5.71E-06
1,2-Dichloroethane	107-06-2	100.00	0.00	1.00E-04
1,2-Dichloroethene	540-59-0	100.00	0.00	4.04E-05
1,2-Dichloropropane	78-87-5	100.00	0.00	1.29E-05
1,3,5-Trimethylbenzene	108-67-8	100.00	0.00	1.79E-01
1,3-Butadiene	106-99-0	100.00	0.00	9.93E-03
1,3-Dichlorobenzene	541-73-1	100.00	0.00	1.14E-05
1,4-Dichlorobenzene	106-46-7	100.00	0.00	3.18E-06
1-Acetoxyacetone	592-20-1	100.00	0.00	2.24E-04
1-Bromo-2-chloroethane	107-04-0	100.00	0.00	2.26E-05
1-Butanol	71-36-3	100.00	0.00	3.75E-06
1-Butene	106-98-9	100.00	0.00	1.19E-03
1-Chloro-2-methylbenzene	95-49-8	100.00	0.00	3.68E-04
1-Chloro-3-methylbenzene	108-41-8	100.00	0.00	3.03E-05
1-Chloro-4-ethylbenzene	622-98-0	100.00	0.00	4.58E-06
1-Chlorobutane	109-69-3	100.00	0.00	7.11E-06
1-Hexene	592-41-6	100.00	0.00	2.12E-04
1-Hydroxy-2-propanone	116-09-6	100.00	0.00	2.82E-04
1-Penten-3-one	1629-58-9	100.00	0.00	4.95E-05
1-Pentene	109-67-1	100.00	0.00	4.22E-04
2,2,4-Trimethylhexane	16747-26-5	100.00	0.00	8.18E-04
Isooctane	540-84-1	100.00	0.00	7.48E-03
2,2-Dimethylbutane	75-83-2	100.00	0.00	3.83E-03
2,2-Dimethylpropane	463-82-1	100.00	0.00	3.96E-05
2,3,4-Trimethylpentane	565-75-3	100.00	0.00	1.29E-03
2,3-Butanedione	431-03-8	100.00	0.00	4.10E-04
2,3-Dihydro-1-methyl-1H-indene	767-58-8	100.00	0.00	2.38E-02
2,3-Dimethylbutane	79-29-8	100.00	0.00	8.53E-03
2,3-Dimethylhexane	584-94-1	100.00	0.00	2.27E-03
2,3-Dimethylpentane	565-59-3	100.00	0.00	8.19E-03
2,3-Pentanedione	600-14-6	100.00	0.00	1.27E-04
2,4-Dimethylhexane	589-43-5	100.00	0.00	4.57E-03
2,4-Dimethylpentane	108-08-7	100.00	0.00	5.02E-03
2,5-Dimethylfuran	625-86-5	100.00	0.00	5.83E-05

(Sheet 1 of 5)

Table A4 (Continued)

SOPC	CAS#	Vapor Fraction, %	Particle Fraction, %	Maximum Emission Rate, g/s
2,5-Dimethylhexane	592-13-2	100.00	0.00	3.93E-03
2-Bromo-1-chloropropane	3017-95-6	100.00	0.00	2.88E-05
2-Butanone	78-93-3	100.00	0.00	4.95E-03
2-Butoxyethanol	111-76-2	100.00	0.00	0.00E+00
2-Furaldehyde	98-01-1	100.00	0.00	4.50E-04
2-Heptanone	110-43-0	100.00	0.00	1.09E-06
2-Hexanone	591-78-6	100.00	0.00	1.23E-05
2-Methyl-1-butene	563-46-2	100.00	0.00	6.07E-04
2-Methyl-1-pentene	763-29-1	100.00	0.00	3.70E-04
2-Methyl-2-butene	513-35-9	100.00	0.00	2.37E-04
2-Methyl-2-pentene	625-27-4	100.00	0.00	2.37E-04
2-Methylfuran	534-22-5	100.00	0.00	6.32E-05
2-Methylheptane	592-27-8	100.00	0.00	1.25E-02
2-Methylhexane	591-76-4	100.00	0.00	2.72E-02
2-Methylnaphthalene	91-57-6	100.00	0.00	6.36E-03
2-Methylpentane	107-83-5	100.00	0.00	4.37E-02
2-Methylthiophene	554-14-3	100.00	0.00	1.05E-05
2-Nitrophenol	88-75-5	100.00	0.00	7.09E-05
2-Octanone	111-13-7	100.00	0.00	2.97E-07
2-Pentanone	107-87-9	100.00	0.00	2.13E-04
2-Propanol	67-63-0	100.00	0.00	4.75E-05
2-Thiophenecarboxaldehyde	98-03-3	100.00	0.00	1.89E-05
3-Ethylhexane	619-99-8	100.00	0.00	6.47E-06
3-Heptanone	106-35-4	100.00	0.00	3.15E-05
3-Methyl-1-butene	563-45-1	100.00	0.00	2.11E-04
3-Methyl-2-butanone	563-80-4	100.00	0.00	1.93E-05
3-Methylfuran	930-27-8	100.00	0.00	2.11E-05
3-Methylhexane	589-34-4	100.00	0.00	2.96E-02
3-Methylpentane	96-14-0	100.00	0.00	3.08E-02
3-Methylphenol	108-39-4	100.00	0.00	2.81E-04
3-Methylthiophene	616-44-4	100.00	0.00	9.77E-06
3-Pentanone	96-22-0	100.00	0.00	2.21E-05
4-Methyl-1-pentene	691-37-2	100.00	0.00	1.58E-04
4-Methyl-2-Pentanone	108-10-1	100.00	0.00	3.69E-06
4-Methylbenzonitrile	104-85-8	100.00	0.00	3.22E-05
4-Methylphenol	106-44-5	100.00	0.00	2.81E-04
5-Methyl-2-furaldehyde	620-02-0	100.00	0.00	1.47E-04
6-Methyl-2-heptanone	928-68-7	100.00	0.00	1.14E-06
6-Methyl-5-hepten-2-one	110-93-0	100.00	0.00	7.16E-08
Acenaphthylene	208-96-8	99.98	0.02	3.04E-04
Acetaldehyde	75-07-0	100.00	0.00	1.29E-03
Acetic Acid	64-19-7	100.00	0.00	1.03E-02
Acetone	67-64-1	100.00	0.00	7.86E-03
Acetonitrile	75-05-8	100.00	0.00	1.05E-04
Acetophenone	98-86-2	100.00	0.00	1.34E-04
Acetylene	74-86-2	100.00	0.00	9.15E-03

(Sheet 2 of 5)

Table A4 (Continued)

SOPC	CAS#	Vapor Fraction, %	Particle Fraction, %	Maximum Emission Rate, g/s
Acrolein	107-02-8	100.00	0.00	4.00E-03
Acrylonitrile	107-13-1	100.00	0.00	1.40E-04
Aluminum	7429-90-5	0.00	100.00	4.01E+00
Antimony	7440-36-0	0.00	100.00	1.79E-01
Arsenic	7440-38-2	0.00	100.00	3.56E-04
Barium	7440-39-3	0.00	100.00	6.93E-01
Benzaldehyde	100-52-7	100.00	0.00	2.10E-02
Benzene	71-43-2	100.00	0.00	4.68E-01
Benzofuran	271-89-6	100.00	0.00	5.97E-05
Benzoic acid	65-85-0	100.00	0.00	1.85E-05
Benzonitrile	100-47-0	100.00	0.00	1.67E-04
Benzyl alcohol	100-51-6	100.00	0.00	3.09E-04
Beryllium	7440-41-7	0.00	100.00	9.95E-06
Bis(2-ethylhexyl)phthalate	117-81-7	100.00	0.00	4.15E-04
Butanal	123-72-8	100.00	0.00	8.98E-05
Butyl Acetate	123-86-4	100.00	0.00	3.67E-05
Butylbenzylphthalate	85-68-7	97.71	2.30	4.90E-04
Cadmium	7440-43-9	0.00	100.00	8.18E-05
Carbon Dioxide	124-38-9	100.00	0.00	5.42E+01
Carbon Disulfide	75-15-0	100.00	0.00	1.23E-02
Carbon Tetrachloride	56-23-5	100.00	0.00	2.01E-02
Carbonyl Sulfide	463-58-1	100.00	0.00	1.17E-03
Chlorobenzene	108-90-7	100.00	0.00	2.54E-05
Vinyl Chloride	75-01-4	100.00	0.00	2.17E-05
Chloroform	67-66-3	100.00	0.00	1.63E-04
Chromium	7440-47-3	0.00	100.00	1.72E-03
Cis 1,3-Dichloro-1-propene	10061-01-5	100.00	0.00	2.27E-05
Cis-2-Butene	590-18-1	100.00	0.00	2.64E-04
Cis-2-Hexene	7688-21-3	100.00	0.00	1.58E-04
Cis-2-Pentene	627-20-3	100.00	0.00	2.11E-04
Cobalt	7440-48-4	0.00	100.00	1.95E-04
Copper	7440-50-8	0.00	100.00	1.54E-02
Cyclohexane	110-82-7	100.00	0.00	2.25E-02
Cyclohexanone	108-94-1	100.00	0.00	4.32E-06
Cyclopentane	278-92-3	100.00	0.00	3.59E-03
Cyclopentanone	120-92-3	100.00	0.00	3.72E-05
Cyclopentene	142-29-0	100.00	0.00	1.85E-04
Decanal	112-31-2	100.00	0.00	9.17E-03
Dichloroacetonitrile	3018-12-0	100.00	0.00	4.43E-06
Dichlorodifluoromethane	75-71-8	100.00	0.00	5.10E-04
Diethylphthalate	84-66-2	100.00	0.00	6.04E-05
Dimethyldisulfide	624-92-0	100.00	0.00	3.30E-05
Di-n-butylphthalate	84-74-2	100.00	0.00	6.63E-04
Di-n-octylphthalate	117-84-0	90.81	9.189	1.69E-04
Dioxin TEQ	1746-01-6	100.00	0.00	2.86E-09
D-Limonene	5989-27-5	100.00	0.00	0.00E+00

(Sheet 3 of 5)

　　　　　　　　　　　　　　　　　　Appendix A　　Air Dispersion Modeling

Table A4 (Continued)				
SOPC	**CAS#**	**Vapor Fraction, %**	**Particle Fraction, %**	**Maximum Emission Rate, g/s**
Ethane	74-84-0	100.00	0.00	4.45E-04
Ethanol	64-17-5	100.00	0.00	1.72E-05
Ethylbenzene	100-41-4	100.00	0.00	4.52E-01
Chloroethane	75-00-3	100.00	0.00	2.49E-06
Ethylene	74-85-1	100.00	0.00	1.06E-02
Fluorene	86-73-7	100.00	0.00	5.98E-05
Furan	110-00-9	100.00	0.00	1.29E-04
Heptanal	111-71-7	100.00	0.00	2.80E-03
Hexachlorobenzene	118-74-1	100.00	0.00	1.04E-03
Hexachlorobutadiene	87-68-3	100.00	0.00	4.15E-04
Hexachlorocyclopentadiene	77-47-4	100.00	0.00	3.04E-04
Hexachloroethane	67-72-1	100.00	0.00	1.44E-04
Hexachloropropene	1888-71-7	100.00	0.00	2.89E-04
Hexanal	66-25-1	100.00	0.00	4.81E-05
Indane	496-11-7	100.00	0.00	7.75E-02
Isobutane	75-28-5	100.00	0.00	1.50E-03
Isobutene	115-11-7	100.00	0.00	3.09E-03
Isopentane	78-78-4	100.00	0.00	4.29E-02
Isoprene	78-79-5	100.00	0.00	1.03E-04
Cumene	98-82-8	100.00	0.00	1.06E-03
Isothiocyanatomethane	556-61-6	100.00	0.00	2.39E-05
Lead	7439-92-1	0.00	100.00	2.19E-03
Magnesium	7439-95-4	4.91	95.09	4.77E+00
Manganese	7439-96-5	0.00	100.00	7.71E-03
Mercury	7439-97-6	0.00	100.00	4.10E-06
Methacrolein	78-85-3	100.00	0.00	8.50E-05
Bromomethane	74-83-9	100.00	0.00	1.71E-05
1,1,1-Trichloroethane	71-55-6	100.00	0.00	2.98E-06
Methylcyclohexane	108-87-2	100.00	0.00	3.94E-02
Methylcyclopentane	96-37-7	100.00	0.00	1.88E-02
Methylene Chloride	75-09-2	100.00	0.00	4.07E-03
Methylnitrite	624-91-9	100.00	0.00	1.88E-02
M-Ethyltoluene	620-14-4	100.00	0.00	1.10E-02
Methyl-vinyl Ketone	78-94-4	100.00	0.00	1.37E-04
MTBE	1634-04-4	100.00	0.00	4.82E-01
M-Xylene	108-38-3	100.00	0.00	8.37E-01
Naphthalene	91-20-3	100.00	0.00	3.52E-02
N-Butane	106-97-8	100.00	0.00	8.00E-03
N-Decane	124-18-5	100.00	0.00	8.72E-04
Heptane	142-82-5	100.00	0.00	3.86E-02
Hexane	110-54-3	100.00	0.00	5.16E-02
Nickel	7440-02-0	0.00	100.00	4.47E-04
Nitrobenzene	98-95-3	100.00	0.00	5.07E-06
Nitromethane	75-52-5	100.00	0.00	2.67E-03
N-Nonane	111-84-2	100.00	0.00	3.27E-03
Octane	111-65-9	100.00	0.00	1.42E-02
				(Sheet 4 of 5)

Table A4 (Concluded)

SOPC	CAS#	Vapor Fraction, %	Particle Fraction, %	Maximum Emission Rate, g/s
Nonanal	124-19-6	100.00	0.00	1.03E-02
Pentane	109-66-0	100.00	0.00	4.38E-02
N-Propylbenzene	103-65-1	100.00	0.00	6.02E-03
Octanal	124-13-0	100.00	0.00	7.60E-03
O-Ethyltoluene	611-14-3	100.00	0.00	7.08E-03
O-Xylene	95-47-6	100.00	0.00	5.26E-01
Pentachloro-1-propene	1600-37-9	100.00	0.00	1.51E-05
Pentanal	110-62-3	100.00	0.00	2.21E-05
4-Ethyltoluene	622-96-8	100.00	0.00	1.84E-01
Phenanthrene	85-01-8	100.00	0.00	1.77E-04
Phenol	108-95-2	100.00	0.00	1.37E-06
Phenylacetylene	536-74-3	100.00	0.00	1.48E-04
Propanal	123-38-6	100.00	0.00	1.72E-04
Propane	74-98-6	100.00	0.00	1.38E-04
Propanenitrile	107-12-0	100.00	0.00	1.79E-05
Propene	115-07-1	100.00	0.00	4.85E-03
P-Xylene	106-42-3	100.00	0.00	8.37E-01
Sec-Butylbenzene	135-98-8	100.00	0.00	3.65E-02
Selenium	7782-49-2	0.00	100.00	4.54E-05
Silver	7440-22-4	0.00	100.00	7.57E-06
Styrene	100-42-5	100.00	0.00	6.53E-03
Tetrachloroethene	127-18-4	100.00	0.00	2.58E-02
Tetrahydrofuran	109-99-9	100.00	0.00	4.72E-05
Thiophene	110-02-1	100.00	0.00	1.87E-04
Toluene	108-88-3	100.00	0.00	1.18E+00
Trans-1,3-Dichloropropene	10061-02-6	100.00	0.00	4.57E-06
Trans-2-Butenal	123-73-9	100.00	0.00	1.06E-04
Trans-2-Butene	624-64-6	100.00	0.00	8.44E-04
Trans-2-Hexene	4050-45-7	100.00	0.00	2.90E-04
Trans-2-Pentene	646-04-8	100.00	0.00	3.96E-04
Trans-3-Penten-2-one	3102-33-8	100.00	0.00	3.15E-05
Trichloroacetonitrile	545-06-2	100.00	0.00	3.60E-06
Trichloroethylene	79-01-6	100.00	0.00	1.75E-04
Trichlorofluoromethane	75-69-4	100.00	0.00	4.80E-05
1,1-Dichloroethene	75-35-4	100.00	0.00	1.57E-05
Zinc	7440-66-6	0.00	100.00	6.44E-03

(Sheet 5 of 5)

Air Dispersion Modeling

The Industrial Source Complex Short Term (ISCST3) model, Version 3.4.2 (Reference 7), was used to model emissions from each pyrotechnic category. The ISCST3 dispersion and deposition model is recommended by the U.S. Environmental Protection Agency (USEPA) and the regulatory community as the acceptable model to determine resultant concentration/deposition rates (CDR's) from a combustion source. The ISCST3 model is a multi-source, multi-pollutant

model that uses the bivariant normal distribution (Gaussian) algorithm to simulate dispersion. The model uses emission source characteristic data, meteorological data, and receptor locations to determine wet and dry depositions and air concentrations, while conserving mass using plume depletion. The model is applicable for use in simple, intermediate, and complex terrain. Simple terrain is considered to be any receptor located below source release height. Intermediate terrain is considered any receptor located between the release height and the final plume rise. Complex terrain is classified as any receptor that is located above the plume center line. The ISCST3 model incorporates a number of revisions that expand the versatility and accuracy of evaluating emissions from a combustion source. A summary of the improvements to the ISCST class of models include (Reference 7):

   a.   Complex terrain algorithms incorporated.

   b.   Ability to resolve intermediate terrain.

   c.   New dry deposition routine.

   d.   Revised scavenging coefficients for wet deposition calculations.

   e.   Plume depletion algorithms to estimate air concentrations and depositions accounting for the mass of plume lost in the area between the receptor being analyzed and the source.

   f.   Ability to model both vapor and particle phase air CDRs.

   g.   Incorporation of particle distribution information to determine particulate dry deposition rates.

   The development of the final ISCST3 model has been an intensive process including a preliminary air model (COMPDEP) and several draft versions of the ISCST3 model before the final changes were completed. The ISCST3 model refinements make it the best available model to estimate the transport of emissions in the atmosphere, and the results from the modeling process should be the most realistic possible.

Modeled source categories

   For modeling purposes, each pyrotechnic was categorized according to its physical and operational characteristics. The criteria used included the size of the plume formed upon activation, whether it was activated on the ground or propelled into the air (e.g., a ground burst versus a flare), and its intended purpose (e.g., smoke grenade versus a grenade simulator). Table A5 shows the five categories and the specific pyrotechnics in each category.

Table A5
Pyrotechnics Category for Modeling

Category	DODIC	Designation	Pyrotechnics Name	Day/Night Use
1	G940		Green Smoke Grenade	Day
	G945		Yellow Smoke Grenade	Day
	G950		Red Smoke Grenade	Day
	G955		Violet Smoke Grenade	Day
	G930		High Conc. (HC) Smoke Grenade	Day
2	L599	M118	Booby Trap Illumination	Day/Night
	L600	M119	Booby Trap Whistle	Day/Night
3	L311		Red Parachute Signal Flare	Night
	L306	M158	Red Star Cluster Signal Flare	Day/Night
	L305		Green Parachute Signal Flare	Night
	L314		Green Star Cluster Signal Flare	Day/Night
	L312		White Parachute Signal Flare	Night
	L307	M159	White Star Cluster Signal Flare	Day/Night
4	L495		Surface Trip Flare	Day/Night
5	L596	M110	Simulator, Flash Artillery	Day/Night
	L601	M116A1	Simulator Hand Grenade	Day/Night
	L594	M115A2	Simulator Ground Burst	Day/Night
	L598	M117	Booby Trap Flash	Day/Night

Modeled pyrotechnics use

To determine the annual amount of each pyrotechnics type necessary to successfully train troops at the MMR, historical records of use at MMR, as well as Army training manuals, were consulted. The Ammunition Supply Point at the MMR kept detailed records of the amount of each pyrotechnics type issued to Army personnel for training purposes and the amount of unused pyrotechnics returned. These records have been kept for several years (Reference 2) and include the date of issue and return and the unit requesting or returning. In addition, the Army Pamphlet 350-38, Standards in Weapons Training (Reference 3), provides annual requirements of pyrotechnics by type for various military units (e.g., Infantry, Military Police). Both data sources were considered to develop a realistic depiction of proposed pyrotechnics use at MMR. However, because Army training manuals apply to the entire Army regardless of location, and are often only a guideline to aid training coordinators, the historical data from MMR factored more in the usage determination. It is also difficult to determine which combinations of pyrotechnics are used together during training scenarios. For modeling purposes, one pyrotechnic item from each category was used daily and each pyrotechnic category was used at all training areas considered in this study.

Modeled source operation

Training at the MMR follows two schedules: weekend training and a 2-week AT. Therefore, for modeling purposes, pyrotechnics use was divided into

weekend training use and AT use. The AT was assumed to occur during the summer months (June through August). Weekend training is assumed to occur during the rest of the months of the year; however, some months may have reduced training because of poor weather conditions (i.e., winter months). It was assumed that all pyrotechnic categories were used during each training event. For example, all five pyrotechnic categories are used daily at each training range during the weekend training and AT. The total amount of each pyrotechnic category used during the AT months were averaged over 92 days (the number of days in the months June, July, and August).

In addition to the time of year the pyrotechnics are used, pyrotechnics categories are classified into day and/or night use. Certain categories are used primarily during day or night hours only. For example, flares are used mainly at night because of the contrast with the night sky. For each category, a designation of day use only, night use only, or day/night use (last column of Table A5).

In order to more accurately reflect training activities at MMR ranges, the source operation within the model was modified using ISC's "EMISFACT" optional input for variable emission rate factors in the source (SO) pathway. This provides the ability to vary the emission of the sources by time scales, (e.g., hour of day, seasonally, monthly, stability category, and season). For this study, zeros (0) were placed in the hours where sources did not operate, while ones (1) were placed in the hours where training occurred. A one (1) represents the source operating at 100 percent of the specified emission rate. Table A6 provides the "EMISFACT" values used in the model. Although emission rates are varied, a considerable degree of conservatism is intrinsic in the modeling of pyrotechnics using a continuous emissions model. Training was conducted at various times throughout the day, therefore for modeling purposes, it was assumed that all sources operated continuously for 24 hr during a training event.

Table A6 Emission Factor Values for Modeled Pyrotechnics		
Season	**Hr**	**EMISFACT**
Winter Weekday	1 to 24	0
Summer Weekday	1 to 24	1
Spring Weekday	1 to 24	0
Autumn Weekday	1 to 24	0
Winter Saturday	1 to 24	1
Summer Saturday	1 to 24	1
Spring Saturday	1 to 24	1
Autumn Saturday	1 to 24	1
Winter Sunday	1 to 24	1
Summer Sunday	1 to 24	1
Spring Sunday	1 to 24	1
Autumn Sunday	1 to 24	1

Modeled source locations

For modeling purposes, discrete source locations must be established. Using the data gathered from MMR personnel regarding training locations, four main source locations were chosen to represent the distribution of training activities at the MMR. Table A7 shows the locations of the sources with regard to their alphanumeric range designation and their Universal Transverse Mercator (UTM) coordinates. Sources BA41 through BA44 are located in Area BA-4 (north of the Ammunition Supply Point). Sources B81 through B84 are located in Area B-8 (near the intersection of Wood Road and Canalview Road). Sources B111 through B114 are located in Area B-11 (near the intersection of Cat Road and Jefferson Road). Sources 4A1 through 4A4 and 4B1 through 4B4 comprise a training area that spans Areas C15 and C16. Figure A1 shows the general location of each of these areas in relation to the installation fence line. For modeling purposes, pyrotechnics use was divided evenly among all source groups. The naming convention for the source represents the training range and category of pyrotechnic used. For example, source BA41, represents a category 1 pyrotechnic release at Area BA-4. This distribution assumes that pyrotechnics use is consistent throughout the training area. Category 4 and 5 pyrotechnics were combined and represented as BA44, B84, B11, 4A4, and 4B4 at each training area.

Table A7 Source Locations				
Source	**Range Location**	**UTM Coordinates, m**		**Elevation, m**
		Northing	**Easting**	
BA41	BA-4	4617710	369770	70.1
BA42	BA-4	4617710	369770	70.1
BA43	BA-4	4617710	369770	70.1
BA44	BA-4	4617710	369770	70.1
B81	B-8	4620720	369185	42.7
B82	B-8	4620720	369185	42.7
B83	B-8	4620720	369185	42.7
B84	B-8	4620720	369185	42.7
B111	B-11	4622480	370280	45.7
B112	B-11	4622480	370280	45.7
B113	B-11	4622480	370280	45.7
B114	B-11	4622480	370280	45.7
4A1	C-15/16	4620650	375675	27.4
4A2	C-15/16	4620650	375675	27.4
4A3	C-15/16	4620650	375675	27.4
4A4	C-15/16	4620650	375675	27.4
4B1	C-15/16	4621170	374110	70.1
4B2	C-15/16	4621170	374110	70.1
4B3	C-15/16	4621170	374110	70.1
4B4	C-15/16	4621170	374110	70.1

Receptor locations

Compound-specific CDRs were calculated for specific locations, or receptors, around MMR. For each receptor location, three deposition rates and two concentrations were calculated: particulate dry and wet deposition (Pdd and Pwd), vapor wet deposition (Vwd), particulate concentration (Pc), and vapor concentration (Vc).

A Cartesian receptor grid was established in and around the MMR that covered an area including the entire installation and just outside its boundaries. This rectangular receptor grid, roughly centered on the installation, is approximately 17 km by 18.5 km. The grid includes 1,258 individual receptors that are spaced at a distance of 500 m apart. In addition, a 1-sq km grid with 20-m spacing was centered on each source to evaluate emissions closer to the release. A total of five of these refined grids were used which results in an additional 12,500 receptors being evaluated. Figure A2 shows the boundaries and spacing of the receptor grids. These receptors were also used to determine the air concentration and surface deposition rates at specific locations needed to estimate risk to trespassers in the training areas.

Meteorological data and terrain data

Historical meteorological data for the 4-year periods, 1994 to 1995, and 1997 to 1999, were used in the ISCST3 model to calculate air concentration and surface deposition rates. Meteorological data from 1996 was excluded because the data set was incomplete. Data necessary for the model includes wind speed, wind direction, precipitation, and temperature. Surface data and precipitation data compiled from the local meteorological station at Otis Air National Guard Base, and upper air data compiled from Chatham, MA, was used for the same years.

A complete meteorological data set was created using the USEPA preprocessor, PCRAMMET (Reference 7), that combined the surface, precipitation, and upper air data to generate a usable ISCST3 ASCII file. For this evaluation, PCRAMMET required the site-specific parameters that are listed in Table A8 to process the data appropriately. The resulting meteorological file was used to model the transport of emissions from the pyrotechnic items.

To represent as many possible meteorological conditions as possible, pyrotechnics were assumed throughout the year with their use weighted as described in the section on Modeled Source Operation. Digitized terrain data for the MMR area were obtained from the Headquarters, Camp Edwards, Environmental Protection Office, and U.S. Geological Survey. These data were used to provide terrain elevations of the receptor locations.
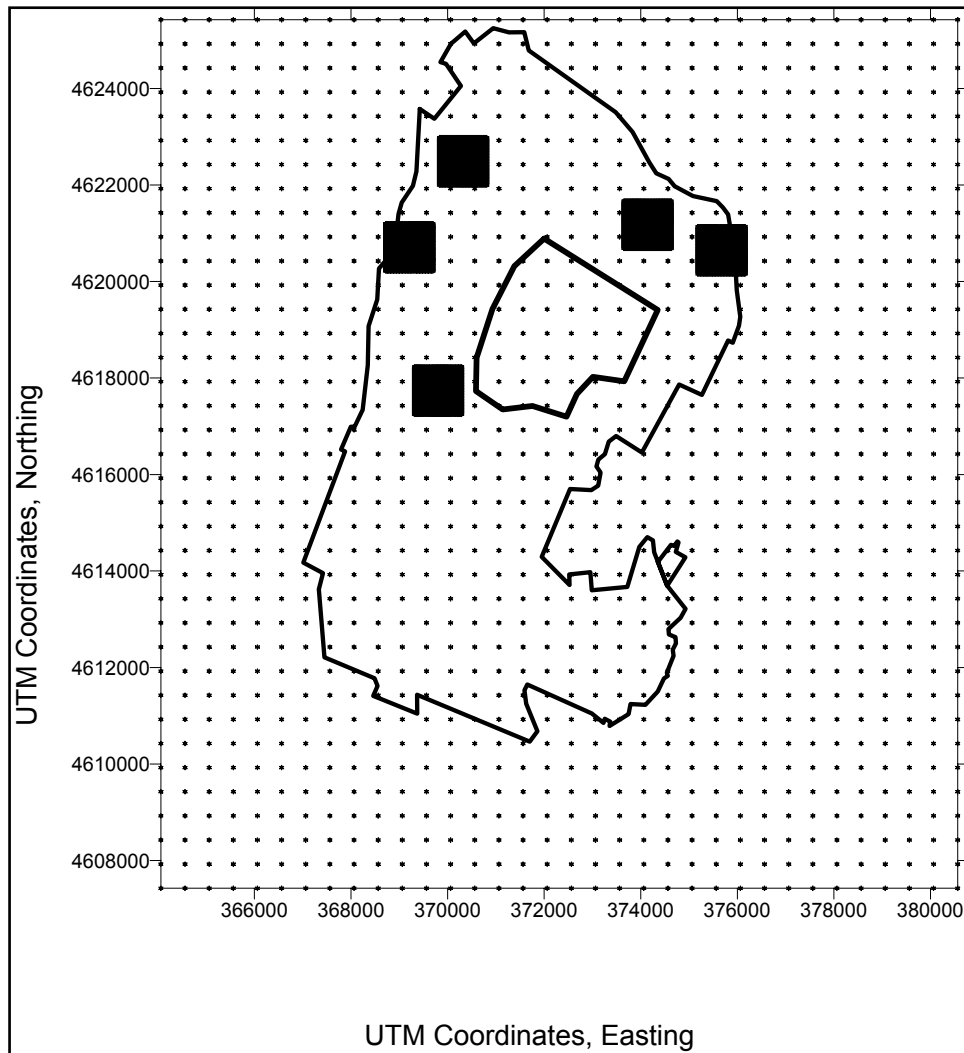
Figure A2. Layout of source receptor grids

Table A8
MMR Input Parameters for PCRAMMET

Input Parameters	Value
Latitude	41.650
Longitude	70.517
Time zone	5
Minimum Monin-Obukhov length	2.0
Anemometer height	10.0
Surface roughness length at measurement site[1]	0.05, 0.10, 0.05, 0.05
Surface roughness length at application site[1]	0.40, 0.50, 0.40, 0.30
Noon time Albedo[1]	0.13, 0.16, 0.15, 0.45
Bowen ratio[1]	0.50, 0.40, 0.80, 1.50
Anthropogenic heat flux	0.00
Fraction of net radiation absorbed at the ground	0.15
[1] This parameter is seasonal. Presented here in order of Spring, Summer, Autumn, Winter.	

Modeling inputs

Table A9 shows the ISCST3 model inputs that were used to simulate the activation of the five pyrotechnics categories being evaluated in this study. The pyrotechnic items to be modeled were treated as volume sources, therefore initial horizontal and vertical dimensions of the resulting plumes needed to be determined for each source category. These volume source dimensions (found in Table A9) were estimated from thermograph data obtained during the Bang Box testing. Apart from these plume dimensions, the modeling inputs for each of the five source categories are the same except for the source height of Category 3 pyrotechnics. Category 3 includes the signal flares and star clusters, which were modeled at a source height of 70 m compared to the other pyrotechnics that are ground based.

Because the goal of this study was to determine average annual values, the model was configured to provide annual average concentrations, dry, and wet deposition rates for each receptor. At each receptor, the contributions from each source location were added together to determine the air concentrations and total depositions from pyrotechnics activities at MMR.

A unit emission rate (1 g/s) was used for each of the five source categories (Table A9) to simplify the modeling inputs. Since the relationship between the emission rate and predicted CDR is linear, the ratio of the modeled CDR to the unit emission rate can be multiplied by each compound-specific emission rate to provide compound-specific modeled CDRs.

The model was run in both particulate mode and vapor mode to simulate different chemical phases emitted from the pyrotechnics use. The compound-specific emission rates were multiplied by the appropriate particulate/vapor ratio before being multiplied by the modeled deposition rates. Table A10 contains the USEPA default particulate and vapor mode input parameters that were used to calculate these emission categories. A list of the particulate/vapor ratios for each chemical was included in Table A4.

Table A9 ISCST3 Model Inputs	
Model Input Parameter	**Setting/Value per Category (1-5)**
Emission rate	1.0 g/s
Source type	Volume
Plume depletion option	Wet and dry
Terrain option	Simple and complex
Averaging time	Annual
Urban/Rural classification	Rural
Source height (Categories 1-5)	0.5, 0.5, 70, 0.5, 0.5 m
Initial horizontal dimension, σ_{yo}	1.0, 0.051, 0.58, 0.38, 1.0 m
Initial vertical dimension, σ_{zo}	2.0, 0.025, 0.32, 0.13, 0.81 m

Table A10
Particle and Scavenging Coefficient Input Parameters

Input Parameter	Value	Units
Particle density	1.0	g/cm^3
Array of particle sizes	1.0, 6.0, 15.0	µm
Fraction of emissions in each particle class	0.78, 0.19, 0.03	unitless
Particle scavenging coefficients for liquid precipitation	4.0E-05, 4.2E-04, 6.7E-04	hr/mm-s
Particle scavenging coefficients for frozen precipitation	1.3E-05, 1.4E-04, 2.2E-04	hr/mm-s
USEPA liquid vapor scavenging coefficient	1.7E-04	hr/mm-s
USEPA frozen vapor scavenging coefficient	5.7E-05	hr/mm-s

Unit concentration and deposition rates (CDRs)

The generic, unit CDRs from all grid receptors determined with the ISCST3 model were averaged over the entire spatial area. This resulted in a long-term, annual average estimate of CDRs irrespective of specific receptor locations. The average annual unit CDR values (Table A12) were used to evaluate the risk for an onsite trespasser. The average annual deposition rates were used to evaluate migration of compounds to the vadose zone (Table A12).

Vapor/particulate fractions

Because both vapor and particulate modeling was done to simulate different chemical phases emitted from the burning, a vapor/particulate (V/P) fraction had to be included in the calculation of CDRs for each chemical. The V/P fractions that were used are listed in Table A4. The USEPA provided some V/P fractions for certain compounds that were incorporated into this evaluation (Reference 8). If a chemical-specific V/P fraction was not provided, then the particulate percentage was estimated using the Junge equation presented in Equation A2 (Reference 8).

$$\Theta = \frac{c * S_T}{p + (c * S_T)} \tag{A2}$$

where

Θ = particulate percentage, unitless

c = constant developed by Junge, 1.7E-04 atm-cm

S_T = total surface area of atmospheric aerosols in relation to total volume of air, cm^2/cm^3

p = solute saturation vapor pressure, atm

Compound-specific concentration and deposition rates

The compound-specific CDRs were determined by combining the compound-specific emission rates (Table A4) with the appropriate vapor/particulate fractions (Table A4) and the generic, unit CDRs (Table A12). Equations A3 through A7 show the calculation for each chemical-specific CDR. The computed chemical-specific CDR values are shown in Table A13.

$$Pc\left(ug/m3\right) = \text{Compound} - \text{Specific Emission Rate}\left(g/s\right)$$
$$*\left(\text{Particulate Fraction}\right)*\text{Unitized } Pc\left(\frac{(ug/m3)}{(1g/s)}\right) \quad \text{(A3)}$$

$$Vc(ug/m3) = \text{Compound} - \text{Specific Emission Rate}\left(g/s\right)$$
$$*\left(\text{Vapor Fraction}\right)*\text{Unitized } Vc\left(\frac{(ug/m3)}{(1g/s)}\right) \quad \text{(A4)}$$

$$Pdd\left(g/m2\right) = \text{Compound} - \text{Specific Emission Rate}\left(g/s\right)$$
$$*\left(\text{Particulate Fraction}\right)*\text{Unitized } Pdd\left(\frac{(g/m2)}{(1g/s)}\right) \quad \text{(A5)}$$

$$Pwd\left(g/m2\right) = \text{Compound} - \text{Specific Emission Rate}\left(g/s\right)$$
$$*\left(\text{Particulate Fraction}\right)*\text{Unitized } Pwd\left(\frac{(g/m2)}{(1g/s)}\right) \quad \text{(A6)}$$

$$Vwd\left(g/m2\right) = \text{Compound} - \text{Specific Emission Rate}\left(g/s\right)$$
$$*\left(\text{Vapor Fraction}\right)*\text{Unitized } Vwd\left(\frac{(g/m2)}{(1g/s)}\right) \quad \text{(A7)}$$

Emission rate and air modeling uncertainties

There are a number of uncertainties associated with estimating emissions and modeling the dispersion of those emissions from a source. The assumptions made for this risk assessment are assumed to be conservative and protective of human health while maintaining a level of practicality with respect to the operations. A discussion of the various types of uncertainties and their effects on the risk assessment is provided in Table A11.

A primary uncertainty is associated with the assumption used in the application of the compound-specific emission rates in Equations A3 through A7 to obtain the compound-specific CDRs. This assumption is explained as follows. The ISCST3 model calculated unitized CDRs on an hourly basis assuming a constant unit release rate over the entire hourly period. Compound-specific emission rates used in Equations A3 through A7 were based on the mass released divided by the actual release duration of each munition. The duration times were less than an hour. Most pyrotechnics are expended within 120 sec. However, when applying these emission rates in Equations A3 through A7, the assumption was that the emission release rates extended throughout the entire duration of each training event. This resulted in the model's overestimating the total amount of mass released and overestimating the resulting risks. The overestimating was considered conservative and acceptable, given the purposes of this study. The highly variable frequency and usage combinations by which munitions are employed made it difficult to determine a more realistic or likely modeling scenario. Therefore, the worst-case assumptions were utilized; i.e., continuous emissions for each munitions type and for each training event, thus, resulting in a total mass released that is greater than would be expected. For example, consider CDRs from a smoke grenade, which has the most releasable mass of all the pyrotechnics evaluated. The CDRs are based upon the mass release rate for a single grenade applied for duration of 4,080 hr. This duration is based upon the previously described training frequency (fall weekends, 26 days at 24 hr/d = 624 potential hours of training; winter weekends, 24 days at 24 hr/d = 576 potential hours of training; spring weekends, 27 days at 24 hr/d = 648 potential hours of training; and summer, 7 days/week for 93 days at 24 hr/d = 2,232 potential hours of training). Since the actual emission duration of each smoke grenade is 2 min, the total emission mass imposed in the analysis is equivalent to 30 smoke grenades being expended per hour for the entire 4,080 hr per year of training.

Table A11
Uncertainties Associated with Emission Estimates and Air Dispersion Modeling

Issue	Uncertainty	Direction of Effect
Compound-specific emission rates were based on the highest/maximum emission rate of a single pyrotechnic from each respective category.	Pyrotechnics used during training scenarios are varied. Pyrotechnics are used in different combinations depending on the targeted objective in a training scenario.	Varies
Emission rate durations were based on the source/munitions being operated for 24 hr/day per training event.	Most pyrotechnics are considered instantaneous and/or semicontinuous emission sources emitting up to 120 sec (2 min) in duration. The ISCST model can not duplicate this source characteristic and can only vary emission durations on an hourly basis.	Overestimates
Use of air dispersion model to estimate air concentrations and depositions.	Several notable atmospheric scientists have observed that models are more reliable for estimating longer time-averaged concentrations, and for estimating the highest concentration. However, due to "inherent" uncertainties in air models, estimated output may deviate by as much as ±10 to 40% from the highest estimated concentration. These uncertainties are a result of using both known and unknown conditions in model development.	Varies
The dispersion model results vary according to the input parameters.	Many input parameters are estimated. Some examples include surface heat flux and particle sizing data. In addition, surrogate data are used when actual site data are not available as in the case of emissions estimates and meteorological data.	Varies
Choosing average onsite receptor locations for each type of CDR to evaluate risk.	The point of average depositions and air concentrations may not be located at the same receptor location or where a person actually traverses. Therefore, these exposures represent an average exposure level over the entire spatial area.	Varies

Table A12
Average Unit CDRs Used in Equations A3 through A7

Average Unit Concentration/Deposition Rates					
Source GRP	Pc, $\mu g/m^3$	Pdd, $g/m^2/yr$	Pwd, $g/m^2/yr$	Vc, $\mu g/m^3$	Vwd, $g/m^2/yr$
ALL	2.36E+01	2.03E+00	5.31E-02	2.43E+01	8.59E-02

Table A13
Average Annual CDRs for the Trespasser Exposure Scenario

SOPC	CAS#	Pc, µg/m³	Pdd, g/m²/yr	Pwd, g/m²/yr	Vc, µg/m³	Vwd, g/m²/yr
1,1,2,2-Tetrachloroethane	79-34-5	0.00E+00	0.00E+00	0.00E+00	4.07E-05	1.44E-07
1,1,2-Trichloro-1,2,2-trifluoroethane	76-13-1	0.00E+00	0.00E+00	0.00E+00	4.02E-04	1.42E-06
1,1,2-Trichloroethane	79-00-5	0.00E+00	0.00E+00	0.00E+00	1.11E-04	3.93E-07
1,1-Dichloro-2-propanone	513-88-2	0.00E+00	0.00E+00	0.00E+00	4.09E-04	1.45E-06
1,1-Dichloroethane	75-34-3	0.00E+00	0.00E+00	0.00E+00	4.72E-05	1.67E-07
1,2,3-Trichloropropane	96-18-4	0.00E+00	0.00E+00	0.00E+00	3.44E-04	1.22E-06
1,2,4-Trichlorobenzene	120-82-1	0.00E+00	0.00E+00	0.00E+00	2.97E-05	1.05E-07
1,2,4-Trimethylbenzene	95-63-6	0.00E+00	0.00E+00	0.00E+00	8.44E+00	2.98E-02
1,2-Dichloro-2-methylpropane	594-37-6	0.00E+00	0.00E+00	0.00E+00	2.25E-03	7.94E-06
1,2-Dichloro-3-methylbenzene	32768-54-0	0.00E+00	0.00E+00	0.00E+00	3.52E-04	1.24E-06
1,2-Dichlorobenzene	95-50-1	0.00E+00	0.00E+00	0.00E+00	4.69E-04	1.66E-06
1,2-Dichlorobutane	616-21-7	0.00E+00	0.00E+00	0.00E+00	1.39E-04	4.90E-07
1,2-Dichloroethane	-654726	0.00E+00	0.00E+00	0.00E+00	2.44E-03	8.61E-06
1,2-Dichloroethene	540-59-0	0.00E+00	0.00E+00	0.00E+00	9.83E-04	3.47E-06
1,2-Dichloropropane	78-87-5	0.00E+00	0.00E+00	0.00E+00	3.14E-04	1.11E-06
1,3,5-Trimethylbenzene	108-67-8	0.00E+00	0.00E+00	0.00E+00	4.36E+00	1.54E-02
1,3-Butadiene	106-99-0	0.00E+00	0.00E+00	0.00E+00	2.41E-01	8.53E-04
1,3-Dichlorobenzene	541-73-1	0.00E+00	0.00E+00	0.00E+00	2.77E-04	9.80E-07
1,4-Dichlorobenzene	106-46-7	0.00E+00	0.00E+00	0.00E+00	7.73E-05	2.73E-07
1-Acetoxyacetone	592-20-1	0.00E+00	0.00E+00	0.00E+00	5.45E-03	1.93E-05
1-Bromo-2-chloroethane	107-04-0	0.00E+00	0.00E+00	0.00E+00	5.49E-04	1.94E-06
1-Butanol	71-36-3	0.00E+00	0.00E+00	0.00E+00	9.13E-05	3.23E-07
1-Butene	106-98-9	0.00E+00	0.00E+00	0.00E+00	2.89E-02	1.02E-04
1-Chloro-2-methylbenzene	95-49-8	0.00E+00	0.00E+00	0.00E+00	8.96E-03	3.17E-05
1-Chloro-3-methylbenzene	108-41-8	0.00E+00	0.00E+00	0.00E+00	7.38E-04	2.61E-06
1-Chloro-4-ethylbenzene	622-98-0	0.00E+00	0.00E+00	0.00E+00	1.11E-04	3.94E-07
1-Chlorobutane	109-69-3	0.00E+00	0.00E+00	0.00E+00	1.73E-04	6.11E-07
1-Hexene	592-41-6	0.00E+00	0.00E+00	0.00E+00	5.15E-03	1.82E-05
1-Hydroxy-2-propanone	-651342	0.00E+00	0.00E+00	0.00E+00	6.85E-03	2.42E-05
1-Penten-3-one	1629-58-9	0.00E+00	0.00E+00	0.00E+00	1.20E-03	4.25E-06
1-Pentene	109-67-1	0.00E+00	0.00E+00	0.00E+00	1.03E-02	3.63E-05
2,2,4-Trimethylhexane	16747-26-5	0.00E+00	0.00E+00	0.00E+00	1.99E-02	7.03E-05
2,2,4-Trimethylpentane	540-84-1	0.00E+00	0.00E+00	0.00E+00	1.82E-01	6.43E-04
2,2-Dimethylbutane	75-83-2	0.00E+00	0.00E+00	0.00E+00	9.31E-02	3.29E-04
2,2-Dimethylpropane	463-82-1	0.00E+00	0.00E+00	0.00E+00	9.63E-04	3.41E-06
2,3,4-Trimethylpentane	565-75-3	0.00E+00	0.00E+00	0.00E+00	3.15E-02	1.11E-04
2,3-Butanedione	-536473	0.00E+00	0.00E+00	0.00E+00	9.96E-03	3.52E-05
2,3-Dihydro-1-methyl-1H-indene	767-58-8	0.00E+00	0.00E+00	0.00E+00	5.79E-01	2.05E-03
2,3-Dimethylbutane	79-29-8	0.00E+00	0.00E+00	0.00E+00	2.08E-01	7.33E-04
2,3-Dimethylhexane	584-94-1	0.00E+00	0.00E+00	0.00E+00	5.52E-02	1.95E-04
2,3-Dimethylpentane	565-59-3	0.00E+00	0.00E+00	0.00E+00	1.99E-01	7.04E-04
2,3-Pentanedione	600-14-6	0.00E+00	0.00E+00	0.00E+00	3.10E-03	1.10E-05
2,4-Dimethylhexane	589-43-5	0.00E+00	0.00E+00	0.00E+00	1.11E-01	3.93E-04
2,4-Dimethylpentane	-654294	0.00E+00	0.00E+00	0.00E+00	1.22E-01	4.31E-04
2,5-Dimethylfuran	625-86-5	0.00E+00	0.00E+00	0.00E+00	1.42E-03	5.01E-06

(Sheet 1 of 5)

Appendix A   Air Dispersion Modeling

Table A13 (Continued)

SOPC	CAS#	Pc, µg/m^3	Pdd, g/m^2/yr	Pwd, g/m^2/yr	Vc, µg/m^3	Vwd, g/m^2/yr
2,5-Dimethylhexane	592-13-2	0.00E+00	0.00E+00	0.00E+00	9.56E-02	3.38E-04
2-Bromo-1-chloropropane	3017-95-6	0.00E+00	0.00E+00	0.00E+00	6.99E-04	2.47E-06
2-Butanone	78-93-3	0.00E+00	0.00E+00	0.00E+00	1.20E-01	4.25E-04
2-Butoxyethanol	111-76-2	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
2-Furaldehyde	35796	0.00E+00	0.00E+00	0.00E+00	1.09E-02	3.87E-05
2-Heptanone	110-43-0	0.00E+00	0.00E+00	0.00E+00	2.66E-05	9.39E-08
2-Hexanone	591-78-6	0.00E+00	0.00E+00	0.00E+00	2.99E-04	1.06E-06
2-Methyl-1-butene	563-46-2	0.00E+00	0.00E+00	0.00E+00	1.48E-02	5.22E-05
2-Methyl-1-pentene	763-29-1	0.00E+00	0.00E+00	0.00E+00	9.01E-03	3.18E-05
2-Methyl-2-butene	513-35-9	0.00E+00	0.00E+00	0.00E+00	5.77E-03	2.04E-05
2-Methyl-2-pentene	625-27-4	0.00E+00	0.00E+00	0.00E+00	5.77E-03	2.04E-05
2-Methylfuran	534-22-5	0.00E+00	0.00E+00	0.00E+00	1.54E-03	5.43E-06
2-Methylheptane	592-27-8	0.00E+00	0.00E+00	0.00E+00	3.03E-01	1.07E-03
2-Methylhexane	591-76-4	0.00E+00	0.00E+00	0.00E+00	6.62E-01	2.34E-03
2-Methylnaphthalene	91-57-6	0.00E+00	0.00E+00	0.00E+00	1.55E-01	5.46E-04
2-Methylpentane	107-83-5	0.00E+00	0.00E+00	0.00E+00	1.06E+00	3.75E-03
2-Methylthiophene	554-14-3	0.00E+00	0.00E+00	0.00E+00	2.56E-04	9.06E-07
2-Nitrophenol	88-75-5	0.00E+00	0.00E+00	0.00E+00	1.72E-03	6.09E-06
2-Octanone	111-13-7	0.00E+00	0.00E+00	0.00E+00	7.23E-06	2.56E-08
2-Pentanone	107-87-9	0.00E+00	0.00E+00	0.00E+00	5.18E-03	1.83E-05
2-Propanol	67-63-0	0.00E+00	0.00E+00	0.00E+00	1.15E-03	4.08E-06
2-Thiophenecarboxaldehyde	35857	0.00E+00	0.00E+00	0.00E+00	4.61E-04	1.63E-06
3-Ethylhexane	619-99-8	0.00E+00	0.00E+00	0.00E+00	1.57E-04	5.56E-07
3-Heptanone	106-35-4	0.00E+00	0.00E+00	0.00E+00	7.66E-04	2.71E-06
3-Methyl-1-butene	563-45-1	0.00E+00	0.00E+00	0.00E+00	5.13E-03	1.81E-05
3-Methyl-2-butanone	563-80-4	0.00E+00	0.00E+00	0.00E+00	4.68E-04	1.65E-06
3-Methylfuran	930-27-8	0.00E+00	0.00E+00	0.00E+00	5.12E-04	1.81E-06
3-Methylhexane	589-34-4	0.00E+00	0.00E+00	0.00E+00	7.19E-01	2.54E-03
3-Methylpentane	96-14-0	0.00E+00	0.00E+00	0.00E+00	7.48E-01	2.64E-03
3-Methylphenol	108-39-4	0.00E+00	0.00E+00	0.00E+00	6.83E-03	2.41E-05
3-Methylthiophene	616-44-4	0.00E+00	0.00E+00	0.00E+00	2.37E-04	8.39E-07
3-Pentanone	96-22-0	0.00E+00	0.00E+00	0.00E+00	5.38E-04	1.90E-06
4-Methyl-1-pentene	691-37-2	0.00E+00	0.00E+00	0.00E+00	3.85E-03	1.36E-05
4-Methyl-2-pentanone	-654239	0.00E+00	0.00E+00	0.00E+00	8.98E-05	3.17E-07
4-Methylbenzonitrile	104-85-8	0.00E+00	0.00E+00	0.00E+00	7.83E-04	2.77E-06
4-Methylphenol	106-44-5	0.00E+00	0.00E+00	0.00E+00	6.83E-03	2.41E-05
5-Methyl-2-furaldehyde	620-02-0	0.00E+00	0.00E+00	0.00E+00	3.58E-03	1.27E-05
6-Methyl-2-heptanone	928-68-7	0.00E+00	0.00E+00	0.00E+00	2.77E-05	9.78E-08
6-Methyl-5-hepten-2-one	110-93-0	0.00E+00	0.00E+00	0.00E+00	1.74E-06	6.15E-09
Acenaphthylene	208-96-8	1.51E-06	1.30E-07	3.39E-09	7.39E-03	2.61E-05
Acetaldehyde	75-07-0	0.00E+00	0.00E+00	0.00E+00	3.13E-02	1.11E-04
Acetic Acid	64-19-7	0.00E+00	0.00E+00	0.00E+00	2.51E-01	8.88E-04
Acetone	67-64-1	0.00E+00	0.00E+00	0.00E+00	1.91E-01	6.76E-04
Acetonitrile	27522	0.00E+00	0.00E+00	0.00E+00	2.55E-03	9.02E-06
Acetophenone	98-86-2	0.00E+00	0.00E+00	0.00E+00	3.26E-03	1.15E-05
Acetylene	74-86-2	0.00E+00	0.00E+00	0.00E+00	2.22E-01	7.86E-04

(Sheet 2 of 5)

Table A13 (Continued)					
SOPC	CAS#	Pc, µg/m^3	Pdd, g/m^2/yr	Pwd, g/m^2/yr	Vc, µg/m^3	Vwd, g/m^2/yr
Acrolein	-654840	0.00E+00	0.00E+00	0.00E+00	9.72E-02	3.44E-04
Acrylonitrile	107-13-1	0.00E+00	0.00E+00	0.00E+00	3.40E-03	1.20E-05
Aluminum	7429-90-5	9.48E+01	8.16E+00	2.13E-01	0.00E+00	0.00E+00
Antimony	7440-36-0	4.22E+00	3.63E-01	9.50E-03	0.00E+00	0.00E+00
Arsenic	7440-38-2	8.42E-03	7.25E-04	1.89E-05	0.00E+00	0.00E+00
Barium	7440-39-3	1.64E+01	1.41E+00	3.68E-02	0.00E+00	0.00E+00
Benzaldehyde	100-52-7	0.00E+00	0.00E+00	0.00E+00	5.09E-01	1.80E-03
Benzene	71-43-2	0.00E+00	0.00E+00	0.00E+00	1.14E+01	4.02E-02
Benzofuran	271-89-6	0.00E+00	0.00E+00	0.00E+00	1.45E-03	5.13E-06
Benzoic acid	65-85-0	0.00E+00	0.00E+00	0.00E+00	4.50E-04	1.59E-06
Benzonitrile	100-47-0	0.00E+00	0.00E+00	0.00E+00	4.06E-03	1.44E-05
Benzyl alcohol	100-51-6	0.00E+00	0.00E+00	0.00E+00	7.50E-03	2.65E-05
Beryllium	7440-41-7	2.35E-04	2.02E-05	5.29E-07	0.00E+00	0.00E+00
bis(2-Ethylhexyl)phthalate	117-81-7	0.00E+00	0.00E+00	0.00E+00	1.01E-02	3.56E-05
Butanal	123-72-8	0.00E+00	0.00E+00	0.00E+00	2.18E-03	7.71E-06
Butyl Acetate	123-86-4	0.00E+00	0.00E+00	0.00E+00	8.93E-04	3.16E-06
Butylbenzylphthalate	85-68-7	2.65E-04	2.28E-05	5.97E-07	1.16E-02	4.11E-05
Cadmium	7440-43-9	1.93E-03	1.66E-04	4.35E-06	0.00E+00	0.00E+00
Carbon Dioxide	124-38-9	0.00E+00	0.00E+00	0.00E+00	1.32E+03	4.66E+00
Carbon Disulfide	75-15-0	0.00E+00	0.00E+00	0.00E+00	2.99E-01	1.06E-03
Carbon tetrachloride	56-23-5	0.00E+00	0.00E+00	0.00E+00	4.90E-01	1.73E-03
Carbonyl Sulfide	463-58-1	0.00E+00	0.00E+00	0.00E+00	2.84E-02	1.00E-04
Chlorobenzene	108-90-7	0.00E+00	0.00E+00	0.00E+00	6.17E-04	2.18E-06
Chloroethene	27398	0.00E+00	0.00E+00	0.00E+00	5.27E-04	1.86E-06
Chloroform	67-66-3	0.00E+00	0.00E+00	0.00E+00	3.96E-03	1.40E-05
Chromium	7440-47-3	4.07E-02	3.50E-03	9.16E-05	0.00E+00	0.00E+00
cis 1,3-Dichloro-1-propene	10061-01-5	0.00E+00	0.00E+00	0.00E+00	5.52E-04	1.95E-06
cis-2-Butene	590-18-1	0.00E+00	0.00E+00	0.00E+00	6.41E-03	2.27E-05
cis-2-Hexene	7688-21-3	0.00E+00	0.00E+00	0.00E+00	3.85E-03	1.36E-05
cis-2-Pentene	627-20-3	0.00E+00	0.00E+00	0.00E+00	5.13E-03	1.81E-05
Cobalt	7440-48-4	4.61E-03	3.97E-04	1.04E-05	0.00E+00	0.00E+00
Copper	7440-50-8	3.64E-01	3.13E-02	8.18E-04	0.00E+00	0.00E+00
Cyclohexane	110-82-7	0.00E+00	0.00E+00	0.00E+00	5.47E-01	1.93E-03
Cyclohexanone	108-94-1	0.00E+00	0.00E+00	0.00E+00	1.05E-04	3.71E-07
Cyclopentane	278-92-3	0.00E+00	0.00E+00	0.00E+00	8.74E-02	3.09E-04
Cyclopentanone	120-92-3	0.00E+00	0.00E+00	0.00E+00	9.03E-04	3.19E-06
Cyclopentene	142-29-0	0.00E+00	0.00E+00	0.00E+00	4.49E-03	1.59E-05
Decanal	112-31-2	0.00E+00	0.00E+00	0.00E+00	2.23E-01	7.88E-04
Dichloroacetonitrile	3018-12-0	0.00E+00	0.00E+00	0.00E+00	1.08E-04	3.81E-07
Dichlorodifluoromethane	75-71-8	0.00E+00	0.00E+00	0.00E+00	1.24E-02	4.38E-05
Diethylphthalate	84-66-2	0.00E+00	0.00E+00	0.00E+00	1.47E-03	5.19E-06
Dimethyldisulfide	624-92-0	0.00E+00	0.00E+00	0.00E+00	8.02E-04	2.84E-06
Di-n-butylphthalate	84-74-2	0.00E+00	0.00E+00	0.00E+00	1.61E-02	5.70E-05
Di-n-octylphthalate	117-84-0	3.66E-04	3.15E-05	8.24E-07	3.73E-03	1.32E-05
Dioxin TEQ	-56240	0.00E+00	0.00E+00	0.00E+00	6.95E-08	2.46E-10
d-Limonene	5989-27-5	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

(Sheet 3 of 5)

Appendix A   Air Dispersion Modeling

Table A13 (Continued)						
SOPC	CAS#	Pc, µg/m³	Pdd, g/m²/yr	Pwd, g/m²/yr	Vc, µg/m³	Vwd, g/m²/yr
Ethane	74-84-0	0.00E+00	0.00E+00	0.00E+00	1.08E-02	3.83E-05
Ethanol	64-17-5	0.00E+00	0.00E+00	0.00E+00	4.19E-04	1.48E-06
Ethylbenzene	100-41-4	0.00E+00	0.00E+00	0.00E+00	1.10E+01	3.89E-02
Ethylchloride	75-00-3	0.00E+00	0.00E+00	0.00E+00	6.06E-05	2.14E-07
Ethylene	74-85-1	0.00E+00	0.00E+00	0.00E+00	2.59E-01	9.14E-04
Fluorene	86-73-7	2.82E-08	2.43E-09	6.35E-11	1.45E-03	5.13E-06
Furan	110-00-9	0.00E+00	0.00E+00	0.00E+00	3.14E-03	1.11E-05
Heptanal	111-71-7	0.00E+00	0.00E+00	0.00E+00	6.80E-02	2.40E-04
Hexachlorobenzene	118-74-1	0.00E+00	0.00E+00	0.00E+00	2.52E-02	8.90E-05
Hexachlorobutadiene	87-68-3	0.00E+00	0.00E+00	0.00E+00	1.01E-02	3.57E-05
Hexachlorocyclopentadiene	77-47-4	0.00E+00	0.00E+00	0.00E+00	7.38E-03	2.61E-05
Hexachloroethane	67-72-1	0.00E+00	0.00E+00	0.00E+00	3.50E-03	1.24E-05
Hexachloropropene	1888-71-7	0.00E+00	0.00E+00	0.00E+00	7.02E-03	2.48E-05
Hexanal	66-25-1	0.00E+00	0.00E+00	0.00E+00	1.17E-03	4.14E-06
Indane	-512487	0.00E+00	0.00E+00	0.00E+00	1.88E+00	6.66E-03
Isobutane	75-28-5	0.00E+00	0.00E+00	0.00E+00	3.66E-02	1.29E-04
Isobutene	-651646	0.00E+00	0.00E+00	0.00E+00	7.51E-02	2.65E-04
Isopentane	78-78-4	0.00E+00	0.00E+00	0.00E+00	1.04E+00	3.68E-03
Isoprene	78-79-5	0.00E+00	0.00E+00	0.00E+00	2.52E-03	8.89E-06
Isopropylbenzene	98-82-8	0.00E+00	0.00E+00	0.00E+00	2.57E-02	9.07E-05
Isothiocyanatomethane	556-61-6	0.00E+00	0.00E+00	0.00E+00	5.81E-04	2.05E-06
Lead	7439-92-1	5.18E-02	4.46E-03	1.17E-04	0.00E+00	0.00E+00
Magnesium	7439-95-4	1.07E+02	9.22E+00	2.41E-01	5.69E+00	2.01E-02
Manganese	7439-96-5	1.82E-01	1.57E-02	4.10E-04	0.00E+00	0.00E+00
Mercury	7439-97-6	9.69E-05	8.34E-06	2.18E-07	0.00E+00	0.00E+00
Methacrolein	78-85-3	0.00E+00	0.00E+00	0.00E+00	2.07E-03	7.31E-06
Methylbromide	74-83-9	0.00E+00	0.00E+00	0.00E+00	4.17E-04	1.47E-06
Methylchloroform	71-55-6	0.00E+00	0.00E+00	0.00E+00	7.24E-05	2.56E-07
Methylcyclohexane	108-87-2	0.00E+00	0.00E+00	0.00E+00	9.59E-01	3.39E-03
Methylcyclopentane	96-37-7	0.00E+00	0.00E+00	0.00E+00	4.56E-01	1.61E-03
Methylene chloride	27639	0.00E+00	0.00E+00	0.00E+00	9.90E-02	3.50E-04
Methylnitrite	624-91-9	0.00E+00	0.00E+00	0.00E+00	4.57E-01	1.61E-03
M-Ethyltoluene	620-14-4	0.00E+00	0.00E+00	0.00E+00	2.68E-01	9.46E-04
Methyl-vinyl Ketone	78-94-4	0.00E+00	0.00E+00	0.00E+00	3.33E-03	1.18E-05
MTBE	-97059	0.00E+00	0.00E+00	0.00E+00	1.17E+01	4.14E-02
M-Xylene	108-38-3	0.00E+00	0.00E+00	0.00E+00	2.04E+01	7.19E-02
Naphthalene	91-20-3	0.00E+00	0.00E+00	0.00E+00	8.56E-01	3.03E-03
N-Butane	106-97-8	0.00E+00	0.00E+00	0.00E+00	1.95E-01	6.87E-04
N-Decane	124-18-5	0.00E+00	0.00E+00	0.00E+00	2.12E-02	7.49E-05
N-Heptane	142-82-5	0.00E+00	0.00E+00	0.00E+00	9.39E-01	3.32E-03
N-Hexane	110-54-3	0.00E+00	0.00E+00	0.00E+00	1.25E+00	4.43E-03
Nickel	7440-02-0	1.06E-02	9.09E-04	2.37E-05	0.00E+00	0.00E+00
Nitrobenzene	98-95-3	0.00E+00	0.00E+00	0.00E+00	1.23E-04	4.35E-07
Nitromethane	75-52-5	0.00E+00	0.00E+00	0.00E+00	6.50E-02	2.30E-04
N-Nonane	111-84-2	0.00E+00	0.00E+00	0.00E+00	7.96E-02	2.81E-04
N-Octane	111-65-9	0.00E+00	0.00E+00	0.00E+00	3.45E-01	1.22E-03
						(Sheet 4 of 5)

SOPC	CAS#	P_c, µg/m³	P_{dd}, g/m²/yr	P_{wd}, g/m²/yr	V_c, µg/m³	V_{wd}, g/m²/yr
Table A13 (Concluded)						
Nonanal	124-19-6	0.00E+00	0.00E+00	0.00E+00	2.50E-01	8.83E-04
n-Pentane	109-66-0	0.00E+00	0.00E+00	0.00E+00	1.06E+00	3.76E-03
n-Propylbenzene	103-65-1	0.00E+00	0.00E+00	0.00E+00	1.46E-01	5.17E-04
Octanal	124-13-0	0.00E+00	0.00E+00	0.00E+00	1.85E-01	6.53E-04
o-Ethyltoluene	611-14-3	0.00E+00	0.00E+00	0.00E+00	1.72E-01	6.08E-04
o-Xylene	95-47-6	0.00E+00	0.00E+00	0.00E+00	1.28E+01	4.52E-02
Pentachloro-1-propene	1600-37-9	0.00E+00	0.00E+00	0.00E+00	3.67E-04	1.30E-06
Pentanal	110-62-3	0.00E+00	0.00E+00	0.00E+00	5.36E-04	1.90E-06
p-Ethyltoluene	622-96-8	0.00E+00	0.00E+00	0.00E+00	4.47E+00	1.58E-02
Phenanthrene	31055	0.00E+00	0.00E+00	0.00E+00	4.31E-03	1.52E-05
Phenol	108-95-2	0.00E+00	0.00E+00	0.00E+00	3.34E-05	1.18E-07
Phenylacetylene	536-74-3	0.00E+00	0.00E+00	0.00E+00	3.59E-03	1.27E-05
Propanal	123-38-6	0.00E+00	0.00E+00	0.00E+00	4.19E-03	1.48E-05
Propane	74-98-6	0.00E+00	0.00E+00	0.00E+00	3.35E-03	1.18E-05
Propanenitrile	107-12-0	0.00E+00	0.00E+00	0.00E+00	4.35E-04	1.54E-06
Propene	-651775	0.00E+00	0.00E+00	0.00E+00	1.18E-01	4.17E-04
p-Xylene	106-42-3	0.00E+00	0.00E+00	0.00E+00	2.04E+01	7.19E-02
Sec-Butylbenzene	135-98-8	0.00E+00	0.00E+00	0.00E+00	8.88E-01	3.14E-03
Selenium	7782-49-2	1.07E-03	9.22E-05	2.41E-06	0.00E+00	0.00E+00
Silver	7440-22-4	1.79E-04	1.54E-05	4.02E-07	0.00E+00	0.00E+00
Styrene	100-42-5	0.00E+00	0.00E+00	0.00E+00	1.59E-01	5.61E-04
Tetrachloroethene	127-18-4	0.00E+00	0.00E+00	0.00E+00	6.27E-01	2.22E-03
Tetrahydrofuran	109-99-9	0.00E+00	0.00E+00	0.00E+00	1.15E-03	4.05E-06
Thiophene	-653751	0.00E+00	0.00E+00	0.00E+00	4.54E-03	1.61E-05
Toluene	108-88-3	0.00E+00	0.00E+00	0.00E+00	2.88E+01	1.02E-01
trans 1,3-Dichloro-1-propene	10061-02-6	0.00E+00	0.00E+00	0.00E+00	1.11E-04	3.93E-07
trans-2-Butenal	123-73-9	0.00E+00	0.00E+00	0.00E+00	2.59E-03	9.15E-06
trans-2-Butene	624-64-6	0.00E+00	0.00E+00	0.00E+00	2.05E-02	7.25E-05
trans-2-Hexene	4050-45-7	0.00E+00	0.00E+00	0.00E+00	7.06E-03	2.50E-05
trans-2-Pentene	-457915	0.00E+00	0.00E+00	0.00E+00	9.62E-03	3.40E-05
trans-3-Penten-2-one	3102-33-8	0.00E+00	0.00E+00	0.00E+00	7.66E-04	2.71E-06
Trichloroacetonitrile	-494749	0.00E+00	0.00E+00	0.00E+00	8.75E-05	3.09E-07
Trichloroethylene	28861	0.00E+00	0.00E+00	0.00E+00	4.24E-03	1.50E-05
Trichloromonofluoromethane	75-69-4	0.00E+00	0.00E+00	0.00E+00	1.17E-03	4.12E-06
Vinylidene chloride	75-35-4	0.00E+00	0.00E+00	0.00E+00	3.82E-04	1.35E-06
Zinc	7440-66-6	1.52E-01	1.31E-02	3.42E-04	0.00E+00	0.00E+00
						(Sheet 5 of 5)

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1. Massachusetts Military Reservation Site Visit Notes. (2000a). 21-22 August.

2. Massachusetts Military Reservation Site Visit Notes. (2000b). 1-2 November.

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4. U.S. Army. (1988). *Field Manual, Grenades and Pyrotechnic Signals*, FM 23-30.

5. Camp Edwards Regulation 385-63. (2002). Range Safety & Trainer's Guide 1.

6. U.S. Army Aberdeen Test Center for the U.S. Army Environmental Center. (1999). "Final Report for the Phase I of the Firing Point Emissions Study."

7. U.S. Environmental Protection Agency. (1995). "User's guide for the industrial source complex (ISC3) dispersion models," Volumes I and II, Research Triangle Park, NC.

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Appendix B
Ecological Assessment

Screening- Level Ecological Evaluation

The purpose of this component was to qualitatively assess the potential for impacts to ecological receptors resulting from exposure to chemicals in the surface soil via training activities at MMR. The qualitative discussion was structured according to the framework for ecological risk assessment provided by the USEPA (1998a).[1] The problem formulation step, which includes describing habitats and potential exposure resources at the site, identifying potential exposure pathways, potential ecological receptors, measures, and chemicals of potential concern (COPC) was primarily used for the qualitative discussion. The problem formulation step resulted in:

   a. The identification of adequate assessment endpoints;

   b. A conceptual site model that described relationships between stressor (s) and assessment endpoint(s);

   c. An analysis plan.

Problem Formulation

The purpose of the problem formulation section is to identify COPCs and the ecological receptors and exposure pathways for evaluation. Available information is evaluated regarding site history, past and present land use activities, habitat and wildlife, and COPCs associated with the site in order to identify the pathways by which ecological receptors could be exposed to chemicals.

Site history

(Main text, Chapter 2, "Site Description," and Chapter 3, "Modeling approach," subparagraph "Human health analysis.")

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[1] References are listed at the end of Appendix B.

Past and present land use activities

(Main text, Chapter 2, Site Description)

Habitats and wildlife

MMR contains the single largest tract of open space on Cape Cod. Much of Cape Cod has been extensively developed and many plant and animal species lack sufficient habitat. Rare plant and animal species are having greater success on MMR (especially on Camp Edwards) because of the lack of habitat fragmentation and development. Camp Edwards contains the largest pine barrens north of the renowned New Jersey Pine Barrens, and many state-listed threatened, endangered, and of special concern species inhabit the area (MNGE&RC et al. 2001).

The Impact Area, which is part of the Camp Edwards Training site, is comprised primarily of Scrub Oak Barrens habitat; however, Pitch Pine Forest is interspersed throughout the area. The plant community represents one of the earliest states of vegetative succession. Shrub species prevalent in the Scrub Oak Barrens include huckleberry, blueberry, cat brier, and wintergreen (CEEPO 2000).

Camp Edwards represents an island of natural resources surrounded by a sea of development (CEEPO 2000). Small mammal and bird populations have been surveyed since 1993, and faunal populations have been surveyed for several years as well. Invertebrates have also been studied; however, they are one of the least studied because of their high diversity. Moths, dragonflies, and aquatic invertebrates have been the main focus of past surveys. The Scrub Oak Barrens and Pitch Pine/Scrub Oak communities provided habitat for seven state-listed rare moth species, and the Scrub Oak Barrens habitat is highly preferable to many state-listed rare moth species.

Populations of small mammals have been monitored on Camp Edwards since 1994. The most abundant small mammal species captured during the surveys were white-footed mice and the southern red-backed vole. The Pitch Pine/Scrub Oak community produced a relatively moderate number of individuals. Whitetail deer are also abundant on Camp Edwards. According to deer harvest data, the whitetail deer population has not fluctuated greatly. Bat surveys were also conducted at Camp Edwards in 1999 and 2000. Three species, the big brown bat, the red bat, and the northern myotis were documented during the surveys (CEEPO 2000).

Camp Edwards contains the second highest number of state-listed rare species within the Cape Cod Ecoregion with 35 state-listed (i.e., endangered, threatened, and special concern) and 7 watch-listed species (CEEPO 2000). See Table B1 for the state-listed and watch-listed species observed at Camp Edwards. The management of the ecology and endangered species by various environmental agencies and organizations serves to maintain the biological diversity at Camp Edwards making it a unique area for native flora and fauna.

Table B1
State-Listed and Watch-Listed Species Observed at
Camp Edwards

Group	Endangered	Threatened	Special Concern	State-listed	Total Watch-listed
Plants	4	1	0	5	6
Odonates	0	1	3	4	0
Butterflies	0	0	0	0	1
Moths	0	5	9	14	0
Reptiles	0	0	2	2	0
Amphibians	0	0	0	0	0
Birds	1	4	5	10	0
Total	5	11	19	35	7

Conceptual site model

The suspected source of the contaminants is from modeled air emissions that result from the use of munitions during future military training and deposition onto the surface soil. Refer to Figure B1 for the conceptual site model (CSM) that includes the general environmental fate of substances released from munitions on the impact area.
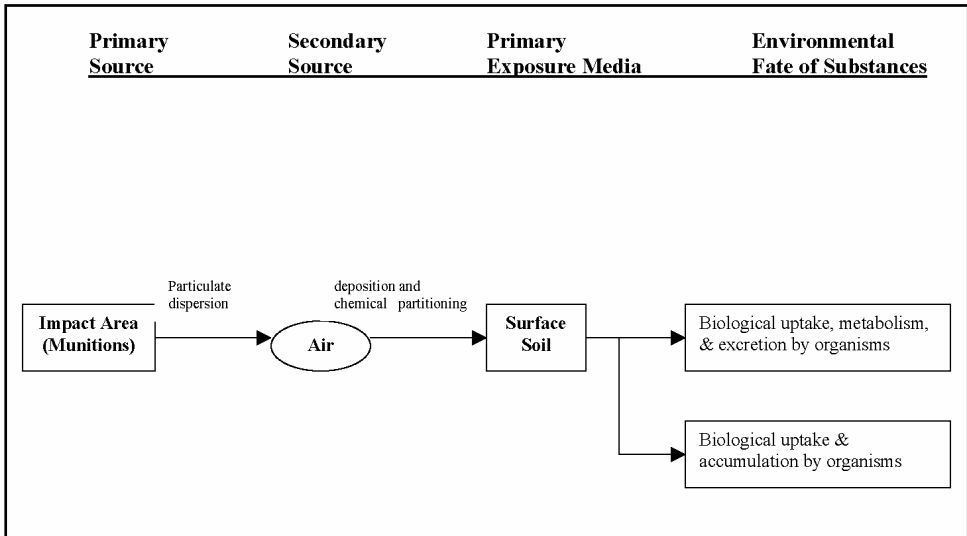
Figure B1. General environmental fate of substances released from the munitions on the impact area of MMR

The risk hypothesis is that specific substances in the munitions may accumulate in the soil to sufficient levels to induce the following effects:

a. Increased stress on individual organisms that may reduce population densities (e.g., through reduced reproductive performance, less resistance to disease, or impaired development).

b. Stressed populations of organisms.

c. Altered structure and function and decreased productivity of ecological communities.

d. Altered, and potentially decreased, biological diversity.

It is believed that toxicological effects (i.e., decrease reproductive potential and developmental impairment of organisms) can lead to stressed populations of organisms if those effects become sufficiently prevalent. Then, such stressed populations are expected to potentially lead to changes in population dynamics and community interactions that can alter the actual kinds of species (structure) and processes (function) within the affected ecological community. In general, the assumption is that such changes can lead to decreased community productivity and biological diversity. Figure B2 illustrates the hypothesized ecological consequences that munitions emissions may have on terrestrial communities. This particular ecological assessment will focus on the first bullet (i.e., the potential for toxicological effects in organisms). Individual species or organisms (e.g., Meadow vole) are usually selected to represent wildlife populations (i.e., all herbivore, all small mammals, or all herbivorous small mammals). These species are representative in the sense that they may be a sensitive species, have intimate contact with contaminated media, and/or are easy to study because they are abundant in the field.

Selection of Assessment Endpoints

Assessment endpoints are explicit expressions of the actual environmental values that are to be protected and are operationally defined by an ecological entity and its attributes (USEPA 1998a). The ecological entities within each assessment endpoint are those that are considered to be susceptible to the stress. The specific assessment endpoints for this ecological assessment are as follows:

a. Community structure of Pitch Pine/Scrub Oak Forest.

b. Survival of wildlife populations.

c. Survival of individuals of threatened or endangered species.

Analysis Plan

The analysis plan is the final stage of problem formulation and includes a description of the assessment design, data needs, and measures. This ecological assessment will evaluate the potential for adverse changes in each of the three assessment endpoints in context with the risk hypothesis that was stated in the conceptual model.
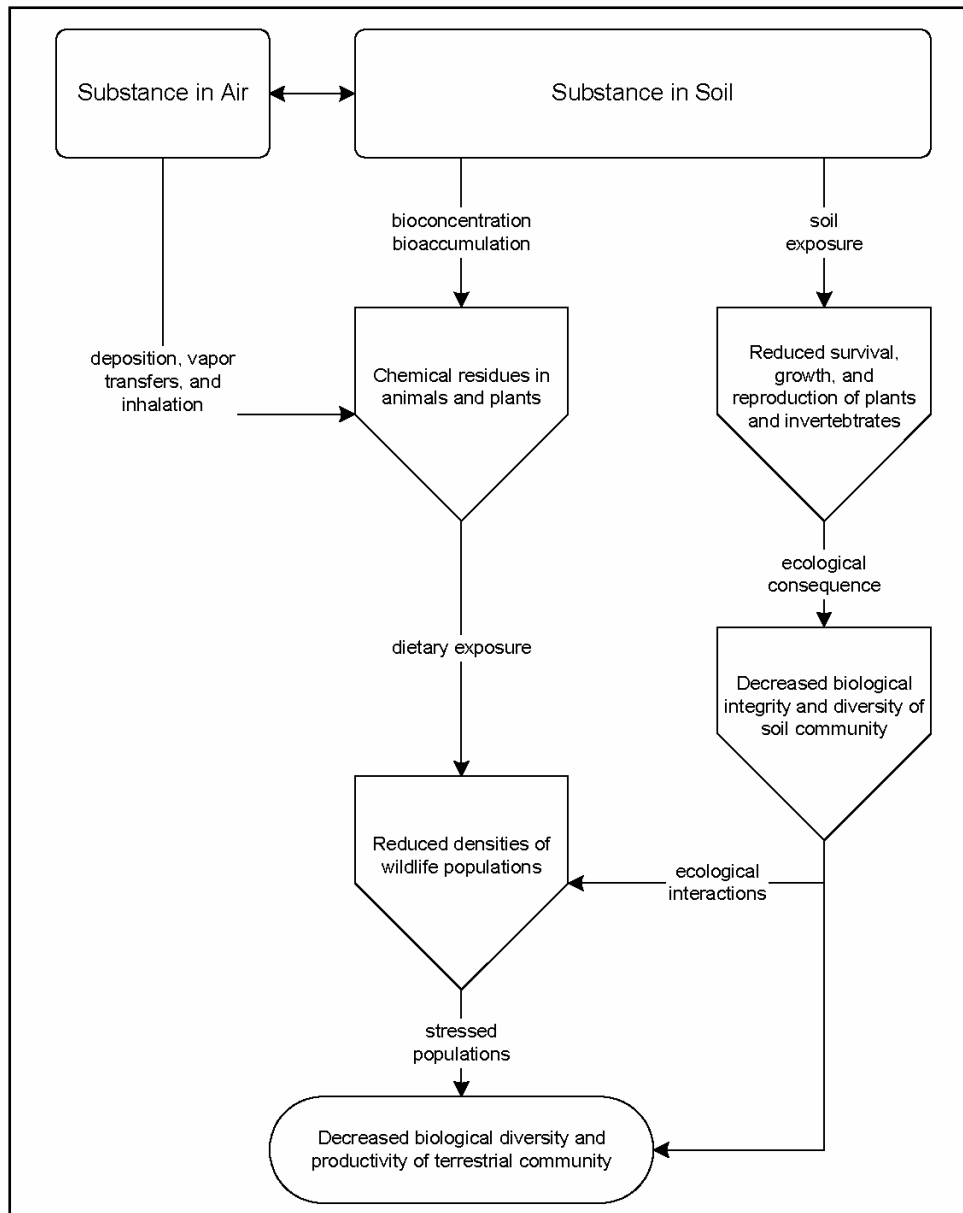
Figure B2. Hypothesized ecological consequences in terrestrial environments if munition emissions are determined to be ecologically adverse

Measures to evaluate the risk hypothesis

Two categories of measures will be employed in this assessment and are as follows:

a.   Measures of exposure. These measure the movement of stress through the environment and how exposure may occur to receptors (e.g., modeled media concentrations).

b. Measures of effect. These are measurable changes in an attribute of an assessment endpoint in response to a stressor to which it is exposed. (e.g., surface soil toxicity benchmarks).

For assessment endpoint No. 1 (Pitch Pine/Scrub Oak community structure), the following measures were selected:

a. Measures of exposure – Modeled concentrations of substances in the surface soil.

b. Measures of effect – Surface soil toxicity benchmarks.

For assessment endpoint No. 2 (Survival of wildlife populations), the following measures were selected:

a. Measures of exposure – Modeled concentrations of substances in the surface soil.

b. Measures of effect – Surface soil toxicity benchmarks.

For assessment endpoint No. 3 (Survival of individuals of threatened or endangered species), the following measures were selected:

a. Measures of exposure – Modeled concentrations of substances in the surface soil.

b. Measures of effect – Surface soil toxicity benchmarks.

For this screening-level assessment, the measures exposure (i.e., modeled surface soil concentrations) will be compared to the measures of effect (i.e., surface soil toxicity benchmarks) in order to identify any chemicals that may be of potential concern to ecological receptors.

Chemicals of Potential Concern

Emissions data from munitions were modeled to predict the fate and transport of combustion byproducts from the air to the surface soil. An initial screen was set forth to determine COPCs by comparing modeled soil concentrations for 24 chemicals to conservative soil quality benchmarks. benchmarks (Table B2). The average (initial) soil concentration (i.e., the soil concentration we would expect after 1 year of deposition) and the average (final) soil concentrations (i.e., the soil concentrations we would expect after 70 years of deposition) are provided in Table B2. To remain consistent with the human health assessment, final average soil concentrations were used in this assessment. Most chemicals, with the exception of Toluene (soil concentration slightly exceeded benchmark) and hexachlorobenzene, did not exceed the surface soil benchmarks. Benzaldehyde did not have a soil benchmark for comparison purposes, therefore, it was not evaluated. Table B2 presents the modeled surface soil concentrations. Two ecotoxicological benchmarks were provided, when available, for each chemical that represents different levels of effect. The lower

values (i.e., low-effect benchmarks) represent basic screening-level benchmarks that, if exceeded, indicate that the exposures need to be further investigated. The higher values (i.e., moderate-effect benchmarks) represent exposures that are likely to result in observable effects, if exposures in the field match those assumed in the evaluation. The higher values can be useful during interpretation of any predicted exceedances of the lower values.

Table B2
Chemicals of Potential Concern

Chemical	Average (Initial) Soil Concentration, mg/kg	Average (Final) Soil Concentration, mg/kg	Low-effect Soil Benchmark, mg/kg	Moderate-effect Soil Benchmark, mg/kg
Arsenic	0.0241	0.0285	10.0 [1]	19 [2]
Benzene	0.008	0.008	0.05 [3]	NA
Cadmium	0.016	0.046	1.6 [4]	5.0 [5]
Carbon tetrachloride	0.001	0.001	1000.0 [6]	NA
Chloroform	1.940E-06	1.940E-06	1.0E-03 [6]	NA
Chromium VI	0.081	0.090	8.0 [2]	NA
Ethylbenzene	0.046	0.046	0.05 [3]	1.2 [2]
Lead	0.526	2.406	50.0 [5]	85.0 [3]
Methylene chloride	7.861E-05	7.861E-05	2.0 [6]	NA
Nitrobenzene	1.318E-07	1.318E-07	40.0 [6]	NA
Tetrachloroethylene	9.872E-04	9.872E-04	0.01 [6]	NA
Toluene	0.061	0.061	0.05 [6]	NA
Trichloroethylene	3.707E-06	3.707E-06	1.0E-03 [6]	NA
Trans 1,2-Dichloroethylene	2.699E-07	2.699E-07	0.2 [6]	NA
2-Butanone	1.043E-04	1.043E-04	89.6 [6e]	NA
Benzaldehyde	4.902E-04	4.902E-04	NA	NA
2,3,7,8-TCDD	2.959E-08	1.558E-07	5.0E-05 [8]	NA
Furan	6.077E-07	6.077E-07	5.0E-05 [8]	NA
Carbon Disulfide	8.985E-05	8.985E-05	9.4E-02 [6e]	NA
Naphthalene	6.583E-03	6.583E-03	0.1 [5]	0.6 [2]
Phenanthrene	3.954E-04	4.494E-04	0.1 [5]	5.0 [5]
Trimethylbenzene	6.374E-02	6.374E-02	0.1 [6]	NA
Hexachlorobenzene	**8.039E-03**	2.043E-02	2.0E-03 [6]	NA
Di-n-octyphthalate	3.972E-03	2.248E-02	709.0 [6e]	NA

Note: Chemicals that exceeded the low-effect soil benchmark are in bold text.)
NA = Not Available
[e] = supplemental screening values (USEPA Region V Ecological Data Quality Levels. Online. Based on the most conservative NOAELs for plants, earthworms, voles, and shrews.)
[1] Efroymson et al. 1997a
[2] CCME 1997
[3] MHSPE 1994
[4] Crommenttuijn et al. 1997
[5] Beyer 1990
[6] USEPA 2000
[7] Efroymson et al. 1997b
[8] USEPA 1985

Selection of surface soil benchmarks

Measures of effects in soil invertebrates and plants are evaluated by a soil concentration benchmark for each chemical. Various sources for the development of these values are discussed below.

The primary source for selecting low-effect soil benchmarks was the USEPA Region IV document, "Ecological Risk Assessment at Military Bases: Process Considerations, Timing of Activities, and Inclusion of Stakeholders" (USEPA 2000). If unavailable from the above source, low-effect benchmarks (the lowest value), as well as moderate-effect benchmarks (the next highest value from the low-effect benchmark) were selected from Friday (1998). Sources from Friday (1998) included the following: U.S. Fish and Wildlife (Beyer 1990), Oak Ridge National Laboratory (Efroymson et al. 1997a and 1997b), the Canadian Council of Ministers of the Environment (CCME 1997), the Dutch Ministry Standards which included the Ministry of Housing, Spatial Planning, and Environment (MHSPE 1994), and Crommentuijn et al. (1997).

U.S. Fish and Wildlife (Beyer 1990) listed over 200 contaminants from Japan, Netherlands, Canada, United States, and the former Soviet Union. Screening levels from the Netherlands, which are sanctioned by the USEPA Region IV, were taken from the interim Dutch Soil Cleanup Act (Richardson 1987).

During the 1980s, the Dutch government issued three categories of soil quality values (i.e., A, B, and C). In 1994, the ABC benchmarks were redefined as follows: (1) "A" values are "target values," (2) "B" values are the sum of the target value and intervention value divided by two, and (3) "C" values are "intervention values" (MHSPE 1994). The target values were based on standards for drinking water and surface waters and indicated the soil quality required for sustainability or, expressed in terms of remedial policy, the soil quality required for the full restoration of the soil's functionality for human, animal, and plant life. Values for heavy metals, arsenic and fluoride were derived from the analysis of field data from relatively pollution-free rural areas and aquatic sediments regarded as uncontaminated. The target values for soil were based on the target values for surface waters when scientifically possible (Friday 1998).

Intervention values apply to terrestrial soil and to soil from the beds of rivers, lakes, etc. (i.e., sediments), and indicate the concentration levels of the contaminants in the soil above which the functionality of the soil for human, plant, and animal life is seriously impaired or threatened. These values are based on ecotoxicological effects that are quantified in terms of the concentrations in the soil at which 50 percent of the species present or potentially present may undergo adverse effects. Concentrations exceeding the intervention values reflect severe contamination (Friday 1998).

In 1997 the Dutch Ministry issued Maximum Permissible Concentrations (MPC's) for 18 metals (Crommentuijn et al. 1997) using three methods. When No Observed Effect Concentrations (NOEC's) were available for at least four taxons, statistical extrapolation was used. When only LC50 or a few NOEC's were available, a modification of the USEPA method was used. When no

laboratory data were available, equilibrium partitioning was used to derive a benchmark value. The Dutch values are based on ecotoxicological effects that are quantified in terms of the concentration at which 50 percent of the species and 50 percent of the microbial processes in the ecosystem are threatened or adversely affected (Friday 1998).

The Oak Ridge screening benchmarks for terrestrial plants and soil invertebrates (Efroymson et al. 1997a and 1997b) were used for determining whether the modeled soil concentrations had potential for causing adverse effects to soil organisms and plants. These benchmarks were based on laboratory toxicity tests that evaluated a variety of plant responses ranging from germination to root growth. The confidence in most of these benchmarks is low because of the limited number of studies. Many of the species used in these studies are agricultural species, and the study results may not be representative of the vegetation in the study area; however, they are the best available data. The soil benchmarks for invertebrates were derived using NOAA's Effects Range-Low (Long and Morgan 1990) approach supported by information from field and laboratory studies, bibliographic databases, and the published literature. Lowest Observed Effect Concentrations (LOECs) were ranked, and a value representing the 10th percentile of the distribution was selected. If less than 10 values were available, the lowest NOEC was used. Some benchmarks were derived by utilizing the author's expert judgment and interpolation (Efroymson et al. 1997a,b). Terrestrial plant benchmarks were derived similarly to that used for invertebrates and microbial processes (Efroymson et al. 1997b).

The Canadian Council of Ministers of the Environment (CCME 1997) issued soil quality guidelines for 20 substances that were derived specifically for the protection of ecological receptors in the environment. The derivation process for soil quality guidelines (SQGs) considers adverse effects from direct soil contact and from the ingestion of soil and food. The approaches used to evaluate contact with soil included:

a. Weight of evidence

b. LOEC method

c. Median effects method

d. Comparison with nutrient and energy cycling

The weight of evidence method, which is a modification of Long and Morgan (1990), estimates no adverse effects (Friday 1998).

Other sources were utilized when benchmark values were not provided by the above sources. For instance, the USEPA (1999) draft Screening-Level Ecological Risk Assessment Protocol for Hazardous Waste Combustion Facilities was used when no other above sources were available.

Validated background soil concentrations that represent an uncontaminated site should be used as a check for these benchmarks. Screening benchmarks lower than the background should not be used if the exposed site does not

contain forms of the chemicals that are more bioavailable or more toxic than forms at the background sites (Suter and Tsao 1996).

Discussion

Most chemicals (i.e., 21 out of 24) had soil concentrations that did not exceed the screening-level (i.e., conservative) soil benchmarks. Toluene had a soil concentration that did exceed the benchmark; however, it exceeded only slightly (modeled soil concentration of 0.06 mg/kg compared to a screening soil benchmark of 0.05 mg/kg). As determined by the log K_{ow} (octanol-water partition coefficient), which determines a chemical's potential to bioaccumulate (e.g., log K_{ow} <3.0 = non-bioaccumulating), toluene is considered to be a non-bioaccumulating volatile organic compound with a log K_{ow} of 2.67 (USEPA 1998b). Because of the slight exceedance, conservative nature of the soil benchmark, and nonbioaccumulating properties, toluene will not be retained as a COPC.

Hexachlorobenzene had a (final) soil concentration that did exceed the benchmark (modeled final soil concentration of 0.020 mg/kg compared to a screening soil benchmark of 0.002 mg/kg). The (initial) soil concentration was also exceeded but to a much lesser extent (modeled initial soil concentration of 0.008 mg/kg compared to a screening soil benchmark of 0.002 mg/kg). Hexachlorobenzene is considered to be a bioaccumulating compound with a log K_{ow} of 5.50 (USEPA 1998b). Hexachlorobenzene may warrant further investigation, however, the conservative assumptions that exist with regard to the modeled soil concentrations ("Uncertainties" paragraph below) should be recognized. It should also be noted that conservative (i.e., screening-level) soil benchmarks were used in this assessment.

As determined by its log K_{ow}, benzaldehyde is considered to be a non-bioaccumulating semivolatile organic compound with a log K_{ow} of 1.47 (USEPA 1998b). Because of the inability to evaluate benzaldehyde (i.e., lack of toxicity data) via comparison to the modeled soil concentration and nonbioaccumulating properties, benzaldehyde will not be retained as a COPC.

Uncertainties

Soil concentrations were not obtained via collecting samples from the impact area. However, munitions emissions data were modeled to predict the fate and transport of combustion by-products from the air to the surface soil. Important natural processes, such as photodegradation and environmental degradation (e.g., half-life) of the COPCs were not included in the air fate and transport modeling process. Additionally, soil degradation was assumed to be only the result of volatilization. These assumptions are conservative and tend to overestimate risks.

The modeled average (final) soil concentrations assumed the same deposition rate for 100 years, which tends to overestimate risks. Additionally, these results are based on the highly conservative assumption used in the application of

emission factors to obtain compound-specific air concentrations and deposition rates (CDRs). As explained in Appendix A, continuous emissions for each munitions type and for each training event were assumed, thus, resulting in a total mass released that is greater than would be expected, which translates into greater, but more conservative, exposure and risks.

Discussion of ecological effects from modeled chemical concentrations in the surface soil is limited to a qualitative analysis and rudimentary comparison to toxicological benchmarks. The predictive model focused only on the fate and transport of compounds through abiotic media that oversimplifies the ecosystem and ignores confounding factors that likely have a greater impact on ecological resources than the compounds being modeled. Confounding factors include the effects of physical disturbance (i.e., fire, vehicle traffic) from training on habitat and regional influences (i.e., weather patterns). Such confounding factors are important in the fact that they may determine the presence or absence of particular species at the site.

Soil quality benchmarks were not available for a single chemical, therefore, a chemical that contained a data gap could not be evaluated.

The soil benchmarks utilized were screening-level benchmarks. Therefore, if the modeled soil concentrations exceeded the soil screening benchmarks, further investigation may be necessary.

Summary and Conclusions

Twenty-one (21) out of 24 chemicals did not exceed surface soil screening toxicity benchmarks. Toluene exceeded the toxicity benchmarks; however, because of the slight exceedence and its nonbioaccumulating properties, it was not retained as a COPC. Benzaldehyde could not be evaluated because of a lack of toxicity information; however, as the result of its nonbioaccumulating properties, it was not retained as a COPC.

Hexachlorobenzene exceeded the toxicity benchmark, however, conservative assumptions associated with the modeled soil concentrations and the use of conservative soil benchmarks should be recognized.

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14. ABSTRACT
This study was conducted to evaluate potential human and ecological health risks associated with emission of pyrotechnic compounds during future training exercises at the Massachusetts Military Reservation. Air dispersion modeling was used to determine air concentrations and deposition rates for emissions. Annual average and spatially averaged air concentrations and deposition rates were used to perform the risk assessments. The Army Risk Assessment Modeling System (ARAMS) was used to conduct the human health risk assessment, which evaluated a site visitor or trespasser exposed to air and soil using air concentrations and deposition rates from the air dispersion modeling. ARAMS was also used to evaluate the time for deposited compounds to reach groundwater and the peak concentration upon contact with the water table. Of the 24 compounds evaluated, only Cr(VI), with an incremental cancer risk of 2.4×10^{-6}, posed a potential concern for human health with the maximum exposure and effect through the air inhalation pathway/route. None of the compounds are suspected to cause a groundwater problem. Computed soil concentrations were compared to soil screening toxicity benchmarks for the ecological risk assessment for the purpose of retaining or eliminating chemicals from the assessment. Toluene and hexachlorobenzene were the only compounds that exceeded the soil toxicity benchmarks. However, because of the slight exceedence and its nonbio-accumulating properties, toluene is not considered to be a chemical of potential concern. Although hexachlorobenzene exceeded the toxicity benchmark, uncertainties and conservative assumptions associated with the modeled soil concentrations and conservative soil benchmarks should be recognized.

15. SUBJECT TERMS

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