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LIST OF ACRONYMS AND ABBREVIATIONS

AIRMAG	Airborne magnetometer
AMEC	AMEC Earth & Environment, Inc.
ANG	Air National Guard
ASR	Archive Search Report
Bgs	below ground surface
BEHP	bis(2-ethylhexyl)phthalate
DOE	U.S. Department of Energy
ECC	Environmental Chemical Corporation
EDB	Ethylene dibromide
EPA	U.S. Environmental Protection Agency
EPH	Extractable Petroleum Hydrocarbons
ETI	extraction treatment and re-injection
ETR	extraction, treatment, rejection
FS	Feasibility Study
FS-12	Fuel Spill Number 12 (with an extraction, treatment and re-injection system in place and operating)
GAC	Granular Activated Carbon
g/cm^3	grams per cubic centimeter
HA	health advisory
HE	High Explosives
HERA	Human Health and Ecological Risk Assessment
HHRA	Human Health Risk Assessment
HMX	Octahydro-1,3,5,7-Tetranitro-1,3,5,7-Tetrazocine
IAGWSP	Impact Area Groundwater Study Program
Kg	Kilogram
M	Meter
Mg	milligram
LTGM	Long Term Groundwater Monitoring
M	Million
MAARNG	Massachusetts Army National Guard
MassDEP	Massachusetts Department of Environmental Protection
MCL	maximum contaminant level
MCPA	2-Methyl-4-Chlorophenoxyacetic Acid
MCPP	Mecoprop [2-(4-chloro-2-methylphenoxy) propanoic acid]
MEC	Munitions and Explosives of Concern
mg/Kg	milligrams per kilogram
mg/L	milligrams per liter
mL	Milliliters
Mm	Milliliter
MMCL	Massachusetts maximum contaminant level
MMR	Massachusetts Military Reservation
ngvd	national geodetic vertical datum
MNX	hexahydro-1-nitroso-3,5-dinitro-1,3,5-triazine
MTU	Mobile Treatment Unit
NGB	National Guard Bureau
PCB	polychlorinated biphenyl

LIST OF ACRONYMS AND ABBREVIATIONS

PEP(s)	propellant, explosive, and pyrotechnic(s)
pH	Scale for measuring aqueous hydrogen ion (H*) concentration
RDX	Hexahydro-1,3,5-Trinitro-1,3,5-Triazine
SSL	Soil Screening Level
SVOC	Semi Volatile Organic Compounds
TNT	2,4,6- trinitrotoluene
TERC	Total Environmental Restoration Contract
TR	target risk
USACE	United States Army Corps of Engineers
UXO	Unexploded Ordnance
VOC	Volatile Organic Compounds
2A-DNT	2-amino-4,6-dinitrotoluene
4A-DNT	4-amino-2,6-dinitrotoluene
2,4-DNT	2,4-dinitrotoluene
Cm	Centimeter
F_{oc}	soil organic carbon fraction
°F	degrees Fahrenheit
K_d	distribution coefficient
K_{oc}	organic carbon partition coefficient
µg/Kg	microgram per kilogram

EXECUTIVE SUMMARY

L Range is located on Camp Edwards at the Massachusetts Military Reservation (MMR), southeast of the impact area, between the J-1 and J-3 Ranges. The L Range Study Area includes the L Range proper and three adjacent areas, unrelated to L Range other than by proximity, referred to as Area 46, Cleared Area 11, and Area 79 (Figure 2-2).

L Range was primarily used as a 40mm grenade launcher training range from the 1970s to the 1990s. A portion of L Range was previously used as an infiltration course. The terrain at L Range is flat, with a series of firing points located atop an earthen berm at the southern end of the range.

The top of the groundwater mound within the western Cape Cod groundwater aquifer system is located beneath the southeast ranges of Camp Edwards. Groundwater flows radially outward from this area. Groundwater in the L Range study area flows to the south, where several discontinuous, low concentration areas of Hexahydro-1,3,5-Trinitro-1,3,5-Triazine (RDX) and perchlorate contamination have been detected.

The investigation at L Range and source response actions were conducted under the authority of United States Environmental Protection Agency (EPA) Administrative Orders SDWA 1-97-1019 and SDWA 1-2000-0014 and in consideration of the substantive cleanup standards of the Massachusetts Contingency Plan. This Remedial Investigation/Feasibility Study (RI/FS) presents the results of soil and groundwater investigations and an evaluation of remedial alternatives for contaminated groundwater associated with the L Range. The contaminant source has been removed and is being treated as part of an on-going removal action. The removal action will be documented in a Completion of Work Report. Thus, all L Range alternatives include removal of the source area.

L Range Soil Investigations

The first phase of the L Range soil investigations began in March 1999 and continued through July 2005. During this timeframe, 473 soil samples were collected from 60 locations within the L Range Study Area.

The 1999 to 2005 analytical data collected and reviewed for this investigation identified volatile organic compounds (VOC), semi-volatile organic compounds (SVOC), pesticides, herbicides, explosives, and metals at various concentrations in L Range soils. Fuel-related extractable petroleum hydrocarbons (EPH) compounds were detected in Area 46. Dieldrin was detected at the Firing points, Area 46 and Area 79. A Draft Soil Remedial Investigation report was submitted in December 2005. The EPA did not approve the findings of this report, and requested multi-increment soil sampling and an assessment of remaining unexploded ordnance (UXO). In response to these concerns, the IAGWSP proposed the use of robotics technology to assess and remove remaining ordnance on the Range.

L Range Robotics Technology Demonstration, Investigation, and Post-Clearance Soil Sampling

The Air Force Research Laboratory (AFRL) conducted a robotics technology demonstration at L Range in 2008 to evaluate the effectiveness of using remotely operated equipment to safely remove UXO from L Range. The robotics technology demonstration was performed over a 7.47 acre area (approximately 95% of the range floor) which included the entire range floor where the former targets were located and, therefore, where the probability of finding UXO was the greatest. A total of 53 potential High Explosive grenades, 47 other items with possible explosive properties (typically, fuzes), and more than 12,000 pounds of munitions debris (thousands of practice grenades) were recovered from the range floor. Approximately 70% of these materials were recovered from the mid-range area. A post-robotics confirmatory geophysical survey and intrusive investigations (excavation of 750 feet of trenches and investigation of 16 select anomalies) in the range floor found no high explosive grenades and two items with potentially live fuzes. Intrusive investigations in the areas of the range firing fan outside the range floor (meandering path survey, excavation of a portion of the southern range floor boundary berm), also found no UXO.

After completion of the robotics demonstration, multi-increment soil samples were collected from a total of 23 decision units in the up-range, mid-range, and down-areas of L Range for explosives and perchlorate analyses. Analytical results indicated exceedances of relevant standards (RDX, HMX) and or reporting concentration (2,4,6-trinitrotoluene (TNT)) at 10 of the 15 decision units in the mid-range area. None of the three up-range or five down-range decision units had any detections of explosives. Perchlorate was detected but only at very low levels throughout the range and well below relevant standards. A second round of multi-increment soil samples, collected in May 2009 from the mid-range decision units, confirmed the presence of explosives in this portion of the range. However, they were detected at significantly lower levels than the first round of sampling.

L Range Source Removal Action

Based on these results, approximately 2,700 cubic yards of contaminated soils were removed from the 3.33 acre mid-range area as part of on-going removal actions for on-site treatment. The action will be documented in a Completion of Work Report. The excavation of soils in the mid-range area as well as post-excavation anomaly removal greatly reduced the possibility that further UXO remain in this portion of the range. In addition, portions of the up-range and down-range area have been manually cleared.

During the screening of overs generated during soil sifting, six HE items have been identified (as of April 9, 2010). It is estimated that an additional 6 HE items will be found after completion of this sifting process. Two HE grenades were identified during the post excavation clearance activity. Thus, although an occasional stray round may have resulted in a UXO, it is unlikely a significant number of UXO remain on the range. The Munitions Source Assessment, presented in Appendix B, includes an evaluation of potential UXO remaining.

L Range Groundwater Investigations

The L Range Groundwater Characterization Report analyzed data available through July 31, 2004. Since July 2004, more than 340 groundwater samples have been collected from 70 wells in conjunction with L Range Interim Groundwater Monitoring Plans. The groundwater samples have been analyzed for perchlorate and/or explosives.

The L Range groundwater contamination was mapped as three lobes for RDX and six lobes for perchlorate in the *Final L Range Groundwater Characterization Report* (ECC 2005), which had a data cutoff date of July 2004. The L Range groundwater contamination presented in this report, which includes data through May 2007, has been remapped to two lobes for RDX and four lobes for perchlorate. In numerous areas, concentrations have decreased below the detection limit or continue to remain below the detection limit, and the volume of contamination has decreased.

The fate and transport modeling presented in the *Final L Range Groundwater Characterization Report* (ECC 2005) indicated the RDX contamination would migrate south in the direction of the northernmost FS-12 extraction wells. The modeling suggested that perchlorate would not migrate appreciably beyond its current location in the aquifer. The report concluded that it is extremely unlikely that RDX from the L Range area will reach the northernmost FS-12 extraction wells.

Based on the nature and extent of contamination and the risk-screening process, RDX and perchlorate in groundwater are retained as COCs since they are detected in a number of wells at concentrations above risk based standards indicating the presence of a plume of groundwater contamination.

Feasibility Study

A Feasibility Study was prepared to describe the development and evaluation of remedial action alternatives for the L Range groundwater study area. UXO as a potential source was removed along with contaminated soil in the mid-range area under an ongoing response action. The Feasibility Study evaluated three alternatives: (1) no further action, (2) monitored natural attenuation and land use controls, and (3) focused extraction (long-term monitoring and institutional controls with groundwater treatment). All alternatives focus on groundwater since the source was recently removed by a $1.5 million response action. Based on preliminary information relating to types of contaminants, environmental media of concern, and potential exposure pathways, response action objectives were developed to aid in the development and screening of alternatives. The response action objectives for the selected response action for the L Range are to restore the useable groundwater to its beneficial use wherever practicable, within a timeframe that is reasonable given the particular circumstances of the site; to provide a level of protection in the aquifer that takes into account that the Cape Cod aquifer, including the Sagamore Lens, is a sole source aquifer that is susceptible to contamination; and to prevent ingestion and inhalation of groundwater containing contaminants of concern (COCs) (RDX and perchlorate) in excess of federal maximum contaminant levels, Health Advisories, drinking water equivalent levels (DWELs), applicable State standards, or an unacceptable excess lifetime cancer risk or non-cancer Hazard Index.

Alternative 1 – No Further Action

The no further action alternative would remove/abandon existing monitoring wells. Existing land use controls would remain in place. Natural attenuation process would reduce the RDX concentration to below 0.6 µg/L by approximately 2027, but offers no monitoring or confirmation of existing land-use controls to ensure that future exposures do not occur. The present value cost of this alternative is $109,725.

Alternative 2 – Monitored Natural Attenuation and Land Use Controls

This alternative would provide for implementation and management of land use controls and long term monitoring of the L Range groundwater to minimize human exposure to groundwater. Natural attenuation process would reduce the RDX concentration to below 0.6 µg/L by approximately 2027. The present value costs of this alternative are estimated at $1.87 M.

Alternative 3 – Focused Extraction (long-term monitoring and institutional controls with groundwater treatment)

Alternative 3 would provide for active treatment of the L Range groundwater, monitoring of groundwater, and maintaining land use controls. The conceptual design includes installation of one new extraction well, a containerized treatment facility, piping, an infiltration trench. This alternative also provides for monitoring of the L Range groundwater and treatment system as long as active remediation continues. However, modeling predicts that RDX concentrations in the extraction well will fall below the method detection limit within two years of system startup and the system would be shut down. Reduction in contaminant levels to less than 0.6 µg/L would occur through remediation and natural attenuation by approximately 2016. The present value costs are approximately $3.74 M.

Alternative 1 provides no groundwater monitoring or confirmation of land use controls to ensure that future exposures do not occur. Alternative 2 relies on natural attenuation, and protects human health by maintaining and enforcing current land use controls. Alternative 3 actively removes contaminants from the L Range plume. The implementability concerns and short-term impacts to workers and the environment generally increase with the amount of construction and groundwater sampling associated with a given alternative (Alternative 1 is the least and Alternative 3 is the greatest). The costs also increase commensurate with the amount of groundwater sampling and construction. Alternative 1 has the lowest cost $109,725 and Alternative 3 has the highest costs ($3.74 M).

1.0 INTRODUCTION

The L Range was primarily a 40mm grenade launcher familiarization range that was investigated along with several neighboring ranges, which were collectively known as the southeast ranges of Camp Edwards. The L Range study area includes several sub-areas, related to L Range only by proximity, that are described in this report as Area 46, Cleared Area 11 (CA-11), and Area 79. The L Range investigation and cleanup were conducted under United States Environmental Protection Agency (EPA) Safe Drinking Water Act Administrative Orders SDWA 1-97-1019 and SDWA 1-2000-0014 and in consideration of the substantive cleanup standards of the Massachusetts Contingency Plan.

Soil and groundwater sampling in the L Range study area began in 1999 and continued through 2008.

A final groundwater characterization report was submitted in November 2005, and in December 2005 a draft soil characterization report was submitted to the regulatory agencies. In May 2008 a final human health risk assessment was submitted. The groundwater characterization report and the human health risk assessment were approved by the Agencies. The EPA did not approve of the findings of the soil characterization report and requested additional soil characterization and an assessment of remaining UXO.

In the Air Force Research Laboratory conducted a robotics technology demonstration at the L Range. This work resulted in the removal of vegetation, targets and munitions from the range floor (based on the maximum amount of vegetation clearance noted on a 1977 aerial photograph). It also included a geophysical survey of 7.47 acres (approximately 95% of the range floor) and soil sifting of over 2,700 cubic yards of soil. The resulting reduction in safety hazard allowed comprehensive multi-increment soil sampling in a 7.47 acre portion of the range floor that was most likely to contain contamination.

The multi-increment soil sampling identified explosives contamination in portions of the range floor. These soils were excavated and treated. Groundwater investigations at L Range have identified several small, discontinuous, low concentration lobes of explosives and perchlorate contamination in groundwater downgradient from L Range.

1.1 Purpose of the Report

This *L Range Soil and Groundwater Remedial Investigation/Feasibility Study Report* provides a summary of activities conducted and data gathered for characterization of soil and groundwater contamination at the L Range. All available analytical data have been used to delineate the nature and extent of contamination. The report also includes a Feasibility Study, which evaluates remedial actions for groundwater contaminants.

1.2 Report Organization

Section 2.0 of this report provides site description of the L Range Study Area and its subcomponent areas, presents a history of past military activities conducted there and describes the physical characteristics of the site. Section 3.0 provides a summary and description of site investigation activities. Section 4.0 presents a summary and evaluation of soil analytical results. Section 5.0 presents the conclusions of the L Range Groundwater Characterization Report (ECC 2005) and discusses recent groundwater sampling results. A conceptual site model is presented in Section 6.0. Section 7.0 presents the risk screening. Section 8.0 presents remedial investigation findings. Section 9.0 presents the groundwater feasibility study. Section 10.0 discusses the development of alternatives. Detailed analysis of the alternatives is presented in Section 11.0, while Section 12.0 provides the comparative analysis of alternatives.

2.0 SITE BACKGROUND

The MMR includes Camp Edwards, Otis Air National Guard Base, United States Coast Guard Air Station Cape Cod, Cape Cod Air Force Station, and the Veteran's Affairs Cemetery. It is located on the western side of Cape Cod, Massachusetts (Figure 2-1). The L Range Investigation Area is located southeast of the Impact Area between the J-1 and J-3 Ranges. The L Range is one of several ranges collectively referred to as the Southeast Ranges of Camp Edwards.

2.1 Site Description

The L Range Study Area (Figure 2-2) includes the L Range proper [Firing Points (Figure 2-2a) and Targets (Figure 2-2b)] plus two adjacent areas referred to as Area 46 (Figure 2-2c) and Cleared Area 11 (Figure 2-2d). These three areas have been grouped together due to their proximity. Several samples collected in Area 79 during other investigations at MMR have also been included in this report due to their spatial proximity to Cleared Area 11 and Area 46 (Figure 2-2e). The exact targets, their historic locations, and their periods of use are unknown. Access to L Range is restricted by a continuous chain-link fence around its perimeter.

Brief descriptions of the components of the L Range Study Area discussed in this report are presented below.

L Range: Throughout its history the area currently occupied by the L Range was primarily and, most recently, used as a 40mm grenade launcher range. The current layout of the range is shown in Figure 2-2. Firing occurred from Firing Points at the southeastern portion of the range (i.e. up-range) near the range parking area (Figure 2-2a). Grenades were fired down-range (northwest) toward multiple targets that were located at varying distances and cross-range angles (Figure 2-2b). The exact targets, their historical locations, and their periods of use are unknown. Access to the L Range is restricted by a continuous chain-link fence around its perimeter. The target area is centrally flat but bounded by heavily vegetated berms along its sides.

Area 46: Area 46 is located south of the L Range across Greenway Road (Figure 2-2c). This area was included in the L Range Study Area as part of an effort to identify the source of explosives contamination in groundwater collected from nearby well 90WT0013 (AMEC 2001c). Available archival records have not identified any evidence of military activities, disposal, burning, or demolition activities at Area 46. The only documented activities associated with Area 46 are construction, operation, and maintenance of the former Installation Restoration Program FS-12 source area soil vapor extraction (SVE) treatment system.

Cleared Area 11: Cleared Area 11 (CA-11) is an approximately 1-acre area located along Greenway Road between the L Range and the J-3 Range (Figure 2-2d). This area was identified because it appeared as a cleared area on historic photographs, and currently contains few trees.

Area 79: Several soil samples collected as part of the investigation of Former H Range (designated Area 79) are located immediately adjacent to CA-11 and Area 46 (Figure 2-2e). These adjacent samples are included in this report to ensure a robust evaluation of all available data and to demonstrate delineation of any identified soil contamination.

2.2 Site History

Sources for information on the history of the L Range Investigation Area included the *Ordnance and Explosives Archive Search Report* (ASR) (USACE 1999a and b) the *Draft Range Use History Report* (Ogden 1997), and the *Aerial Photographic Site Analysis, Groundwater Study Region 4* (ERI 2005).

The ASR includes interviews with past workers and persons knowledgeable of activities at MMR, including the L Range. The ASR also included munitions discoveries and range usage information obtained from Range Control Logs, Explosive Ordnance Disposal Reports and Site Inspections. Any witness observations or range records that were found pertaining to the L Range have been evaluated during the preparation of this report.

L Range: The area currently occupied by the L Range was originally developed in the 1940s along Greenway Road between the J-1 and J-3 Ranges. This area was originally established as an infiltration course, termed H Range in a memorandum (USACE 1999a). An evaluation of MMR records and aerial photographs suggest that this area may have been used into the 1950s (Figures 2-3a and 2-3b). In the mid- to late 1970s, infiltration activities previously conducted at the I Range (formerly located on the site of the current J-1 Range) were relocated to the area currently occupied by the L Range. During this period, the H Range (in the L Range's current location) was also used as an M79 and M203 grenade launcher familiarization range (Figures 2-3c and 2-3d). In the late 1980s, the L Range was used as an M203 grenade launcher range (Figure 2-3e). Details of the historic use periods are presented below.

<u>H Range - Infiltration Course (1940s to 1950s)</u>

In the early 1940s, an infiltration course was established in the current L Range location. The course is visible in the 1943 aerial photograph (Figure 2-3a). A historical photo (K-59) contained in the ASR confirms the infiltration course in this location in 1947 (USACE, 1999b). As indicated in a 1943 Memorandum (USACE 1999a), the course was 80 yards wide by 115 yards long. There was a starting trench located down-range closest to the Impact Area. Barbed wire entanglements ran across the course at two points. At intervals throughout the course, a total of 30 demolition craters were dispersed. 2,4,6-Trinitrotoluene (TNT) was detonated in these craters as personnel navigated the course. Machine guns were emplaced on four platforms in front of the finishing trench; live fire from the machine guns was also used as personnel navigated the course. A control tower was located in between the machine gun platforms. This course may have been used into the 1950s, based on the level of grounds keeping apparent in the 1955 aerial photograph (Figure 2-3b). ASR photo K-42 clearly depicts the infiltration course in a 1951 photo.

L Range - Grenade Launcher Range (1970s - late 1980s)

In the mid to late 1970s, the area was designated as I Range. Under the I Range designation, the area was used as a M79 and M203 grenade launcher familiarization range. Both 40mm practice and HE grenades were fired from the firing points, which are presumed to have been located in the same location as the existing firing points. The location or distribution of the targets is unknown.

The initial development of the I Range (Figure 2-3b) can be seen in the 1966 aerial photograph (Figure 2-3c). The developed I Range is visible in both the 1977 (Figure 2-3d) and 1986 (Figure 2-3e) aerial photographs, as well as in ASR photo K-48 (1971).

The primary round types used at L Range included the M381 40mm HE, M382 40mm practice, the M406 40mm HE, the M407 40mm practice, the 40mm M713/M715/M716 40mm smoke, the M781 40mm practice and the Parachute M661/M662 Illumination. The 40mm M382 practice grenade contained an inert dye and a small RDX booster pellet used to shatter the round. The 40mm M406/M381 HE grenades contain .68 ounces of RDX, .45 ounces of TNT, and a small percussion primer. The 40mm M716/M715/M713 Smoke grenade contained a pyrotechnic mixture which included aluminum, barium chromate, zinc, dye, and nitroglycerin. Table 4 of Appendix B presents the known munitions fired at the L Range.

L Range – Grenade Launcher Range (late 1980s – 1997):

In the late 1980s, the L Range was established in its current location as an M203 grenade launcher range with its current configuration including eight firing points with multiple targets positioned at varying locations downrange around the northern portion of the range (USACE 1999a). Review of MMR Range Records identifies the last date of the use of L Range as a Grenade Launcher range as March 1994.

The last record of use listed in the Range Safety Regulations for Camp Edwards was dated 1997 and identified the usage as “Squad/Platoon Attack Course” but did not specify what items were used in authorized activities. No records have been identified indicating the use of L Range after the 1997 suspension on ordnance firing at MMR.

Area 46: Area 46 is associated with the former Installation Restoration Program FS-12 SVE treatment system. The aerial photographs (Figures 2-3a through 2-3f) show vegetation covering Area 46 until 1994 when a rough access road is visible among the vegetation (Figure 2-3g). The FS-12 SVE system was constructed in 1995 to treat the source area of Fuel Spill Number 12. The system operated from late 1995 until early 1998, after which it was decommissioned. By 1997, some vegetation clearance is apparent (Figure 2-3h). By 2002 (Figures 2-3i and 2-3j), some vegetation appears to be returning to this area.

CA-11: CA-11 may have been associated with the former H Range mortar position visible as a small cleared area at the southeastern tip of the J-3 Range on the 1943 aerial photograph (Figure 2-3a). The area designated as CA-11, south of the L Range, is first visible in the 1966 photograph (Figure 2-3c). The cleared area does not change significantly in the 1977 and 1986 photographs (Figures 2-3d and 2-3e). Some vegetation returned to the area in the 1991 photo (Figure 2-3f). Little change is seen in the photos following 1991: 1994 (Figure 1-3g), 1997 (Figure 2-3h), 2001 (Figure 2-3i), and 2002 (Figure 2-3j).

Area 79: Like CA-11, Area 79 may have also been associated with the former H Range mortar position, which is visible as a small, cleared area at the southeastern tip of J-3 Range on the 1943 aerial photograph (Figure 2-3a). The area designated as Area 79 is located south of L Range, with the majority of the areas located south of Greenway Road. The cleared area is visible in the 1943 aerial photograph but appears re-vegetated in the 1955 aerial photograph (Figure 2-3b). No significant changes were observed in the 1966, 1977, 1986, 1991, 1994, 1997, 2001, and 2002 aerial photographs (Figures 2-3c, 2-3d, 2-3e, 2-3f, 2-3g, 2-3h, 2-3i, and 2-3j).

2.3 Environmental Setting

2.3.1 Geographic Setting

The MMR includes Camp Edwards, Otis Air National Guard Base, United States Coast Guard Air Station Cape Cod, Cape Cod Air Force Station, and the Veteran's Affairs Cemetery. It is located on the western side of Cape Cod, Massachusetts. The northern, non-cantonment area, is a wooded area on the Upper Cape that is largely undeveloped, but fringed with highways, homes, and other development (Cape Cod Commission, 1998). The predominant land use surrounding the MMR is residential or commercial development. The MMR is situated adjacent to the towns of Bourne, Sandwich, Falmouth, and Mashpee. The L Range Study Area is located in the southeastern portion of Camp Edwards between Greenway Road and the Impact Area.

2.3.2 Cultural Setting

Land use near the MMR is primarily residential and recreational, and secondarily agricultural and industrial. Portions of the MMR are opened for deer and turkey hunting by permit from the Massachusetts Division of Fisheries and Wildlife. The major agricultural land use near the MMR is the cultivation of cranberries. Commercial and industrial development in the area includes service industries, landscaping, sand and gravel pit operations, and municipal landfills (USACE, 2002).

MMR contains a cantonment area which includes a housing area for 2,000 year-round residents. This area includes a chapel, a golf course, a base exchange, a medical dispensary, and two schools. Several areas of the MMR are used as airfields and other military support facilities. The MMR resident population increases by as much as several thousand people during the summer training activities.

An archaeological survey covering 72 percent of Camp Edwards was conducted in 1987 to assess its archaeological sensitivity. One historic site and 26 prehistoric sites were identified within Camp Edwards. Findings from these surveys indicate that humans inhabited the Camp Edwards area up to 10,000 years ago. No sites are located within the L Range study area.

2.3.3 Ecological Setting

The northern two-thirds of the MMR are characterized as undeveloped open area, while the southern third is characterized as developed land. The dominant vegetation types vary accordingly. The northern portion of the MMR consists of forested uplands dominated by stands of pitch pine and mixed oak species (*Quercus* spp.) with a diverse shrubby understory. Remnant vegetation in the southern portion of the MMR consists of open grassland fields interspersed with scattered trees and shrubs. The present composition of these forests is a reflection of eighteenth-century logging practices, replanting strategies, and fire suppression activities. The other dominant cover type in this area consists of pitch pine and scrub oak barrens that are maintained by periodic fires (USACE, 2002).

There are 39 state-listed species observed on the MMR. About half of these are lepidoptera (i.e., moths), such as Gerhard's underwing moth (*Catocala herodias gerhardi*), the barrens daggermoth (*Acronicta albarufa*), and Melsheimer's sack bearer (*Cicinnus melsheimeri*). State-listed plant species documented on the MMR include broad tinker's weed (*Triosteum perfoliatum*), ovate spikerush (*Eleocaris obtusa var. ovata*), Torrey's beak-sedge (*Rhynchospora torreyana*), and adder's tongue fern (*Ophioglossum pusillum*). Rare bird species on MMR include the upland sandpiper (*Bartramia longicauda*), the grasshopper sparrow (*Ammodramus savannarum*), the vesper sparrow (*Pooecetes gramineus*), and the northern harrier (*Circus cyaneus*). These species are primarily associated with the grassland fields in the southern cantonment area. No threatened or endangered amphibians, reptiles, fish, or mammals are known to inhabit the MMR; however, the MMR does support a number of animals that are listed by the state as species of special concern. These include the eastern box turtle (*Terrapene carolina*), the Cooper's hawk (*Accipiter cooperii*), and the sharp-shinned hawk (*Accipiter striatus*) (USACE, 2002).

2.3.4 Climate

The climate for Barnstable County, where MMR is located, is defined as humid continental. The neighboring Atlantic Ocean has a moderating influence on the temperature extremes of winter and summer. Winds of 30 miles per hour may be expected on an average of at least one day per month. Gale force winds can be common and more severe in winter. Average daily temperatures range from 29.6 ^{o}F in February to 70.4 ^{o}F in July. The yearly average temperature is 49.6 ^{o}F (USDA, 1993).

Mean annual rainfall and snow melt water ranges from 45 to 48 inches per year. Occasional tropical storms that affect Barnstable County may produce 24-hour rainfall events of 5 to 6 inches (NGB 1990). Average snowfall is 24 inches per year (MAARNG 2001).

2.3.5 Geology

The surficial geology of western Cape Cod comprises glacial sediments deposited during the retreat of the Wisconsin stage of Holocene glaciation. Three extensive sedimentary units dominate the regional geology: the Buzzards Bay and Sandwich Moraines, and the Mashpee Pitted Plain. The Buzzards Bay Moraine and the Sandwich

Moraine are located and visible as hummocky ridges along the western and northern boundaries of Camp Edwards, respectively (Figure 2-4). The Buzzards Bay Moraine and Sandwich Moraine are composed of ablation till, which is unsorted material ranging from clay to boulder size that was deposited at the leading edge of two lobes of the Wisconsinian glacier at its furthest advance. The Mashpee Pitted Plain is a broad outwash plain that lies between the two moraines and consists of fine to coarse-grained sands and is underlain by fine-grained glaciolacustrine sediments and a basal till layer over bedrock. The Mashpee Pitted Plain underlies most of MMR, including the L Range Study Area.

2.3.6 Hydrogeology

Surface water is not significantly retained due to the excessively drained sandy soils of Camp Edwards. No large lakes, rivers, or streams exist on the property, only small, marshy wetlands and ponds exist. Most of the wetlands and surface waters in the Sandwich and Buzzards Bay Moraines on Camp Edwards are considered to be perched (MAARNG 2001).

The aquifer system is unconfined (i.e., it is in equilibrium with atmospheric pressure and is recharged by infiltration from precipitation). The sole source of natural fresh water recharge to this groundwater system is rainfall and snow melt-water that averages approximately 48 inches per year. Except on extreme slopes, surface water runoff at Camp Edwards is virtually nonexistent due to the highly permeable nature of the sand and gravel underlying the area. Additional water is returned to the aquifer as wastewater from domestic septic systems. Municipal sewer systems at the MMR and in parts of Falmouth return treated wastewater to the groundwater flow system through infiltration beds at the sewage treatment facilities. Wastewater return flow accounts for approximately 5 percent of the total groundwater recharge in the MMR region (ANG 2001).

The top of the groundwater mound within the western Cape Cod groundwater system is located beneath the ranges on the southeast side of MMR (Figure 2-5). Groundwater flows radially outward: north to either the Cape Cod Canal or the Cape Cod Bay, east to the Bass River, south and southeast to Nantucket Sound, and west and southwest to Buzzards Bay (ANG 2001). The height of the water table in and around the MMR can fluctuate up to seven feet annually due to seasonal variations in groundwater recharge and pumping demand (USGS 1996). Groundwater levels are highest in the spring when recharge rates are high and pumping demand is low; levels are lowest in the late summer/early autumn when rainfall is minimal and pumping demand is at its maximum. The total thickness of the aquifer varies from approximately 80 feet in the south to approximately 350 feet in the north. The variation in thickness is due to the episodes of glacial advance and retreat, the underlying bedrock geology, and the presence of fine-grained materials in the deeper sediments beneath the southern portion of the aquifer (ANG 2001). Within the L Range Study Area, the groundwater elevation is typically between 60 and 70 feet national geodetic vertical datum (ngvd) or approximately 100 feet below ground surface (bgs).

The unconsolidated deposits in the unsaturated zone consist of very coarse sand and gravel associated with topset and foreset sedimentary facies. Unconsolidated deposits within the saturated zone exhibit a coarsening upward sequence (lacustrine, bottomset, foreset, and topset sedimentary facies) consistent with a glacial depositional environment (Masterson et al., 1996). The lithologic material varies from very coarse sand and gravel at the top of the saturated zone to silt and clay at the bottom. The horizontal hydraulic conductivity of these materials is assumed to range from 125 to 350 feet/day based on grain size analysis (Masterson et al., 1996). The average hydraulic conductivity of the coarse outwash deposits, where the L Range plume is situated, is approximately 200 feet per day. A layer of till (< 5 to 20 feet thick) is present on top of bedrock. The hydraulic conductivity of the till is estimated at five ft/day. Bedrock is present at a depth of 280 to 310 feet bgs beneath the L Range and can be considered impermeable. Therefore, the bulk of regional groundwater flow is transmitted though the upper outwash units.

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3.0 SOURCE REMEDIAL INVESTIGATION ACTIVITIES

The L Range investigations, which commenced in March 1999, were conducted in accordance with the following work plans: Final J-1, J-3 and L Range Workplan [JLWP] (Ogden, 2000a), the Final J-1, J-3 and L Ranges Additional Delineation Workplan No. 1 [ADWP1] (AMEC 2001e), the Final J-1, J-3 and L Ranges Additional Delineation Workplan No. 2 [ADWP2] (AMEC 2002a), the Revised L Range Supplemental Soil Work Plan [LSWP] (AMEC 2003), and the L Range Post-AFRL MEC Clearance Confirmation Soil Sampling Approach, Camp Edwards, MA (ECC 2008a).

Results were reported in the *Final J-1, J-3 and L Ranges Interim Results Report, TM 01-9* [J13L Interim Report No. 1 (AMEC 2001f)]. This report includes analytical data collected from the beginning of the L Range investigation through 02 March 2001. The *Draft J-1, J-3 and L Ranges Interim Results Report No. 2, TM 01-16* [J13L Interim Report No. 2]. This report includes analytical data collected from the beginning of the L Range Investigation in August 2000 through 27 July 2001 (AMEC 2001d); and the *Draft J-1, J-3, and L Ranges Additional Delineation Report No. 1 [ADR1]*. This report presents analytical results from the beginning of the L Range investigation in August 2000 through 14 April 2002 (AMEC 2002c). A *Draft Soil Characterization Report* was previously prepared and submitted to the regulatory agencies on December 2005. A *Final Human Health Risk Assessment* was also submitted in May 2008.

In 2008, subsequent to previous soil investigations of the range, a technology demonstration was conducted to evaluate the effectiveness of using remotely operated equipment to remove potential sources of groundwater contamination related to munitions. This technology demonstration was conducted by the Air Force Research Laboratory. Following the technology demonstration, soil sampling was conducted in the range floor and an EM-61 ground-based geophysical survey and an all-metals detection-aided reconnaissance and intrusive investigation were conducted to assess the effectiveness of the clearance activity. Details of the soil sample collection conducted after completion of the remote clearance are presented in Section 3.4.

3.1 Geophysics

An airborne magnetometer (AIRMAG) survey of the Southeast Ranges was conducted in 2000. Multiple techniques were used to identify AIRMAG anomalies. Many of the anomalies were determined to be cultural items, (caused by artificial, permanent features, such as power lines, fences, structures, flagpoles, road barriers, targets, debris, or other ferrous items.

A second AIRMAG survey of the Southeast Ranges Area was conducted in 2001. The L Range AIRMAG results are presented in Figure 3-1. This figure shows significant interference from the L Range perimeter fence. A field reconnaissance conducted in the fall of 2001 included visual examination of surface features in the location of 439 anomaly clusters located along the perimeter fence. Figure 3-1 also indicates the presence of several anomalies located approximately in the center of the L Range. These anomalies appear to coincide with targets that were also identified on aerial photographs.

All-metals detectors were used extensively to examine areas of the ground surface outside the perimeter fence where previous AIRMAG anomalies had been identified. The all-metal detectors are capable of detecting aluminum, which is the primary component of the 40mm casing. This technique was used to examine a series of cultural features proposed for further study in the revised Final L Range Supplemental Soil Workplan (AMEC 2003). The cultural features investigated in April 2005 are listed on Table 3-1 along with descriptions of the feature, the investigative action taken to identify any hazards that might be posed by the feature and the results of that investigation. As indicated on the table, all seven of the cultural features were identified as non-UXO related debris or remnants of structures.

3.2 Soil Sampling

During the period from March 1999 to April 2005, 473 soil samples were collected from 60 locations within the L Range Study Area, including: 4 locations at the L Range Firing Points (multiple depths and analytical suites); 27 locations at the L Range Targets (multiple depths and analytical suites); 10 locations at Cleared Area 11 (multiple depths and analytical suites); 19 locations at Area 46 (multiple depths and analytical suites) and 3 locations at Area 79 (multiple depths and analytical suites). The number, type, and locations of all samples collected are summarized in Table 3-2.

L Range Firing Points: Eight firing points, used since the 1970s, are located on the L Range. Composite and discrete soil samples were collected from four grids (103AA-103AD) centered on four of the eight firing points. Grid locations were centered on every other firing point in a line from west to east (Figure 2-2a). The results from the four sampled firing points are assumed to be representative of all eight firing points. A summary of the samples collected is presented in Table 3-2. The objectives of the samples collected at these locations was to determine whether activities conducted at the L Range Firing Points resulted in a release of propellant compounds to surface soil.

L Range Targets: Multiple targets were located at various distances across the L Range. Based on a review of aerial photographs and a photograph of a schematic diagram of current targets (USACE 1999a, Appendix J, Photograph J-50), it appears that ten targets were present on the range at the time the investigation was initiated (these targets were removed from the range floor during the 2008 robotics technology demonstration). Sample locations were selected assuming that the existing targets were those used historically at the L Range.

Samples were collected from seven ring grids (103BA -103BF, 103BH) centered on seven targets. Three additional ring grids (103BG, 103BI, and 103BJ) were located at an eighth target location. This eighth target is believed to be a cluster of three items and the three ring grids were centered on each of these items. The ring grids consisted of eight evenly distributed nodes which were established five feet out from the corners of each of the ten targets. A composite sample at each ring grid was comprised of soil collected from all nodes from that ring grid (i.e. all nodes are located approximately equal radial distance from the center of the grid). Discrete samples were also collected at Nodes 1, 3, 5, and 7. Samples were collected at three depth intervals: 0-0.25 feet, 0.25-0.5 feet, and 0.5-1.0 feet at each sampling point.

The targets selected for sampling were those in the center of the range and closest to the firing points under the assumption that these were the most highly used target locations. Samples were also collected from deeper intervals at sample locations 103BB, 103BC, 103BD, and 103BG, and also expanded the spatial coverage at sample locations 103BB, 103BC, 103BD, 103BG, 103BE and 103BF.

Composite and discrete samples were collected from the 1.5-2.0 feet interval at grids around four targets and from an outer ring grid established at a 15 foot radius around six targets. The outer ring grids were sampled at two depth intervals (0-0.25, 0.25-0.5 feet) at two targets and at four depth intervals (0-0.25 feet; 0.25-0.5 feet, 0.5-1.0 feet and 1.5-2.0 feet) at four targets.

Samples were also collected from five previously sampled soil grid locations, and submitted for perchlorate analysis to supplement the existing analytical results. Three optional samples focused in an area of 250-foot radius situated around existing location 103BK were also sampled based on field observations as defined in the L Range Supplemental Soil Work Plan. These samples were collected using the MMR standard five-point composite grid methodology with the final node of the sample grid selected from a location determined using an all-metals detector. Each sample was a five-point composite sample with three depth intervals, 0-0.25 feet, 0.25-0.5 feet, and 0.5-1.0 feet.

The locations of all samples collected pursuant to the L Range Supplemental Soil Work Plan are presented graphically in Figure 2-2b and summarized in Table 3-2.

Area 46: In order to identify potential sources of groundwater contamination observed in well 90WT0013, soil samples were collected from four soil grid locations (46A through 46D) spaced throughout Area 46 (Figure 2-2c). These four soil sample grids were placed in the immediate vicinity of well 90WT0013 in order to evaluate the potential for a local source of the RDX and DNT contamination observed in this water table well. One soil grid (46A) was centered on well 90WT0013 and the other three were located generally upgradient of the well. In order to complete the delineation of elevated concentrations of polyaromatic hydrocarbons (PAHs) and dieldrin observed at some of the initial sample locations, additional soil samples were collected from six new soil grids and from deeper intervals at two previously sampled soil grids. A summary of the samples collected is presented in Table 3-2.

CA-11: Camp Edwards' archives and historical records provided no indication that CA-11 was used for military purposes. The lack of background information suggested that the most representative soil samples would be obtained using a random sample location survey design for this area. Thus, five randomly chosen composite soil grid locations were selected (103CA through 103CE, Figure 2-2d). CA-11 is most clearly visible in the 1977 aerial photograph (Figure 2-3d). Locations 103CB, 103CD, and 103CE are within the center of CA-11, location 103CA is located in the northern portion of CA-11, and grid sample 103CC is located along the western boundary of CA-11. The objectives of the samples collected at these locations was to determine whether activities conducted at Cleared Area 11 resulted in a release of contaminants to surface soil.

Area 79: During the Gun and Mortar Position Investigation, soil samples were collected from eight grid locations (79J through 79Q) in Area 79 (Figures 1-2d and 1-2e). These samples locations were selected based on the 1943 aerial photograph (Figure 1-3a), and are included in this evaluation due to their close proximity to Area 46 and Cleared Area 11.

3.3 Robotics Technology Demonstration and Post Demonstration Source Investigation

In 2008, a technology demonstration was performed by the Air Force Research Laboratory at L Range (Appendix B, Figure 2-3). The objective of the demonstration was to evaluate the effectiveness of using remotely operated equipment to remove potential UXO. Since L Range was a known direct fire testing range for the M79 and M203 grenade launchers, 40mm grenades were considered to be the predominate munition likely to be found at this range. It is not expected that 40mm grenades would penetrate deeper than six inches due to the size and characteristics of the munition and the grenade launcher. An additional goal of the demonstration was to assist in determining munitions distribution at L-Range. The project demonstrated a combination of robotic equipment and remotely controlled construction equipment.

The technology demonstration included vegetation clearance using a remotely operated brush cutter, removal of remaining range targets, an EM-61MK2 baseline geophysical survey towed by an Advanced Mobility Research and Development system (AMRADS), munitions clearance (using remote controlled equipment), and an EM-61 MK2 confirmation geophysical survey towed again by the AMRADS. The baseline geophysical survey indicated significant metallic response with heavy concentrations of anomalies within former target areas.

A variety of equipment (including a surface rake, a power rake and a rotary tiller) attached to an All Purpose Remote Transport System (ARTS) was used to loosen the top layer of soil and root matter. Material removed during soil loosening was staged along the edges of the range floor. After the soil was loosened, an ARTS-mounted screener with blade (barber rake) was hydraulically driven into the loosened, top six inches of soil. The soil was then conveyed up onto the screen deck where material less than one inch in diameter fell back to the range floor and the material greater than one inch in diameter (including 40mm grenades) was collected into a hopper. Material collected by the screener was staged along the opposite edge of the range from where the stockpiles accumulated during soil loosening were staged. The staged material on each edge of the range was then manually inspected and all recovered munitions and scrap items were removed. The approximate location of individual items recovered was documented with respect to the specific search area from which they were recovered. Cross-range lanes of 50-foot width were created for documenting of recovered items, with each 50-foot lane consisting of multiple clearance swaths. All recovered items were weighed, and the number of pounds recovered from the 50-foot lanes was recorded (Appendix B, Figure 2-3 and Table 2).

After completion of the technologies demonstration, including an EM-61 confirmation survey, soil samples were collected. The L Range floor was divided into three areas: an up-range area, a mid-range area, and a down-range area. The areas are depicted on Figure 3-2 and a description of these three areas is as follows:

Up-range area: This area encompasses the portion of the range between the firing points and the majority of the former targets. This portion of the range was divided into three decision units. One 100-point multi-increment sample was collected from each decision unit, with two replicates from the middle decision unit.

Mid-range area: This area includes the majority of the former target locations. In addition, the majority of the explosive items and a large portion of the scrap removed from the range were discovered in this portion of the range. This area was divided into 12 decision units. One 100-point multi-increment sample was collected from each decision unit, with two replicates collected in four of the decisions units. In addition, three over-lapping decision units were created using an 80-foot radius centered around the location of former targets 103BM, 103BF, and 103BD. One 100-point multi-increment sample was collected from each decision unit.

Down-range area: This area includes the three furthest down range former targets. This portion of the down-range range was divided into five decision units. One 100-point multi-increment sample was collected from four of the five decision units, with two replicates from one of the decision units. A 200-point multi-increment sample and two replicates were collected from the fifth decision unit.

The decisions units, along with replicate locations, are shown on Figure 3-2. The number type and locations of all samples collected are summarized in Table 3-3. All samples were collected in accordance with Engineer Research and Development Center/Cold Regions Research and Engineering Laboratory (ERDC/CRREL) TR-07-10 from a depth of 0- to 0.25-feet bgs. In addition, all samples were processed and analyzed for explosives. Ten decision units were later analyzed for zinc and lead (Table 3-3).

The L Range floor sample results were then used to develop an initial remediation strategy. This initial remediation strategy involved a bench scale study for which grid SSLRMR05 was selected as the source for the contaminated soil. During April 2009, a total of 15 baseline multi-increment samples (including replicates) were collected from study bins containing soil originating from grid SSLRMR05. All samples were submitted for explosives compounds analyses by method SW846/8330B to include MNX, DNX, and TNX.

To determine current site conditions and more accurately define the amount of explosives heterogeneity at the site, all 12 mid-range decision units were re-sampled along with a new decision unit at the L Range firing point berm (Figures 3-2 and 4-3). In addition, three decision units (MR02, MR04 and MR05) were subdivided into four quadrants and one, 50-point, multi-increment sample was collected from each quadrant to evaluate the heterogeneity in contaminant distribution within the selected decision units. All samples were collected in accordance with ERDC/CRREL TR-07-10 from a depth of 0- to 3-inches below ground surface and were processed and analyzed for explosives by method SW/846/8330B to include MNX, DNX, and TNX. Elevated concentration of explosives were identified in the mid-range decision units as further discussed in Section 4.1.2, and were excavated and treated on-site.

After the robotics work, the confirmation survey data indicated an overall reduction in elevated responses across the entire survey area. However, former target areas still showed some geophysical responses. Additional intrusive investigations were conducted at 16 anomalies located in both the up-range and mid-range portions of the range. No UXO items were found during the investigation of these anomalies. Additionally, two intersecting trenches (one foot deep) were excavated in the mid-range area to determine the quantity and nature of metallic residuals. These trench locations were selected in areas of elevated residual geophysical responses. The base of each trench, as well as the materials removed during the excavation, were then investigated with all-metals detectors. No anomalies were detected in the base of either trench, and no UXO were recovered from the excavated materials

An additional five trenches, were excavated (0.5 feet deep) in the down-range area. One of these trenches was located in an area outside the footprint of the technology demonstration. Munitions debris was primarily recovered from these trenches. However, two 40mm smoke rounds with possible live fuzes were recovered from trench #5, located in the center of the down-range area. No anomalies were detected beneath the base of any of the trenches except for trench #5, where two items (one of the two 40mm smoke rounds mentioned above and one inert rocket) visible in the trench bottom, were recovered. The trench investigations support the assumption that 40mm grenades would generally not penetrate deeper than six inches due to the size and characteristics of the munition and the grenade launcher. Only one 40mm smoke grenade was discovered in Trench 5 at a depth greater than six inches below ground surface (bgs) (eight inches bgs).

In order to evaluate areas outside of the range floor that were not addressed during the AFRL technology demonstration, a detailed reconnaissance survey, using all metals detectors, was conducted along a meandering path. No UXO items were found during the meandering path survey. In addition to the meandering path survey/investigation, a representative section of the southern range floor boundary berm was excavated down to the elevation of the range floor. This was done to determine the presence of any items located within the body of the berms. The excavated soils were subsequently investigated by UXO personnel and no UXO items were found during the investigation. These findings are consistent with conceptual site model presented in Appendix B and suggest that the quantity of UXO present outside the range floor is likely to be minimal.

Oversize material, removed from the soil during the mechanical screening of excavated soil (i.e. “overs”), are currently stockpiled in Grid MR-07. These “overs” will be inspected by UXO technicians. After inspecting approximately half of the overs, UXO Technicians recovered six M406 40mm HE, 13 M407 40mm practice with suspect fuze, nine 40mm M713/M715/M716 Smoke, and three M551 fuzes. After the “overs” are removed from grid MR-07, UXO technicians will perform a subsurface clearance of the grid. UXO technician also performed a subsurface clearance of grid MR-02 to support on-site soil treatment activities. There were no HE items identified in this grid; however, one smoke grenade with a suspected live fuze was discovered. Table 2 in Appendix B indicates items found.

Based on the numerous geophysical investigations and robotics demonstrations the Munitions Source Assessment (Appendix B) concluded that the excavation of contaminated soils in the mid range area and the removal of all magnetic anomalies in the range floor reduced the probability of UXO remaining in the target areas. Intrusive investigations outside the range floor (berm excavation and meandering path) found no UXO. Thus, although an occasional stray round may have resulted in a UXO, it is unlikely there are a significant number of UXO outside the range floor.

3.4 Soil Removal

Soil from the 10 mid-range decision units (Figure 3-3) with explosives detections was excavated to a depth of six-inches below ground surface. (Please note: target samples SS103BF and SS103BD fall within the footprint of the decision units excavated). Excavation activities were conducted in September 2009 and October 2009.

Approximately 2,700 cubic yards of explosives-contaminated soil was excavated. Post-excavation, 100-pt multi-increment soil samples were collected in each of the 10 decision units from 0- to 3-inches below the excavation floor. All samples were processed in accordance with ERDC/CRREL TR-07-10 and analyzed for explosives by method SW 846/8330B. One set of replicate samples (three total samples) was collected from the decision unit identified as SSLRMR04. Results from post-excavation sampling indicated no detections of explosives or perchlorate.

All excavated soils were mechanically screened to one inch to remove any remaining munitions. The excavated soils were treated beginning in November 2009. The soils were treated using alkaline hydrolysis, which involved raising the pH of the soil by blending it with water and hydrolyzed lime to mineralize the explosive compounds to more elemental compounds of inorganic nitrogen and carbon dioxide. After blending, the soils were staged in a lined treatment cell. After treatment the soils were sampled to determine the effectiveness of treatment. No explosives compounds were detected in the samples from the treated soils. The soils will be removed from the treatment cell in April 2010 and placed back on the range. Details of the L Range soil treatment are provided in Final Interim L Range Source Remediation Report, dated 23 April 2010. The total costs for the soil excavation, screening, sampling and treatment is expected to be approximately $1.5M.

A completion of work report detailing all excavation, confirmatory sampling and soil treatment activities will be prepared after soil treatment is complete.

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4.0 NATURE AND EXTENT OF SOIL CONTAMINATION

The objectives of the soil sampling activities were to identify and characterize any potential soil contamination associated with past range activities. The sampling methodology was designed to achieve these objectives by focusing sampling efforts based on range use, historical records, witness interviews, and historical aerial photo assessment. In addition, more extensive sampling of the range floor was conducted after completion of the robotics technology demonstration cleared the range.

The number, type, and locations of all samples collected are summarized in Table 4-1 (pre-robotics soil samples) and Table 4-2 (multi-increment soil samples). The analytical results for all samples are summarized in Tables, Appendices, and graphical depictions as follows:

- Table 4-1 - Summary statistics for all pre-robotics samples (including L Range, CA-11, Area 46, and Area 79).
- Table 4-2 – Summary statistics for November 2008 post-robotics multi-increment soil samples.
- Figures 4-1 and 4-2 – Graphical depictions of spatial distribution of detections.
- Figure 4-3 – Graphical depiction of spatial distribution of explosives and perchlorate detections in post-robotics multi-increment soil sample.
- Appendix A (compact disk [CD] only) – Analytical data (complete analytical database).

The summary statistics presented in Tables 4-1 and 4-2 illustrate key information for the analytical data collected in the L Range Study Area as a whole. It addresses each analyte separately, but groups them each analyte into analytical suites of related substances. The statistics are intended to aid in understanding the overall character of analytes detected at the study area. The table specifies each analytes maximum concentration and highlights key items such as frequency of detection (FOD) and the location of the maximum detections.

4.1 Explosives and Perchlorate Summary

Table 4-1 presents pre-robotics summary statistics for all analytes at the L Range Study Area (including L Range Targets and Firing Points, plus CA-11, Area 46, and a few samples previously collected pursuant to Gun and Mortar investigations at the former H Range (Area 79).

Figures 4-1 to 4-2 present all L Range pre-robotics soil samples that contained detectable concentrations of explosives and perchlorate. Table 4-2 and Figure 4-3 summarize the soil sample results from the November 2008 post-robotics, multi-increment samples, which were analyzed for explosives and perchlorate. The May 2009 post-robotics sampling results are presented in Figure 4-3. Figure 4-3 presents a summary of all post-robotics, multi-increment soil results that contained detectable concentrations of explosives and perchlorate.

4.1.1 Pre-Robotics Explosives and Perchlorate

The pre-robotics soil sample results for explosives and perchlorate indicate limited detections of tetryl and nitroglycerine. Tetryl was detected in one soil sample from the targets area of the L Range at 2,100 µg/Kg. The sample containing this analyte (HD103B17CAA) is bounded on all sides by samples where this compound was not detected. Likewise the two detections of nitroglycerin at Area 46 (HD46B2AAA - maximum concentration of 4,700 µg/Kg) were from the same sample location (two sample depths (0.25-feet bgs and 0.25- to 0.50-feet bgs) and are bounded in all directions by clean sample locations.

There were no detections of explosives or perchlorate in the samples collected from the Firing Points or CA-11.

4.1.2 Post-Robotics Explosives and Perchlorate

Six explosive compounds were detected in soil collected during the November 2008 post-robotics, multi-increment soil sampling event, including: RDX, HMX, TNT, 2,4-DNT, 2A-DNT, and 4A-DNT. All of the detected concentrations of these contaminants were located in the mid-range portion of L Range, particularly in the decision units located in the vicinity of Targets 103BE, 103BF, and 103BD (Figure 4-3). The maximum concentration of RDX in soil was 92,000 µg/Kg, which was collected from sample location SSLRMR05. The maximum concentration of HMX detected in soil was 9,700 µg/Kg, which was collected from sample location SSLRMR05.

Concentrations of 2A-DNT and 4A-DNT were found in four soil grids in the mid-range area of L Range. The maximum concentrations of 2A-DNT and 4A-DNT were 1,200 µg/Kg and 2,300 µg/Kg, respectively.

Concentrations of TNT were found in 11 decision units (including two targets) in the mid-range area of L Range. The maximum concentration of TNT detected in soil was 450,000 µg/Kg, collected from sample location SSLRMR01.

In addition to the explosives compounds, perchlorate was detected in soil collected from the post-robotics, multi-increment soil sampling event. The soil sample with the highest perchlorate concentration (10.2 µg/Kg) was collected from sample location SS103BD.

The May 2009 soil sample results confirmed the presence of explosives compounds in the mid-range area. However, explosives were detected at much lower concentrations than from the November 2008 sampling event (Figure 4-3). RDX was only detected in five decision units, with the maximum detected concentration of RDX of 7,300 µg/Kg (SSLRMR04). HMX was detected in only two decision units with a maximum concentration of 670 µg/Kg (SSLRMR10 and SSLRMR04). Detectable concentrations of TNT were only identified in five decision units with a maximum of 3,300 µg/Kg

(SSLRMR10). Contaminated soil from ten decision units (SSLRM01, SSLRM03, SSLRM04, SSLRM05, SSLRM06, and SSLRM08 through SSLRM12) (Figure 4-3) was excavated for treatment due to elevated concentrations.

4.2 Massachusetts Extractable Petroleum Hydrocarbons (MA EPH) and Semi-Volatile Organic Compound (SVOC) Summary

Table 4-1 summarizes the overall occurrence of MA EPH and SVOC compounds detected in pre-robotics soils collected from the L Range Study Area.

Seventeen MA EPH compounds were detected in pre-robotics soils. The highest MA EPH concentrations are located in Area 46, near the intersection of Greenway Road and the cleared area where the former FS-12 treatment facility was located. The detected concentrations are spatially discontinuous and were detected only in shallow soil samples (< 1' bgs). Refer to Table 4-1 for the locations of the maximum detections.

PAHs are common combustion byproducts and are also present in asphalt. The presence of PAHs in primarily shallow soil samples may be due to the close proximity of these Area 46 locations to the roadway.

Thirteen SVOC compounds were detected in pre-robotics soils. The highest detections of SVOC compounds in soil were generally collected from L Range proper and Area 46.

Based on the pre-robotics MA EPH and SVOC soil sample results, MA EPH and SVOCs analyses were not performed for the post-robotics, multi-increment soil samples.

The analytical laboratory reports tentatively identified compounds (TICs) when a peak is present in the gas chromatographic/mass spectrophotometer (GC/MS) analysis that is not identified as a target analyte in the SVOC analysis. No TICs were identified in any of the soil samples submitted for SVOC analyses.

4.3 Pesticides/PCBs Summary

Table 4-1 summarizes the overall occurrence of pesticides and PCB compounds detected in pre-robotics soils collected from the L Range Study Area.

Fourteen of 29 pesticide compounds analyzed were detected in L Range Study Area samples. Dieldrin was the only pesticide to be detected at elevated concentrations in a spatially contiguous distribution in predominantly shallow soils (i.e. depths less than one-foot bgs) in the Firing Points and Areas 46 and 79. No PCB compounds were detected in pre-robotics soils collected from the L Range Study Area.

Pesticide compound detections in shallow soil are indicative of surface deposition and application of pesticides. Pesticide applications in the vicinity of roadways and structures were a common practice at the MMR and similar concentrations and distribution of pesticides are routinely detected in soil at other locations at the MMR.

Based on the pre-robotics Pesticides/PCBs soil sample results, Pesticides/PCB analyses were not performed for the post-robotics multi-increment soil samples.

4.4 Herbicides Summary

Table 4-1 summarizes the overall occurrence of herbicide compounds detected in pre-robotics soils collected from the L Range Study Area.

Ten herbicides were detected in pre-robotics samples of soil from L Range. The analyses for herbicides MCPP and MCPA prior to 2001 have been shown to be affected by interferences that have led to tentative identifications and estimated quantifications of these compounds (AMEC 2002a). In 2001, modifications were made to the herbicide analytical method to minimize interferences (AMEC 2002a). Since 2001, neither MCPP nor MCPA has been detected at concentrations above the laboratory reporting limit in any soil samples collected from the L Range Site. The MCPP and MCPA were detected in L Range soils in 1999 and 2000, thus the results shown on Table 4-1 are attributed to interferences.

Based on the pre-robotics herbicides soil sample results, herbicides analyses were not performed for the post-robotics multi-increment soil samples.

4.5 Volatile Organic Compound (VOC) Summary

Table 4-1 summarizes the overall occurrence of VOC compounds detected in pre-robotics soils collected from the L Range Study Area.

Eleven of 44 volatile organic compounds analyzed (VOCs) were detected in at least one soil sample from the L Range Study Area. VOCs were primarily detected in soil collected from L Range proper and Area 46. With the exception of acetone, no VOC maximum concentration exceeded 20 µg/Kg in any sample. Acetone is considered a common laboratory contaminant (USEPA 1989). Furthermore, as indicated in a detailed letter from AMEC (AMEC 2001), the presence of acetone is attributed to cross-contamination that may occur in either the laboratory or the field. Acetone would not persist in soil due to its high volatilization rate. The analytical laboratory reports tentatively identified compounds (TICs) when a peak is present in the gas chromatographic/mass spectrophotometer (GC/MS) analysis that is not identified as a target analyte in either the VOC or SVOC analysis. No TICs were identified in any of the soil samples submitted for VOC or SVOC analyses.

Based on the pre-robotics soil sampling results, no VOC analyses were performed for the post-robotics multi-increment soil samples.

4.6 Metals/Inorganics Summary

Table 4-1 summarizes the overall occurrence of metals/inorganics detected in pre-robotics soils collected from the L Range Study Area.

Concentrations of 26 of the 27 metals analyzed at L Range were detected in at least one soil sample. Cyanide was not detected. The highest concentrations of metals detections were collected from L Range target areas. The average metals concentrations are either below or similar to background concentrations and are further discussed in Section 7. Refer to Table 4-1 for the location of the maximum detections.

As discussed in Section 3.3, ten decision units sampled during the November 2008 MIS sampling event were later analyzed for lead and zinc in March 2009. Lead results ranged from 17.9 mg/Kg to 59.4 mg/Kg, and zinc concentrations ranged from 31.3 to 82.1 mg/Kg.

Based on the pre-robotics Metals/Inorganics soil sample results and the results of a risk assessment which identified no COCs in soil that pose a risk, metals/inorganics analyses were not performed for the post-robotics multi-increment soil samples

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5.0 GROUNDWATER CHARACTERIZATION SUMMARY

This section summarizes the *Final L Range Groundwater Characterization Report* (ECC 2005) and discusses groundwater data collected after the characterization report was completed. Table 5-1 includes data collected from 2004 to 2009.

5.1 2005 Groundwater Characterization

The *Final L Range Groundwater Characterization Report* (ECC 2005) analyzed data available through July 31, 2004. Results of this evaluation are summarized below and tabulated in Table 5-1. Groundwater data collected after the data cut-off for this RI/FS is also presented in Table 5-1.

Groundwater in the L Range study area generally flows horizontally to the south-southeast at approximately one foot/day in an unconfined sandy aquifer comprised of glacial outwash deposits. Groundwater flow is influenced locally by discontinuous fine-grained units, hydraulic gradients, and proximity to the top of the groundwater mound. Snake Pond and the groundwater extraction, treatment and reinjection (ETR) system for the Fuel Spill-12 (FS-12) plume also influence groundwater flow.

The primary contaminants in the L Range groundwater study area were low levels of perchlorate and RDX. The perchlorate and RDX contamination was characterized as diffuse and occurred as isolated and noncontiguous zones or lobes detached from upgradient source areas. The groundwater data indicated that the magnitude of contaminant concentrations was very low, and did not identify definitive source areas for the groundwater contamination in the L Range. The maximum perchlorate detection observed in any monitoring well sample was approximately 3 micrograms per liter (µg/L) [Massachusetts Maximum Contaminant Level (MMCL) for perchlorate is 2 µg/L], with the majority of detections less than 1 µg/L in both drilling profile samples and monitoring well samples. The maximum RDX detection observed in monitoring well samples was 9.2 µg/L, with the majority of detections less than the EPA Lifetime health advisory (HA) of 2 µg/L in both drilling profile and monitoring well samples. Octahydro-1,3,5,7-tetranitro-1,3,5,7-tetrazocine (HMX), another explosives contaminant related to site activities, was detected in two wells at concentrations less than 1 µg/L. Low concentrations of inorganic compounds, SVOCs, VOCs, and metals were detected in a few wells, but are likely related to the weathering of fuels associated with the neighboring FS-12 fuel spill or represent sampling artifacts, laboratory contamination, or naturally-occurring elements.

Although in some instances the perchlorate and RDX contaminant lobes were co-located within the same geographical areas, they did not appear to have common sources. The perchlorate detects were more widespread than the RDX detects, located primarily in six lobes of contamination (Figure 5-1). RDX detects were located primarily in three lobes of contamination. The total mass of RDX with concentrations greater than 0.6 µg/L in the L Range plume was approximately 0.2 kilograms (Kg), and the total mass of perchlorate with concentrations greater than 0.35 µg/L in the L Range plume was approximately 0.09 Kg.

The results of regularly sampled monitoring wells indicated that concentrations of perchlorate and RDX in the L Range study area either remained the same or were decreasing with time. The spatial and temporal distribution of perchlorate and RDX concentrations indicated a very stable and attenuating plume. The varying distance and depth of the lobes of contamination relative to the L Range footprint and the lack of spatial correlation between the two primary contaminants suggested that there were either multiple source areas, multiple release events, differences in the chemical-specific subsurface migration and attenuation rates, or (very likely) all of the above. The data did not suggest a continuing source.

The fate and transport modeling indicated the RDX contamination would migrate south in the direction of the northernmost FS-12 extraction wells. The modeling suggested that perchlorate would not migrate (at detectable concentrations) significantly beyond its current location in the aquifer. The model predicted that, in the unlikely event that the FS-12 system was to operate under its current conditions for the next twenty years, extremely low concentrations of RDX may be captured by the northernmost extraction wells in the FS-12 wellfield. Due to the conservatism in the plume shell, the lack of RDX degradation simulated in the model, the extremely low concentrations observed in the plume and observed decreases in contaminant concentrations, the report concluded that it is extremely unlikely that RDX from the L Range area will ever reach even the northernmost FS-12 extraction wells.

5.2 Recent Groundwater Data

Since 2004, L Range monitoring wells have been sampled as part of the LTGM Plan (AMEC 2005) and the *Final L Range Interim Groundwater Monitoring Plan* (ECC 2006). From July 2004 to May 2007, 340 samples were collected from 70 wells and analyzed for perchlorate and/or explosives. The recent perchlorate and RDX results are summarized in Table 5-1.

Based on the recent data, the mapable groundwater contamination in the L Range currently consists of two RDX lobes and four perchlorate lobes (Figure 5-2), compared to the three RDX lobes and six perchlorate lobes previously identified in the L Range groundwater characterization report (ECC 2005) (Figure 5-1). Perchlorate and RDX concentrations have decreased or remained the same in almost all of the monitoring wells (Figure 5-3). By May 2007, the maximum RDX concentration had decreased to 3.6 µg/L (MW-153M1, April 2007, the RDX HA is 2 µg/L) and the maximum perchlorate concentration had decreased to 1.9 µg/L (MW-153M2, April 2007, the MMCL for perchlorate is 2 µg/L). In numerous areas, concentrations have decreased below the detection limit or continue to remain below the detection limit. The current depiction of L Range groundwater contamination is based on both current data and the projected downgradient migration of historic data.

The plan view and cross sections have been updated from the *L Range Groundwater Characterization Report* (ECC 2005) to depict the more recent (July 2004 to May 2007) Distribution of RDX in the aquifer (Figures 5-4 through 5-10). As of May 2007 there were two locations where RDX was detected: MW-153M1 (3.6 µg/L, April 2007) and MW-325M1 (0.28 µg/L, May 2007) (Figures 5-4 through 5-10). These two detections form the RDX Lobe 2 (Figure 6-2). The RDX Lobe 3 has not been detected at MW-140M1 and 90MW0034 for eleven sampling events conducted from 2003 to 2007; thus the lobe is no longer depicted. The RDX Lobe 1 has not been detected at MW-239 since the location was drilled in 2004, but the depiction of the lobe was retained because: 1) RDX was detected during borewater screening (maximum of 3.7 µg/L) at this location, 2) the lack of downgradient well coverage, and 3) the presence of low-hydraulic-conductivity units at MW-239 that may slow the natural attenuation of RDX.

The perchlorate plan view and cross sections have also been updated to depict the more recent (July 2004 to May 2007) detections (Figure 5-11 through 5-17).

The perchlorate Lobe 1 has not been detected at MW-128S for nine sampling events, conducted from 2003 to 2007, and has not been detected in downgradient monitoring wells; thus, the lobe is no longer depicted.

Perchlorate Lobe 2 is not depicted because perchlorate has not been detected at 90MW0013 over two sampling events conducted in 2006 and 2007. Perchlorate Lobe 6 was eliminated because perchlorate has not been detected at MW-290M1 and M2 over the last five and four sampling events, respectively, between 2004 and 2007. The low-level concentrations detected during drilling were never confirmed during monitoring well sampling, suggesting a probable diffuse zone of contamination that has naturally attenuated.

Perchlorate Lobe 3 is now depicted as two lobes of isolated perchlorate contamination. One of the new lobes is based on previous detections at MW-288 that have migrated downgradient. The other Lobe is based on previous detections at MW239 and 90MW0038 that have migrated downgradient. Perchlorate Lobe 5 was not detected at MW-241 in 2006 and 2007, but the depiction of the lobe was retained because it is possible the perchlorate could be downgradient of MW-241, but upgradient of MW-140. Perchlorate Lobe 4 is defined solely by detectable concentrations of perchlorate detected at MW-153.

Contaminant trends at selected wells are presented in Figure 5-3. A select series of wells that had RDX and/or perchlorate detections were subjected to a linear regression. There are only three wells with significant perchlorate trends. Significant decreasing perchlorate trends were observed at MW-239M3 (R^2 = 0.56) with perchlorate concentrations decreasing from 0.7 µg/L to nondetect, and at MW-288M1 (R^2 = 0.83) with perchlorate concentrations from 1.17 µg/L to nondetect. There is an increasing trend at MW-153M2 (R^2 = 0.92) with perchlorate concentrations increasing from nondetect to 1.9 µg/L.

There are significant decreasing RDX trends in four monitoring wells (MW-147M1, M2, MW-153M1, MW-288M2, and MW-325M1), all of which are within the RDX Lobe 2. RDX concentrations at MW-147M1 decreased from 3.2 µg/L to nondetect, RDX at MW-147M2 decreased from 4.1 µg/L to nondetect, RDX at MW-153M1 decreased from 8.3 to 3.6 µg/L, RDX at MW-288M2 decreased from 0.86 µg/L to nondetect, and RDX at

MW-325M1 decreased from 0.81 to 0.28 µg/L. The RDX HA is 2 µg/L). There are no significant increasing RDX trends.

Other explosives detected include HMX, 2,4-DNT, and 2,6-DNT. None of the detections exceeded regulatory levels (i.e. MCLs, MMCLs, HAs, GW-1 Standards, or EPA screening levels for tap water).

Groundwater data collected after the data cut-off for this RI/FS include 50 samples from 27 monitoring wells for explosives analyses and 56 samples from 28 wells for perchlorate analysis. RDX was detected in only three wells during this period which is generally consistent with model predictions of plume behavior. The increases over historic trends in RDX concentrations observed at 90MW0031 and MW-242M1 (0.28 µg/L and 1.3 µg/L, respectively) were lower than predicted in the model and reflect a predicted slight downgradient advancement of the attenuating RDX lobe 2. No other explosives compounds were detected in L Range groundwater during this period. Perchlorate was detected in seven wells during this period with all detections below 1 µg/L, including first time detections at MW-242M3 and MW-246M2 (0.26 µg/L and 0.36 µg/L, respectively).

Overall, the most recent data supports the understanding of the L Range groundwater contamination as diffuse areas of perchlorate and RDX contamination that occur as isolated and noncontiguous zones or lobes detached from upgradient source areas.

6.0 CONCEPTUAL SITE MODEL

The conceptual site model is a depiction of site conditions that relate to contaminant source, environmental pathways for the contaminants, and potential contact of contaminants with human receptors.

6.1 Source

L range is a direct fire range where 40mm rifle grenades were aimed and fired at visible targets located at various distances down range. Therefore, residues and environmental impacts associated with this activity are expected to be greatest in the target areas. Explosives and perchlorate contamination were originally detected in groundwater downgradient from L Range starting in 1998 at water table well 90WT0013 but has also been detected in other wells, mostly in the vicinity of the MMR boundary. The source of the groundwater contamination appears to be related to 40mm rifle grenade training activities that occurred at L Range, primarily between the 1970s and 1990s.

During use, explosives would have detonated (or malfunctioned) near targets, and propellants would have accumulated near the firing points. The sources would have accumulated particulates on or near the surface. Following deposition of explosives compounds, precipitation/infiltration would act to dissolve the constituent compounds and transport them to the groundwater. The heterogeneous nature of the source deposition combined with the episodic pattern of infiltration would have resulted in a heterogeneous (in both space and time) release of contamination to groundwater. TNT, in contrast, rapidly degrades and readily partitions into organic fraction of the soil matrix, and rarely reaches the water table at MMR.

The lack of detections of RDX, HMX and most of the other explosives compounds in the original L Range soil samples suggest that the source areas for the existing discontinuous groundwater contamination are now depleted. The explosives compounds detected the November 2008 soil sampling event likely represented recently deposited explosives contamination which was liberated from munitions during the robotics munitions removal. Subsequent soil sampling conducted in May 2009 in the same decision units as the November 2008 sampling event identified lower concentrations of explosives in the soil. This may be the result of some of the contaminants migrating out of the soil.

6.2 Pathway

Following deposition onto the soil, precipitation will dissolve a fraction of the contaminant mass and then migrate toward the water table. Although dissolution of the solid compounds is relatively slow, once dissolved, compounds such as RDX and HMX move through the soil column with minimal sorption to the soil matrix. Other contaminants such as metals, pesticides, and PAHs move more slowly based on their chemical properties. The unsaturated zone at the L Range is approximately 85-foot thick, representing the distance between the presumed source at the ground surface and the groundwater table. Once at the groundwater table, the dissolved contaminants would mix with and begin to migrate with the groundwater.

Migrating explosives and perchlorate contamination, at discontinuous low concentrations, have been detected in groundwater downgradient from L Range which demonstrates that infiltration of explosive-related contaminants has occurred, and that several discrete small plumes exist in the area. The plumes are present at varying depths with varying proportions of RDX, HMX and perchlorate, indicative of several sources at L Range.

The general decreasing trend of contaminants in the groundwater supports a model of depleted sources. With reduction or cessation of contaminant migration to groundwater, the groundwater plumes beneath the site become further desegregated, and concentrations will decrease due to advection, dispersion, and degradation along the flow path. Concentrations are expected to decline as evidenced by the groundwater data collected to date. Concentrations of explosives compounds, if not already nondetect, are predicted to be essentially nondetect before they reach the FS-12 groundwater extraction fence.

6.3 Receptors

There are no known private or public water supply wells located within the L Range groundwater study area. The closest water supply well is located on the south side of Weeks Pond (this well is currently not operating) about 1.3 miles south of the L Range. The next closest supply wells are located over two miles east of the L Range. The nearest known private water supply wells are located east and west of Snake Pond, with the closest about 1,800 feet from the L Range. In addition, there is no evidence that the plumes are impacting any surface water bodies in the area.

Groundwater impacted by the L Range could be used as a future source of drinking water. This includes future use at MMR and off-Site. Groundwater at some locations at MMR is designated by the State of Massachusetts as a Zone II and by EPA as a Sole Source Aquifer. Portions of the MMR are part of the Upper Cape Water Supply Reserve, per Chapter 47 of the Acts of 2002.

There is no current use of groundwater in the area. The post-treatment (post FS-12 ETR system treatment) effluent has no detectable levels of EDB and BTEX compounds, and is used for irrigation and facility (bathroom) purposes.

Although residential use is not the likely future land use within MMR, hypothetical residents are identified as potential receptors to determine the need for institutional controls and to provide information for evaluating all future-use options in the Feasibility Study. Therefore, hypothetical residents (on- and off-site) were identified as future receptors and the use of groundwater from the L Range as a source of potable water was considered a potential exposure pathway.

The soil removal action at L Range removed and treated all of the explosives-contaminated soil in the mid-range area and thereby eliminated any further leaching of or direct contact exposure to contaminants in surface soils.

L Range contaminated groundwater follows a southern trajectory. A transport simulation model, using the 2004 plume shell, was run for 40 years duration. The simulation showed that RDX concentrations fall below 2 µg/L by 2013 and below 0.6 µg/L by 2027. By Year 33 (2040), RDX concentrations are predicted to be below the reporting limit of 0.25 µg/L. The maximum downgradient extent of the 0.6 µg/L RDX plume contour occurs in approximately 2010 and never migrates beyond the FS-12/J-3 plume management area.

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7.0 RISK SCREENING

7.1 Introduction

A Risk Screening was conducted for L Range. The objective of the risk screening was to identify any contaminants of concern detected at the L Range that require further evaluation.

The L Range plume is situated in close proximity to the Fuel Spill 12 (FS-12) plume. In fact, there is some overlap of the plumes and a number of FS-12 monitoring wells fall within the L Range study area boundary. There has been documented commingling of the contaminants associated with each source area. The groundwater contaminants were segregated by their source with the explosive related contaminants attributed to the L Range and fuel related contaminants attributed to FS-12. As such, groundwater screening evaluations were performed for the L Range contaminants and the FS-12 contaminants.

7.2 Groundwater Screening

Table 7-1 provides the summary of analytes detected in groundwater that are associated with the L Range source area. Table 7-2 presents similar information for the FS-12 related contaminants. As shown on Tables 7-1 and 7-2, the maximum detected concentration of each analyte was compared against various screening levels. The screening values included Federal Maximum Contaminant Levels (MCLs), Health Advisory Levels (HAs), EPA Regional Screening Levels for Tapwater (RSL), and the Massachusetts Contingency Plan (MCP) GW-1 standards.

In addition to the comparisons to the various screening levels, other factors such as an analytes detection frequency, the temporal trends of the concentrations, its magnitude of screening criteria exceedances, site-specific background levels, and ubiquity in the groundwater were considered when determining if further evaluation is required.

A discussion of the significant findings of the groundwater screening process is provided in the following sections.

7.2.1 L Range Contaminants

7.2.1.1 <u>Explosives Compounds and Perchlorate</u>

As presented on Table 7-1, a number of explosives compounds and perchlorate were detected in the groundwater. The maximum detected concentrations for a few of the explosives compounds (2,4-DNT, 2,6-DNT, DNX, nitrobenzene, RDX) and perchlorate exceeded at least one of their respective screening levels. Perchlorate exceeded its GW-1 Standard. RDX exceeded its HA, tapwater RSL and GW-1 screening levels. 2,4-DNT, nitrobenzene and DNX exceeded their respective tapwater RSLs (RDX was used as a surrogate for DNX), and 2,6-DNT exceeded its HA. However, with the exception of perchlorate and RDX these explosives compounds were detected infrequently or were detected at concentrations marginally exceeding the screening values (Table 7-1). 2,4 DNT and DNX were only detected once and nitrobenzene was only detected twice. 2,6 DNT detections only exceeded screening criteria in 0.1% of the samples. The maximum concentrations for the remaining detected explosives compounds did not exceed screening values and were observed at low levels in the groundwater. Based on these findings, it was determined that RDX and perchlorate will be retained as COCs. These compounds will continue to be monitored for in groundwater; however, only RDX was evaluated in the Feasibility Study.

7.2.1.2 Metals

A number of inorganic constituents associated with the L Range source area were detected in the groundwater. The maximum concentrations of antimony, arsenic, cobalt, iron, lead, manganese, mercury, nitrogen (nitrate-nitrite), and thallium exceeded at least one of their respective screening levels. Antimony and thallium exceeded their respective MCL, HA, tapwater RSL, and MCP GW-1 standards, but have low frequencies of detection. Lead exceeded its MCLs. However, in the *Final L Range Groundwater Risk Assessment* (ECC 2007) the Integrated Exposure Uptake Biokinetic model was used to assess the potential impact of exposures to lead in the groundwater by future child residents. The model estimated blood lead levels for the hypothetical future child resident scenario. The estimated blood concentrations were below the EPA recommended threshold of 10 micrograms per deciliter.

Nitrogen as nitrate-nitrite was detected above the MCL, but only in 3.3 percent of the samples. Arsenic exceeded its HA and tapwater RSL, but has a low frequency of detection. Manganese exceeded its HA but the maximum concentration is below the RSL of 880 µg/L. Cobalt, mercury and iron exceeded their respective tapwater RSLs. However, iron is considered a human nutrient and the iron RSL exceedances are limited to two wells: 90WT0013 and MW-45S. The cobalt RSL is based on a provisional toxicity value and the cobalt RSL exceedances are limited to two wells; 90W0015 and MW45S. Mercury has a low frequency of detection.

The table below presents a comparison of site-specific background levels to site concentrations for the metals that exceeded a screening value.

Metal	Background Mean (µg/L)	Background Maximum (µg/L)	Site Maximum (µg/L)
Antimony	0.13	48.6	52.3
Arsenic	0.58	34.5	2.8
Cobalt	Not available	Not available	63.5
Iron	1466	148000	135000

Metal	Background Mean (µg/L)	Background Maximum (µg/L)	Site Maximum (µg/L)
Lead	0.97	80.1	619
Manganese	210	11500	856
Mercury	0.007	0.66	0.6
Nitrogen	Not available	Not available	3400
Thallium	0.23	13.3	7.9

Based on these findings, none of the metals will be evaluated in the Feasibility Study.

7.2.1.3 Semi-volatile Organic Compounds (SVOCs), Pesticides, Herbicides and Polychlorinated Biphenyls (PCBs)

Several SVOCs, pesticides, herbicides, polynuclear aromatic hydrocarbons (PAHs), PCBs, and other analytes were detected in the groundwater. The SVOCs, pesticides and herbicides were detected sporadically throughout the site which does not suggest that a plume exists for any of these compounds. The maximum detected concentrations for Aroclor 1254 and bis(2-ethylhexyl)phthalate (BEHP) exceeded at least one of their respective screening levels. None of the other compounds exceeded a screening value. Aroclor 1254 marginally exceeded its tapwater RSL and was detected in only one of 1,057 samples. BEHP, which exceeded its MCL, tapwater RSL, and MCP GW-1 standard, appears to be an artifact of the investigation methods introduced to the samples from plastic equipment used during collection and analysis. This conclusion is supported by the results of historic sampling on MMR that show much lower levels of the chemical after additional precautions were taken to prevent cross-contamination during sample collection and analysis. Based on these findings, none of the SVOCs, pesticides, herbicides, or PCBs will be carried forward into the Feasibility Study.

7.2.1.4 Volatile Organic Compounds (VOCs)

VOCs were detected in the groundwater. Chloroform, chloromethane, 1,2-dibromo-3-chloropropane, 1,2-dichloroethane, 1,2-dichloropropane, methylene chloride, tetrachloroethene (PCE), 1,2,4-trimethylbenzene, and 1,3,5-trimethylbenzene exceeded at least one of their screening values. 1,2-Dichloroethane, methylene chloride and PCE exceeded their MCL, tapwater RSL, and MCP GW-1 standards. Chloromethane exceeded its HA. Chloroform, 1,2-Dibromo-3-chloropropane, 1,2-Dichloropropane, 1,2,4-Trimethylbenzene and 1,3,5-Trimethylbenzene exceeded their respective tapwater RSLs.

The detection frequency was low for these VOCs except for chloroform. As described in the Final Human Health Risk Assessment (ECC 2008), chloroform is ubiquitous in the groundwater at MMR and it is not considered to be L Range-related. Based on these findings, none of the VOCs will be evaluated in the Feasibility Study.

7.2.1.5 Analytes Without Screening Values

Seven compounds were detected in the L Range groundwater that did not have screening levels. These included: cymene, 1,4-diamino-2,3-dihydroanthraquinone, dibenzofuran, 2-hexanone, n-butylbenzene, sec-butylbenzene, and n-propylbenzene. These compounds are not expected to be related to L Range activities with the exception of 1,4-diamino-2,3-dihydroanthraquinone, and with the exception of cymene were detected infrequently. Cymene was only analyzed in one sample; this detection was evaluated in the Final L Range Groundwater Human Health Risk Assessment (ECC 2008) and found not to pose a risk to a hypothetical future resident. Based on these findings these compounds will not be evaluated in the Feasibility Study.

7.2.2 FS-12 Related Compounds

The maximum concentrations of the FS-12 related VOCs benzene, EDB, ethylbenzene, 2-methylnaphthalene, naphthalene, and xylenes were greater than the screening levels. However, the concentrations of these VOCs are associated with the FS-12 fuel spill source area and not L Range activities and, therefore, will not be evaluated in the L Range Feasibility Study.

The maximum concentrations of arsenic, lead, and manganese associated with the FS-12 source area were greater than the screening levels. However, the concentrations of these metals are associated with the FS-12 source area and therefore will not be evaluated in the L Range Feasibility Study.

7.2.3 Groundwater Evaluation Summary

Based on the screening analysis performed for the L Range groundwater, the explosives compound RDX and perchlorate were identified as COCs in groundwater and will be further evaluated in the Feasibility Study. None of the remaining analytes will be carried forward for further evaluation.

7.3 Soil Screening

Table 7-3 presents the organic analytes detected in the L Range soil. Table 7-4 presents the metals detected at each of the L Range sub-areas. A comparison of the maximum detection concentration of each detected analyte (pre-Robotics soil data) to screening values is also presented on Tables 7-3 and 7-4. The screening values included the MCP S-1/GW-1 Standards, MADEP leaching based soil concentrations, the EPA Region 3 risk-based SSLs and MMR SSLs. Other considerations evaluated in the screening evaluation included whether an analyte was a human nutrient, detection frequency, and background levels. The comparison of site metals concentrations to background levels is also presented on Table 7-4 by sub-area.

7.3.1 Explosives Compounds and Perchlorate

Nitroglycerin and tetryl were the only explosives compounds detected in L Range pre-robotics soil samples (see Table 7-3). The maximum detected concentrations for both of these exceeded their respective MMR SSLs and EPA Region 3 risk-based SSLs. However, nitroglycerin was only detected in two of 376 samples and tetryl was only detected in one of 376 samples. Perchlorate was not detected in pre-robotics soil samples. Based on these findings, the explosives compounds and perchlorate will not be evaluated in the Feasibility Study.

Post-Robotics MIS soil sampling conducted in Nov 2008 and May 2009 identified the presence of explosives compounds and perchlorate in the shallow soils. Elevated detections were associated with ten decision units within the mid-range area (where the majority of the former targets were located). The maximum concentrations of RDX and HMX detected were 92,000 µg/Kg and 9,700 µg/Kg, respectively. In addition, concentrations of TNT up to 450,000 µg/Kg were detected in decision units at the mid-range area. Contaminated soil from ten decision units (SSLRM01, SSLRM03, SSLRM04, SSLRM05, SSLRM06, and SSLRM08 through SSLRM12) (Figure 4-3) was removed. All post-excavation confirmatory soil samples were nondetect for explosives compounds.

7.3.2 Metals

As presented on Table 7-4, the L Range metals data was summarized by sub-area which included the following areas: L Range Firing Points, L Range Targets, Area 46, Cleared Area 11, and Area 79. The maximum detected concentrations of a number of metals exceeded at least one of their respective screening levels at each of the sub-areas.

At the L Range Firing Points, arsenic, chromium, cobalt, iron, lead, manganese, and thallium exceeded the MMR SSL and/or Region 3 risk-based SSL. However, the average site concentrations for these metals are less than background levels. The exception to this is cobalt which was not analyzed for in the MMR background sampling program but is not expected to be related to L Range activities.

At the L Range Targets, a number of metals exceeded their respective MMR SSL and/or Region 3 risk-based SSL. The maximum concentrations of cadmium, chromium, and nickel also exceeded their MCP S-1/GW-1 standards. However, the average site concentrations for the metals exceeding a screening level are less than or similar to background levels.

A number of metals exceeded their respective MMR SSL and/or Region 3 risk-based SSL at Area 46, Cleared Area 11, and Area 79. The maximum concentrations of chromium and nickel also exceeded their MCP S-1/GW-1 standards at Cleared Area 11. However, in all sub-areas, the average site concentrations for the metals exceeding a screening level are less than or similar to background levels. Based on these findings, none of the metals will be evaluated in the Feasibility Study.

7.3.3 SVOCs, Pesticides and Herbicides

Several SVOCs, which includes pesticides, herbicides, PAHs, and other analytes, were detected in the soil. The SVOCs were detected sporadically throughout the site. In general, the detection frequency for a number of the SVOCs was low. The maximum detected concentrations of several PAHs exceeded at least one of their respective screening values (see Table 7-3). The presence of the PAHs is attributed to the presence of asphalt on roadways and parking areas. The maximum detected concentrations of the PAHs were less than or similar to MassDEP background levels.

Dieldrin exceeded its screening levels. However, dieldrin has historically been applied at MMR as a pesticide for facility maintenance. Based on detected pesticide concentrations their application was in accordance with manufacturer guidelines. Dieldrin is not believed to be mobile in the environment and was not detected in L Range groundwater. The maximum detected concentrations for other pesticides exceeded at least one of their respective screening levels but their frequency of detection was low. BEHP exceeded its Region 3 SSL but as described in Section 7.2.1.3, its presence appears to be an artifact of the investigation methods. Based on these findings, the SVOCs and pesticides will not be evaluated in the Feasibility Study.

7.3.4 VOCs

Several VOCs were detected in the soil. The maximum detected concentration of acetone, benzene, bromomethane, chloroform, chloromethane, and methylene chloride exceeded at least one of their respective screening values. The detection frequency for the majority of the VOCs was low. The VOCs were detected sporadically throughout the site. Acetone and methylene chloride are both laboratory contaminants. Based on these findings, the VOCs will not be evaluated in the Feasibility Study.

7.3.5 Soil Evaluation Summary

Based on the soil screening analysis performed, none of the detected analytes will be further evaluated in the Feasibility Study.

8.0 INVESTIGATION FINDINGS

The following presents the summary and findings of the L Range remedial investigation.

8.1 Investigation Summary

The L Range Study Area includes the L Range proper (Firing Points and Targets) plus three adjacent sub-areas, unrelated to L Range other than by proximity, referred to as Area 46, Cleared Area 11, and Area 79. L Range was primarily, and most recently, used as a grenade-launcher range but has also served as an infiltration range. Area 46 is located south of the L Range, across Greenway Road, and was included in the Study Area as part of an effort to identify the source of explosives contamination in groundwater collected from a nearby monitoring well. Cleared Area 11 located along Greenway Road between the L Range and the J-3 Range was identified because it appeared as a cleared area on historic photographs, and currently contains few trees. Area 79 is a suspected Mortar Position associated with the former H Range.

During the period 1999 through 2005, 473 soil samples were collected from 60 locations within the L Range Study Area. In 2008, a robotics technology demonstration was conducted at L Range during which vegetation, debris, and UXO were removed from the eight acre range floor using remotely controlled equipment. A total of 53 potential high explosives rounds and approximately 12,000 lbs of scrap (thousands of practice rounds) were recovered during the technology demonstration. Following the post-clearance geophysical survey, a series of additional intrusive investigations were conducted within the range floor including excavation of 16 large anomalies in the up-range and mid-range areas and a total of 750 linear feet of trenching within the mid-range and down-range areas. No presumed high explosive munitions and only two grenades with presumed live fuzes were recovered during any of these intrusive investigations and no metallic debris was found below the bottom of any of the 0.5-1 foot deep excavations. Multi-increment soil samples were also collected from 23 decision units in the range floor and analyzed for explosives and perchlorate.

Intrusive investigations were also conducted in areas outside the range floor including a meandering path survey of the boundary berms and the area between the berms and the perimeter fence during which approximately 40% of magnetic anomalies were excavated. The categorization of anomalies is a qualitative anomaly size analysis performed by the UXO technicians using all metals detector. All anomalies categorized as “B” (6 inches to 1 foot spatially) and “C” (1 to 3 feet spatially) were intrusively investigated. Only a representative 49 percent of the “A” (< 6 inches spatially) anomalies were investigated because the majority of the “A” anomalies contained only small metal fragments such as pieces of 40mm bases. In addition a portion of the southern boundary berm was excavated down to the level of the range floor.

While no presumed high explosive grenades were identified at depths greater than six-inches bgs, two smoke grenades with presumed live fuzes were discovered during the transect investigation.

8.1.1 Pre-Robotics Soil

During the period March 1999 through April 2005, 473 soil samples were collected from 60 locations within the L Range Study Area. The compounds analyzed included explosives, perchlorate, SVOCs (including extractable petroleum hydrocarbons), pesticides, PCBs, herbicides, VOCs, and metals. Analytes detected in these samples were compared to established MMR screening standards including: USEPA Region 3 risk-based SSLs, MCP S-1/GW-1 standards, MassDEP leaching based soil concentrations, and MMR SSLs. Other considerations in the risk screening evaluation included whether an analyte was a human nutrient, the frequency of detection and background values.

Soil analytical results indicated low concentration contamination to shallow soils (0- to 2-feet bgs). The explosives nitroglycerin and tetryl were detected at concentrations exceeding the screening criteria. However, the frequency of detections were low (<0.5 %). Several SVOCs were also detected sporadically throughout the site, but the frequency of detections was generally low. The most prevalent SVOCs were PAH compounds, which are attributable to the presence of asphalt roadways and parking areas. The maximum detected concentrations of PAHs were similar to or less than the MassDEP background levels. BEHP was detected at concentrations exceeding the risk screening criteria, but the presence of this compound is likely a sampling artifact.

The pesticide dieldrin exceeded the risk screening criteria. Dieldrin is considered ubiquitous to the MMR environment, is not mobile in the environment and has not been detected in groundwater. Dieldrin detections were primarily located in Areas 79 and 46. The dieldrin detections are located in the vicinity of Greenway Road and the access road to the former FS-12 SVE treatment plant. The concentrations of dieldrin decline significantly with depth, which is indicative of ground surface application, and is consistent with pesticide application in accordance with manufacturer's guidelines. Several other pesticides were also detected, however, their frequency of detections were low.

The maximum detected concentrations of a number of metals exceeded at least one of their respective screening levels. The metals data were averaged by sub-area which included the following areas: L Range Firing Points, L Range Targets, Area 46, Cleared Area 11 and Area 79. The average metals concentrations for each sub-area were less than or similar to background levels.

Based on the risk screening no soil COCs were identified.

8.1.2 Post-Robotics Soil

After the completion of the UXO clearance activities in 2008, a total of 37 multi-increment soil samples were collected from shallow soils (0- to 3-inches depth) at the floor of the range. The samples were collected from three distinct areas: up-range, mid-range and down-range. Based on the pre-clearance soil data assessment, samples were initially analyzed for explosives and perchlorate only. Additional analyses for selected metals (lead and zinc only) were performed at a later date. The second round of multi-increment soil sampling in the mid-range area was conducted in May 2009.

Soil analytical results indicate the presence of explosives compounds and perchlorate in the shallow soils. Lead results ranged from 17.9 mg/Kg to 59.4 mg/Kg, and zinc concentrations ranged from 31.3 to 82.1 mg/Kg. Elevated detections were associated with ten decision units within the mid-range area (area with the majority of the former target locations). The maximum concentrations of RDX and HMX detected were 92,000 µg/Kg and 9,700 µg/Kg, respectively. In addition, there were elevated detections of the explosive compound TNT, all of which were associated with decision units at the mid-range area. Contaminated soil from ten decision units (SSLRM01, SSLRM03, SSLRM04, SSLRM05, SSLRM06, and SSLRM08 through SSLRM12) (Figure 4-3) was removed for treatment. All post-excavation confirmatory soil samples were nondetect for explosives compounds. The removal action will be documented in a Completion of Work Report.

8.1.3 Groundwater

The primary contaminants in the L Range groundwater study area were low levels of perchlorate and RDX. The perchlorate and RDX contamination occurs as isolated and noncontiguous zones or lobes detached from upgradient source areas. The groundwater data indicates that the magnitude of contaminant concentrations is very low, and does not identify definitive source areas for the groundwater contamination in the L Range.

Based on recent groundwater data (between 2004 and 2007), the maximum perchlorate detection observed in any monitoring well sample was 1.9 µg/L (MW-153M2), indicating a decline from a maximum detection of 3 µg/L as reported in the *Final L Range Groundwater Characterization Report* (ECC 2005).

Likewise, RDX concentrations have also decreased from a maximum of 9.2 µg/L in the 2005 report to 3.6 µg/L based on recent sampling results. The current groundwater contamination consists of 2 RDX lobes and 4 perchlorate lobes, compared to 3 RDX lobes and 6 perchlorate lobes identified in the *Final L Range Groundwater Characterization Report* (ECC 2005).

The results of regularly sampled monitoring wells indicated that concentrations of perchlorate and RDX in the L Range study area were either constant or decreasing with time. The one exception is that perchlorate concentrations have increased over time in monitoring well MW-153M2, where a perchlorate concentration of 1.9 µg/L was reported in April 2007. However, overall, the spatial and temporal distribution of perchlorate and RDX concentrations indicated a very stable and attenuating plume. The varying distance and depth of the lobes of contamination relative to the L Range footprint and the lack of spatial correlation between the two primary contaminants suggested that there were either multiple source areas, multiple release events, differences in the chemical-specific subsurface migration and attenuation rates, or (very likely) all of the above. The data do not suggest a continuing source.

The fate and transport modeling conducted in support of the *Final L Range Groundwater Characterization Report* (ECC 2005) indicated the RDX contamination would migrate south in the direction of the northernmost FS-12 extraction wells, which were in operation at the time the modeling was conducted. The modeling suggested that perchlorate would not migrate (at detectable concentrations) beyond its current location in the aquifer. The model predicted that if the FS-12 system were to operate under its current conditions at the time the modeling was conducted for the next twenty years, extremely low concentrations of RDX may be captured by the most northern extraction wells in the FS-12 well field. However, due to the change in the FS-12 operating conditions (northern-most extraction wells are not currently operating) conservatism in the plume shell, the lack of RDX degradation simulated in the model, the extremely low concentrations observed in the plume and observed decreases in contaminant concentrations, it is extremely unlikely that RDX from the L Range area will ever reach the northern FS-12 extraction wells at detectable concentrations.

8.2 Conceptual Site Model

L Range is a direct-fire range where 40mm rifle grenades were fired directly at visible targets and where residue, including soil contaminants and UXO, is typically concentrated around the targets and decreases in density with distance from the targets. Explosives contamination was detected in L range soils in 2008 and appears to be limited to the mid range portion of L Range, where a majority of the targets were located. Precipitation events are believed to have carried dissolved contaminants through the soil column to the underlying groundwater.

8.3 Risk Screening

A risk screening identified RDX and perchlorate as a COCs in groundwater. Explosives compounds identified in the mid-range soil have been removed and remediated on-site.

8.4 Findings

- Sources of groundwater contamination are likely the result of L Range historical activities. These activities likely deposited residues in soils at the site, which resulted in detectable groundwater contamination.
- Soil analytical results from the range floor after completion of the munitions clearance indicate that all exceedances of standards for RDX and HMX were concentrated and limited to the mid-range area, where the highest quantities of munitions were recovered.
- Concentrations of downgradient groundwater contaminants perchlorate and RDX are either constant or decreasing with time. The data do not suggest a continuing source.
- The fate and transport modeling indicated the RDX contamination would migrate south in the direction of the northernmost FS-12 extraction wells. However, it is extremely unlikely that RDX from the L Range area will ever reach the northern FS-12 extraction wells. The modeling suggested that perchlorate would not migrate appreciably (at detectable concentrations) beyond its current location in the aquifer.

- Based on multiple lines of evidence (aerial photos, geophysical surveys, range records, munitions finds, robotics clearance, post-robotics intrusive investigation, and contaminated soil removal), it is likely that any future impact to groundwater based upon the number of UXO that may remain would not present an unacceptable risk.
- Contamination that could pose a risk to groundwater has been removed; however, based on the groundwater investigation, a feasibility study is warranted to address RDX groundwater plumes exceeding risk based standards.

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9.0 L RANGE GROUNDWATER FEASIBILITY STUDY

The Feasibility Study (FS) portion of this report presents the evaluation of remedial alternatives to remediate contamination in groundwater at the L Range. Although the COCs include other explosives and perchlorate the alternatives will be evaluated with respect to RDX because it has the highest concentration relative to applicable standards, has the greatest detection frequency and has been mapped into numerous areas of semi-continuous contamination.

The FS considers that soil contaminant concentrations above applicable standards, identified during the multi-increment sampling of the range floor, were remediated concurrently with the development of groundwater remedies. The soil remediation project includes the removal and treatment of the top 6 inches of soil from ten decision units in the mid-range portion of L Range, totaling approximately 2,500 cubic yards of soil. All alternatives focus on groundwater since the source was recently removed by a $1.5 million response action.

The remedies evaluated in the L Range groundwater FS were monitored natural attenuation and focused extraction and treatment with granular activated carbon (GAC). These remedies include technologies implemented as part of the J-3 and J-2 rapid response actions (ECC 2005a, c), and evaluated in the FS for the Demolition Area 1 (AMEC 2004). The technology selected for the active remediation alternative is groundwater extraction, treatment with granular activated carbon (GAC) and return of treated water back into the aquifer. With a GAC adsorption process, groundwater contaminated with explosives is passed through a carbon medium and the explosives are adsorbed onto the surface of, or partition into, the carbon particles. If low levels of perchlorate (below 2 µg/L) are present in the influent, it is anticipated that the perchlorate will partition into the carbon particles. Once the capacity of the GAC has been exhausted, the GAC requires regeneration or disposal.

The return of treated water back to the aquifer can be accomplished by various methods (e.g. reinjection wells, infiltration trenches, surface water discharge). For the FS, an infiltration trench was used to conceptually return water to the aquifer. The specific method will be determined during the wellfield design effort if the selected remedy involves treatment.

The following steps were taken to identify alternatives to address the contamination in the L Range groundwater: (1) response action objectives were developed, (2) alternatives were developed to address the objectives, and (3) alternatives were subjected to a detailed assessment based on seven criteria (protection of human health and the environment; compliance with regulations; long-term effectiveness and permanence; reduction of toxicity, mobility, or volume; short-term effectiveness; implementability; and cost.

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10.0 DEVELOPMENT OF ALTERNATIVES

10.1 Response Action Objectives

This section describes the groundwater response action objectives and potential response actions for L Range groundwater. Based on preliminary information relating to types of contaminants, environmental media of concern, and potential exposure pathways, response action objectives were developed to aid in the development and screening of alternatives. The response action objectives for the selected response action for the L Range are to restore the useable groundwater to its beneficial use wherever practicable within a timeframe that is reasonable given the particular circumstances of the site; to provide a level of protection in the aquifer that takes into account that the Cape Cod aquifer, including the Sagamore Lens, is a sole source aquifer that is susceptible to contamination; and to prevent ingestion and inhalation of groundwater containing contaminants of concern (COCs) (RDX and perchlorate) in excess of federal maximum contaminant levels, Health Advisories, drinking water equivalent levels (DWELs), applicable State standards, or an unacceptable excess lifetime cancer risk or non-cancer Hazard Index.

Table 10-1 presents risk-based and regulatory concentration goals and background concentration for RDX. The background concentration value for use in the feasibility study modeling is equal to the analytical reporting limit of 0.25 µg/L for RDX. The 10^{-6} level, the concentration resulting in an increased lifetime cancer risk of one in a million is currently 0.6 µg/L for RDX. The EPA Lifetime Health Advisory is 2 µg/L. The MCP GW-1 Standard is 1 µg/L.

10.2 Regulatory Considerations

Table 10-1 summarizes the federal and state regulatory considerations for the proposed L Range groundwater remedial action.

10.3 Remedial Alternatives

Remedial alternatives were developed that included:

- A no-action alternative to serve as a baseline for alternative comparisons.
- An alternative that, throughout the entire groundwater plume, reduces the contaminant concentrations to background conditions.
- An alternative that, throughout the entire groundwater plume, reduces the contaminant concentrations to levels that meet or exceed the MCLs, health advisories, DWELS, other relevant standards, results in a Hazard Index of 1 or less, and a cumulative 10^{-6} excess cancer risk and the non-cancer Hazard Risk of one as rapidly as possible and in less than 10 years and shall require no long-term maintenance.
- A limited number of remedial alternatives that attain site-specific remediation levels within different restoration time periods utilizing one or more different technologies if they offer the potential for comparable or superior performance or implementability;

fewer or lesser adverse impacts than others available approaches; or lower costs for similar levels of performance than demonstrated treatment technologies.

This section presents an overview of the three remedial alternatives developed to address the L Range groundwater. The alternatives are:

Alternative 1 – No further action;

Alternative 2 – Monitored natural attenuation and Land Use Controls, and

Alternative 3 – Focused Extraction (long-term monitoring and institutional controls with groundwater treatment)

All alternatives include the removal of the source area. Alternative 1 only includes well abandonment. Alternatives 2 and 3 include installation of two additional monitoring wells on the range to verify that recent source removal activities didn't release any significant quantities of contaminants to the groundwater. Prior to termination of the proposed activities (Alternative 2 or 3), a residual risk assessment will be conducted, pursuant to a work plan approved by EPA, in consultation with MassDEP, to determine if RDX and perchlorate concentrations remaining in the aquifer pose an unacceptable human health risk. If necessary the risk assessment may require additional data collection and analyses.

Monitoring and institutional controls are components of the Alternatives 2 and 3. Institutional controls consist of measures that would prevent human exposure to plume contaminants. The monitoring would consist of chemical monitoring to determine when RDX concentrations have decreased below, and remain below, risk based levels and continued monitoring of perchlorate to confirm concentrations remain below the MMCL.

The extraction treatment and reinjection system (Alternative 3, Figure 10-1) would consist of: 1) extraction of groundwater through an extraction well, 2) pretreatment of the influent to mitigate metals and bacteria that would lead to treatment system biofouling, if required, 3) treatment of the groundwater through a modular treatment unit [(MTU) uses GAC to removes explosives from groundwater], and 4) infiltration of treated water to the aquifer via an infiltration trench. The placement of the extraction well was based on the position of the plume at the time of estimated system startup in 2010. The location of the conceptual extraction well simulated in Alternative 3 is just south of the MMR boundary as depicted on Figure 10-1. If active treatment is the selected remedy, the exact location of the extraction well may be revised during the design process. The specific location of the MTU will be based on the availability of an existing power source and infiltration trench.

Each of the alternatives reduces contaminant concentrations to background conditions. In addition, Alternative 3 reduces the contaminant concentration to levels that meet or exceed regulatory and risk based standards in less than 10 years.

11.0 DETAILED ANALYSIS OF ALTERNATIVES

This section provides a description of the criteria for detailed analysis, groundwater modeling results, and the detailed analysis of the groundwater alternatives. Each alternative is evaluated against the same criteria established by EPA and discussed below.

11.1 Criteria for Detailed Analysis of Alternatives

1. Overall protection of human health and the environment; this shall include prevention of the movement of contaminants into the aquifer and its preservation as a public drinking water supply.

2. Compliance with regulations including:
- Federal regulations;
- State regulations;

3. Long-term effectiveness and permanence considering:
    - The risks remaining after completion of the remedial action;
    - The adequacy and suitability of controls, if any, that are used to manage untreated contaminants remaining at the site.

4. Reduction of toxicity, mobility, and volume through treatment including:
    - The expected reduction in toxicity, mobility or volume measured as a percentage or order of magnitude; and
    - The type and quantity of treatment residuals that will remain following treatment.

5. Short-term effectiveness, including:
    - Protection of the community during the remedial action;
    - Protection of workers during remedial action;
    - Environmental impacts to natural resources; and
    - Time until remedial response objectives are achieved.

6. Implementability, considering:
    - Technical feasibility, including:
        - o Construction and operation;
        - o Reliability of technology;
        - o Ease of undertaking additional remediation, if necessary;
        - o Monitoring considerations, addressing the ability to adequately monitor the effectiveness of the remedy and the risks should monitoring be insufficient to detect a system failure.
    - Administrative feasibility;
    - Availability of services and materials, including:
        - o Availability of adequate offsite treatment, storage capacity, and disposal services;
        - o Availability of necessary equipment and specialists, and any other necessary resources;

- o The potential for obtaining competitive bids (especially for innovative technologies); and
- o Availability of prospective technologies.

7. Cost, considering:
   - Capital costs, both direct and indirect;
   - Annual O&M costs; and
   - Present worth analysis (or net present value) of costs.

The cost estimates for the alternatives include capital, annual and periodic costs associated with the anticipated scope of the alternative. These generally include construction costs, operations and maintenance (O&M) costs, system monitoring costs, and reporting costs. When possible, costs were based on actual costs for similar activities performed previously at the MMR. The general assumptions made for the present value calculation are that costs based on current (present day) information will escalate at a rate of 5 percent per year until year zero; after year zero, costs will discount at a rate of 2.8 percent for Alternative 2 and 2.6 percent for Alternative 3 (OMB 2008). A detailed presentation of the cost estimates and present value calculations are provided in Appendix C.

8. State Acceptance, considering the issues and concerns that the State may have regarding each alternative. This criterion will be evaluated throughout the development, screening and evaluation of alternatives based on comments and input received from MassDEP.

9. Community Acceptance which entails an evaluation of issues and concerns the public may have regarding each alternative. This criterion will be evaluated throughout the development, screening and evaluation of alternatives.

11.2 Feasibility Study Groundwater Modeling

Groundwater modeling was used to predict the fate and transport of RDX in L Range groundwater for each alternative. The L Range model was constructed during the L Range groundwater characterization effort (ECC 2005b). A groundwater RDX data set was compiled and the field measurements of contaminant concentrations were interpolated to a 3-dimensional model grid using geostatistical interpolation (kriging). For transport simulation, the 3-dimensional 3-D concentration field for each constituent was regridded to the L Range model grid to create the concentration initial conditions, which was then simulated under various long-term scenarios. Complete details of the plume shell development process are presented in the *Final L Range Groundwater Characterization Report* (ECC 2005b). The RDX plume shell is intended to represent the distribution of RDX at year 2004.5 A comparison of recent data (since 2004) and the model-predicted 2007 nature and extent of the L Range groundwater contamination are comparable and suggest good agreement between observed conditions and model-predicted conditions for 2007. The extent of model-predicted RDX concentrations in 2007 (Figure 11-1) are slightly bigger than extent of the 2007 L Range groundwater contamination (Figure 5-2) and the model-predicted maximum RDX concentration is slightly higher (4.3 µg/L) than the maximum observed concentration in 2007 (3.6 µg/L).

The L Range 2004 RDX mass (dissolved and adsorbed) accounting for all detections (above the method detection limit of 0.25 µg/L) within the model is 0.205 Kg.

Solute transport modeling was used to evaluate the FS alternatives with respect to time required for RDX concentrations to decrease below 0.6 µg/L, remedial system operation time (estimated time until the remedial system would cease operation), mass capture, and plume volume reduction. The flow and transport simulations were performed with the same programs and transport parameters described in the *Final L Range Groundwater Characterization Report* (ECC 2005b).

The L Range transport model is based on the calibrated 2004 L Range flow model. To model solute transport, input parameters were developed to describe hydrodynamic dispersion, retardation, and degradation processes. These parameters include dispersivity, distribution coefficient, and contaminant half-life. Bulk density and porosity are physical parameters of the aquifer matrix that also influence contaminant transport. Values of longitudinal, lateral and vertical dispersivity used in the L Range transport model were 10, 0.3, and 0.03 feet. The retardation factor of 1.05 was used for the RDX transport. The RDX half-life used was zero.

Each model simulation was initialized in June 2004 and ended in June 2044. The hydraulic stresses simulated in the model were divided into numerous time periods to simulate ongoing remedial actions in nearby plumes and potential groundwater remedial action at L Range. The different stress periods are listed in Table 11-1. All model runs also incorporate other nearby operating remedial system components (i.e. J-3, FS-12), simulated at their design rates, and water supply wells that are within the model domain. The remedial component of the active treatment alternative is assumed to operate unchanged for the duration of the simulation; however, it is likely that the system operating parameters would be adjusted for optimization of the remediation system.

The results of repeatedly sampled monitoring wells indicate that concentrations of RDX in the L Range study area are either constant or decreasing with time. The spatial and temporal distribution of RDX concentrations indicates a very stable and attenuating plume. While 2008 data suggests a continuing source, the conceptual site model assumes there is no remaining source material that would contribute significant mass to the groundwater since the soil remedial action removed contaminated soil at the site. Accordingly, the simulations discussed in this FS do not include continuing source release scenarios. It is noted, however, that the monitoring component of Alternatives 2 and 3 would address source area characteristics.

The conceptual design for the active treatment component of Alternative 3 is shown in Figure 10-1. The infiltration trench in the model is simulated as a series of shallow wells with positive flow rates. The wells are located at the water table and therefore do not simulate infiltration of water through the vadose zone. Recharge into the model cells is not affected by their designation as wells.

Animations that illustrate the future fate of the contaminant plumes were created (Animations 11-1 and 11-2). The first frame of both animations is 2007. Predicted fate and transport of the plume from 2004 to 2007 is shown in animations in the *Final L Range Groundwater Characterization Report* (ECC 2005b). The FS animations were visually examined to estimate remedial time frames of the groundwater contamination and operation time frame of the wellfield.

The animations indicate that some RDX concentrations above 0.6 µg/L are located within, or migrate into, low-hydraulic-conductivity units (less than 10 feet/day), and very slowly disperse to concentrations below 0.6 µg/L without migrating downgradient (Figure 11-1). Field data indicate that the L Range contamination is primarily located within the sandy matrix (i.e. high-hydraulic-conductivity units) and not within the low-hydraulic-conductivity units. Based on the age of the contamination (approximately 40 years) and the general lack of contamination within the low-hydraulic-conductivity units as evidenced in profile results, it appears that the bulk of the contaminant transport occurs through higher hydraulic-conductivity units and around low-hydraulic-conductivity units. The low-hydraulic-conductivity units are carefully mapped into the model, but the extent of the units is approximated based on available data and the conceptual understanding of the aquifer matrix within the study area. The extent of the low-hydraulic-conductivity units within the model is also partially determined by the discretization of layers within the model. The plume shells are carefully constructed to match observed concentrations and migrated data, but kriging (geostatical interpolation) of the data to construct the plume shell can result in an increase of concentration in areas where no data is mapped, such as a low-hydraulic-conductivity unit. The thickness of the layers in the model is variable, but the grid used to construct the plume shell is a regular (orthogonal) grid with constant layer thickness. Therefore, when the plume shell is imported into the model, a small amount of mass can be initialized in low-hydraulic-conductivity units.

Based on this information, the groundwater model appears to be overly conservative with respect to the amount of contaminant mass initialized within the low-hydraulic-conductivity units and the amount of mass that migrates into low-hydraulic-conductivity units. The effect of the low-hydraulic-conductivity units on the fate and transport of the contamination is visible in the animations (Animation 11-1, Figure 11-1). A portion of the L Range contamination is retained in the low-hydraulic-conductivity units located at approximately -80 feet below mean seal level. The interpreted time when RDX concentrations decrease below 0.6 µg/L and below nondetect is based on review of the animations, excluding the area where contamination is retained in the low-hydraulic-conductivity units shown in Figure 11-1. RDX at concentrations above 0.6 µg/L are retained in the low-hydraulic-conductivity units for the length of the simulations (40 years) for all of the alternatives.

The remedial components of the alternative were assumed to operate unchanged for the duration of the simulation; however, it is likely that the system operating parameters will be adjusted for optimization of the remediation system. The time for well shutdown, as described in the later cost sections, was defined as the time the extraction well concentrations fall below the method detection limit for RDX. This information was extracted from modeling output and provided a quantifiable estimate of extraction well performance time. There may be differences between actual remedial system shutdown and the shutdown time estimated in the FS. The animations were reviewed to confirm that the remedial system shutdown time was appropriate and that the amount of mass upgradient would not migrate significantly downgradient after the extraction well was estimated to shutoff. The mass capture was based on mass captured through the extraction well during the estimated operation time. Stills from the animations for each alternative for RDX are presented in Figures 11-1 and 11-2.

The following sections summarize the results of the FS modeling. The fate and transport of the L Range RDX contamination under stressed conditions (L Range active remediation) was simulated for Alternative 3. Alternatives 1 and 2 have the same pumping stress (i.e. only the influence of adjacent public water supply wells and remedial systems) and, thus, are represented by Alternative 1.

11.2.1 Alternative 1 – No Further Action and Alternative 2 – Monitored Natural Attenuation and Land Use Controls

Hydraulically, Alternatives 1 and 2 are the same. Alternative 1 is the ambient condition alternative for the L Range groundwater, and Alternative 2 is an ambient condition alternative with long-term management, including the installation of two new monitoring wells. This simulation was initiated in June 2004. Animation 11-1 shows that L Range contaminated groundwater follows a southern trajectory. RDX concentrations fall below 2 µg/L by 2013 and below 0.6 µg/L by 2027.5 (Figure 11-1, Table 11-2). As the contamination migrates downgradient the concentrations decrease and the volume (defined by concentrations above 0.6 µg/L) increases due to advection and dispersion until approximately 2010, after which the volume decreases. The 0.6 µg/L RDX contamination leading edge migrates approximately 1,900 feet downgradient from 2004 (beginning of the modeling simulation) to its maximum downgradient extent, reached at 2023.

11.2.2 Alternative 3 – Focused Extraction

Alternative 3 represents a new extraction treatment and reinjection system for L Range groundwater. The conceptual design of the system consists of one extraction well operating at 50 gallons per minute (gpm) (Figure 10-1). The water would be treated at an MTU and returned to the aquifer through an infiltration trench. A review of Animation 11-2 (Figure 11-2) indicates RDX concentrations would decrease below 2 µg/L by approximately 2012 and below 0.6 µg/L by approximately 2016 (Figure 11-2, Table 11-2), except for contamination retained in low-hydraulic-conductivity units. The L Range extraction well would reduce the volume of contamination slightly faster than Alternatives 1 and 2.

Modeling predicts that the Alternative 3 system will capture approximately 0.08 Kg of RDX by 2012, the model-predicted system operation time when RDX concentrations in the extraction well fall below the MDL. The 0.6 µg/L RDX contamination leading edge migrates approximately 900 feet downgradient from 2004 (beginning of the modeling simulation) to its maximum downgradient extent, at 2015.

11.3 Detailed Analysis of Alternatives

This section provides the detailed description and analysis of the remedial alternatives. Each alternative description includes assumptions made for planning and costestimating purposes. Each alternative is discussed with respect to the threshold criteria and the primary balancing criteria.

11.3.1 Alternative 1 – No Further Action

Under the no further action alternative, treatment and/or monitoring would not be conducted and the monitoring wells, associated with L Range long-term chemical monitoring, would be abandoned.

<u>Overall Protection of Human Health and the Environment</u>

Alternative 1 would not prevent the migration of the plume, and although residences in the area are on town water, Alternative 1 offers no monitoring or confirmation of existing land-use controls to ensure that future exposures do not occur. RDX concentrations are expected to drop below the HA of 2 µg/L by 2013 and the 10^{-6} risk-based level of 0.6 µg/L by 2027 due to natural processes (dilution, dispersion, and sorption). The plume is predicted to reach background (0.25 µg/L) in 2040.

<u>Compliance with Regulations</u>

Alternative 1 allows for continued migration of the plume. Because no action is taken, chemical-specific regulations would be met only if and when contaminant concentrations decreased below the cleanup standards by natural attenuation. Based on model predictions, Alternative 1 would be compliant with chemical-specific regulations across the entire plume by approximately 2027. Because this alternative takes no action, there are no location-specific or action-specific regulations to be met.

<u>Long-Term Effectiveness and Permanence</u>

In this Alternative, concentrations of RDX in the plume are expected to permanently decrease to below 0.6 µg/L through natural attenuation by 2027. Because no further contribution from the source area is likely, this Alternative is expected to be permanent.

<u>Reduction of Toxicity, Mobility, or Volume through Treatment</u>

No treatment would occur; therefore, no reduction in toxicity, mobility, or volume would occur through treatment. However, the toxicity and volume of the contaminated groundwater would be reduced through natural processes of attenuation.

<u>Short-Term Effectiveness</u>

This alternative would meet the response objectives by 2027. There would be little to no effect on the community, workers or natural resources from implementing Alternative 1 because no construction work would be involved other than well abandonment. A site-specific health and safety plan (HASP) would be followed during well abandonment.

<u>Implementability</u>

Alternative 1 would require no technical implementation other than well abandonment which has been done successfully many times at MMR. Administratively, this alternative is feasible.

Cost

The costs are estimated for Alternative 1 as follows:

- Capital cost: $ 40,425
- O&M: $ 0
- Site closeout documentation: $ 69,300
- Total present worth: $ 109,725

Appendix C provides detailed calculations of the cost of Alternative 1.

State Acceptance

This criterion will be evaluated throughout the development, screening, and analysis of alternatives based on comments and input received from MassDEP.

Community Acceptance

This criterion will be evaluated following comments received on the Remedy Selection Plan.

11.3.2 Alternative 2 – Monitored Natural Attenuation and Land Use Controls

No active remediation would occur with this alternative. This alternative would provide for long term monitoring of the L Range groundwater and for land use controls (Section 8.1.2) to minimize human exposure to groundwater.

The monitored natural attenuation would involve periodic analysis of groundwater for explosives and perchlorate to measure the natural attenuation of the contaminated groundwater, determining when concentrations have decreased to below applicable standards. Groundwater monitoring would continue after RDX concentrations decrease below 0.6 µg/L for two additional years to ensure that concentrations remain below 0.6 µg/L. The monitoring wells would be abandoned at the end of the project.

Overall Protection of Human Health and the Environment

Alternative 2 would not prevent the further migration of the plume although RDX is only expected to migrate 1,900 feet downgradient from 2004 (beginning of the model simulation) to its maximum downgradient extent. Monitoring and land use controls would be implemented to prevent exposure to contamination. As presented in Figure 11-1, which shows time-series plots for the collapse of the L Range plume due to natural processes (dilution, dispersion, and sorption), concentrations are estimated to drop below 2 µg/L by 2013 and 0.6 µg/L by 2027 (Table 11-1). Modeling simulations predict that and the plume will reach background (0.25 µg/L) by 2040.

Compliance with Regulations

Alternative 2 would comply with applicable regulations and meet the response action objectives.

Long-Term Effectiveness and Permanence

In this Alternative, concentrations of RDX in the plume are expected to permanently be reduced to below 0.6 µg/L through natural processes (dilution, dispersion, and sorption) by 2027. Because no further contribution from the source area is likely, this alternative is expected to be permanent. Monitoring of the plume would continue for several years after the plume attenuates to ensure that all areas remain below remedial goals. In the meantime, the land-use controls would ensure that no use of the contaminated water occurs.

Reduction of Toxicity, Mobility, or Volume through Treatment

No treatment would occur, therefore, no reduction in toxicity, mobility, or volume would occur through treatment. However, the toxicity and volume of the contaminated groundwater would be reduced through natural processes.

Short-Term Effectiveness

This alternative would meet the response action objectives by 2027. There would be little effect on the community or workers from implementing Alternative 2 because no major construction work would be involved. A site-specific health and safety plan (HASP) would be followed during long-term groundwater monitoring.

Implementability

Groundwater monitoring associated with the L Range plume would continue using the same sampling and analytical protocols currently in use. Administratively, this alternative is feasible. Access agreements with private landowners may be necessary for future monitoring well sampling.

Cost

The present worth costs were estimated for Alternative 2 as follows:

- Capital cost: $ 112,969
- O & M: $ 1,720,566
- Site Closeout Documentation: $ 39,891
- Total present worth: $ 1,873,426

Appendix C provides detailed calculations of the costs of Alternative 2.

State Acceptance

This criterion will be evaluated throughout the development, screening and analysis of alternatives based on comments and input received from MassDEP.

Community Acceptance

This criterion will be evaluated following comments received on the Remedy Selection Plan.

11.3.3 Alternative 3 – Focused Extraction

Alternative 3 includes the features of Alternative 2 but adds active treatment. The treatment would capture contaminated groundwater in order to decrease the time for concentrations to decrease below 0.6 µg/L. Alternative 3 includes a single extraction well (Figure 10-1), filtration of the groundwater to remove RDX, and infiltration of the groundwater into the aquifer.

Alternative 3 would provide for active treatment of the L Range groundwater, monitoring of the L Range groundwater, and maintaining land use controls. The conceptual design of the L Range extraction treatment and reinjection system includes one new extraction well (50 gpm), treatment at the J-1 South MTU location, and infiltration of the treated water at the J-1 South infiltration trench. The conceptual L Range extraction well is in an area of the aquifer characterized by low dissolved oxygen, evidence of a significant bacteria presence, and high metals concentrations. These conditions are a result of biodegradation of fuels from the FS-12 source area. Pretreatment of the L Range influent would be necessary to prevent biofouling of the treatment system due to increased metals and bacteria in the influent. Active treatment of the L Range groundwater would remove RDX from the extracted groundwater and return the treated water to the aquifer. This alternative includes the option of modifying the system to optimize the L Range extraction treatment and reinjection system performance. Most likely, modifications would be executed within the proposed extraction and infiltration system, and could involve optimization of the operating interval of the extraction well screen by using isolation packers or by flow rate adjustment. Modifications would be made for the purpose of improving treatment system operation and expediting groundwater restoration.

This alternative would also provide for monitoring of L Range groundwater and treatment system as long as active remediation continues and of the aquifer after the system is turned off to ensure that RDX concentrations have decreased to below the applicable standards. Land use controls would minimize potential future exposure to L Range groundwater. Groundwater monitoring would continue for two years after RDX concentrations decreased to below 0.6 µg/L to ensure that concentrations remain below 0.6 µg/L. The monitoring wells would be abandoned at the end of the project.

Overall Protection of Human Health and the Environment

The groundwater model indicates that the HA of 2 µg/L could be achieved throughout the plume by active treatment in 2012, the 10-6 risk-based concentration of 0.6 µg/L could be achieved by 2016 and background concentrations (0.25 µg/L) could be achieved by 2024.

Compliance with Regulations

Alternative 3 would comply with applicable regulations.

Long-Term Effectiveness and Permanence

Both active treatment and natural attenuation components of the alternative are expected to be permanent. Groundwater extraction and treatment would permanently remove some of the RDX from groundwater. The remaining contamination would continue to degrade due to natural attenuation processes, which would also be irreversible.

Reduction of Toxicity, Mobility, or Volume through Treatment

Extraction and treatment of groundwater would reduce the toxicity, mobility and volume of RDX. Approximately 0.08 Kg of RDX would be removed in 2 years of treatment.

Short-Term Effectiveness

This alternative would meet the response action objectives by 2016. There would be some effect on the community and workers from implementing Alternative 3 because of the construction work. Material, equipment, and personnel transport would cause minor impact on roads leading to Camp Edwards.

A site-specific Health and Safety Plan would be followed during system construction where engineering controls and Personal Protective Equipment would be used as necessary to limit potential exposure to COCs. To date, health and safety precautions for unexploded ordnance clearance, soil excavation, construction activities, groundwater sampling, and drilling have been adequate to protect workers.

To the extent feasible, previously disturbed areas would be utilized for the installation of wells, subsurface piping, power lines, and the MTU to minimize impact on cultural and natural resources. However, some disturbance of natural resources would be necessary to complete this alternative.

Alternative 3 would result in secondary impacts to the environment due to motor vehicle use during construction, operations and maintenance, and plume monitoring.

Implementability

Administratively, this alternative would be feasible. Installation of the extraction well, pump, piping, and the MTU, would be technically feasible.

Multiple vendors can provide each component of the alternative.

GAC has been shown to be effective in treating RDX. The treatment system would require regular maintenance and monitoring. Experience at other sites suggests that the components would be reliable. If a pumping well or treatment system failed, the system might require a period of a few days to bring back to full operational status.

Long-term groundwater monitoring would continue using the same sampling and analytical protocols currently in use.

Access agreements with private landowners will be necessary for future monitoring well O&M and sampling, as well as the installation of the extraction well and associated piping.

Cost

The present worth costs were estimated for Alternative 3 as follows:

- Capital cost: $ 2,272,146
- O & M: $ 1,409,374
- Site Closeout Documentation: $ 55,006
- Total present worth: $ 3,736,526

Appendix C provides detailed calculations of the cost of Alternative 3.

State Acceptance

This criterion will be evaluated throughout the development, screening, and analysis of alternatives based on comments and input received from MassDEP.

Community Acceptance

This criterion will be evaluated following comments received on the Remedy Selection Plan.

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12.0 COMPARISON OF ALTERNATIVES

A comparative analysis was conducted to evaluate the relative performance of each alternative in relation to each criterion. The presentation of the comparative analysis refers to each alternative by its number. For reference, a brief description of each alternative follows:

- Alternative 1 – No Further Action. Monitoring wells would be abandoned and site close-out documentation would be completed. RDX concentrations would reduce through natural processes to below the HA of 2µg/L by 2013 and the 10^{-6} risk-based concentration of 0.6 µg/L by 2027. The response action would be complete when the existing groundwater-monitoring-well network is abandoned.

- Alternative 2 – Monitored Natural Attenuation and Land Use Controls. Alternative 2 includes, long-term groundwater monitoring for up to nine years, and institutional controls. RDX concentrations would reduce through natural processes below 2 µg/L by 2013 and 0.6 µg/L by 2027. The response action would be complete when two years of monitoring have shown that goals have been achieved.

- Alternative 3 – Focused Extraction Alternative 3 includes construction of one extraction well installation of piping and a containerized treatment system. A 50-gpm flow rate would achieve 2 µg/L within 2 years of start-up (2012) and 0.6 µg/L within six years of startup (2016). GAC media would be used to treat the extracted water. The response action would be complete when two years of monitoring have shown that goals have been achieved.

The strengths and weaknesses of each alternative are presented in a narrative that addresses each criterion. A summary of the alternatives performance is presented in Table 11-2.

12.1 Overall Protection of Human Health and the Environment

Alternatives 2 and 3 would be protective of human health and the environment. Alternative 1, however, is not protective of human health because it offers no monitoring or confirmation of existing land-use controls to ensure that future exposures do not occur. Alternative 2 adds provisions for plume monitoring and institutional controls to help prevent future exposure to contaminated groundwater. Alternative 3 adds a focused extraction component and achieves risk-based concentrations 11 years earlier than Alternatives 1 and 2. It also reduces overall migration of risk-based concentrations of plume contaminants by approximately 1,000 feet.

12.2 Compliance with Regulations

All three alternatives are expected to eventually result in compliance with applicable regulations. Alternatives 1 and 2 allow for continued migration of the plume. Because these alternatives involve no active remediation, chemical-specific regulations would be met only when contaminant concentrations decrease below the cleanup standards by natural attenuation. Alternative 2 includes monitoring to confirm this occurs; Alternative 1 does not. Alternative 3 includes active treatment to ensure that applicable standards are met.

12.3 Long-Term Effectiveness and Permanence

The source area has been removed so residual soil contamination is unlikely to compromise the permanence of the remedial alternatives once completed.

Alternatives 1, 2, and 3 would all permanently and effectively achieve the cleanup goals; however, time to cleanup would vary.

12.4 Reduction of Toxicity, Mobility, or Volume through Treatment

Alternative 3 reduces the toxicity, mobility, and volume of contaminated groundwater through treatment. Alternative 3 would extract 0.08 Kg of RDX during treatment and would reduce the concentrations of the RDX plume to below 0.6 µg/L within six years of startup (2016). Alternatives 1 and 2 are not treatment alternatives and, therefore, do not reduce toxicity, mobility, or volume through treatment. However, without active treatment, RDX mass would be reduced through natural attenuation to below the HA of 2 µg/L by 2013 and the 10^{-6} risk-based concentration of 0.6 µg/L by 2027.

12.5 Short-Term Effectiveness

As the only alternative with active remediation, Alternative 3 would cause the greatest environmental impact to surrounding natural resources and includes the installation of an extraction well, and associated piping, to a containerized treatment system. The only environmental impact of Alternative 1 and 2 would be from abandonment of the current monitoring-well system.

Alternative 3 would result in the most secondary impact to the environment due to air emissions from the generation of electricity required to operate the extraction, treatment, and reinjection system. Alternative 3 would have the most secondary impacts from motor vehicle use during construction, operation and maintenance, and plume monitoring. Alternative 1 would have the least secondary impact since no additional operation and maintenance or plume monitoring would be required.

Alternative 1 would have the least impact on the community or workers because construction is minimal. Alternative 3 would have the greatest impact because of the construction involved.

12.6 Implementability

None of the alternatives are limited by administrative or technical feasibility. Alternative 1 is the most easily implemented alternative since it requires no further action other than abandoning groundwater monitoring wells and preparing close out documentation. Alternative 2 is the next most easily implemented alternative since only groundwater monitoring and institutional controls implemented, in addition to the requirements of

Alternative 1. Alternative 3 is the most difficult alternative to implement since it also includes the installation of an extraction well, and a containerized treatment system as well as new piping/power lines. The conceptual location of the extraction well is on private property. This location will require a property access agreement with the landowner. Likewise, any additional new monitoring wells installed off base will also require access agreements.

12.7 Cost

Alternative 1 is the least expensive alternative with a total estimated cost of $109,725 Alternative 2 is the next least expensive alternative with a total estimated cost of $1,873,425. Alternative 3 is the most expensive alternative with a total estimated cost of $3,736,526.

12.8 State Acceptance

This criterion will be addressed in detail following comments on the Remedy Selection Plan.

12.9 Community Acceptance

This criterion will be addressed in detail following comments on the Remedy Selection Plan.

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FIGURES

TABLES

ANIMATIONS (Included on CD only)

Animation 11-1
L Range Model - RDX Plume Under Ambient Conditions (Alternatives 1 and 2)

and

Animation 11-2
L Range Model - RDX Plume with Active Pumping (50 gpm) (Alternative 3)

APPENDICES

Appendix A

Soil Sample Analytical Results

(Included on CD only)

Appendix B

L Range Munitions Source Assessment

Appendix C
Feasibility Study Cost Estimate