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Environmental Impacts of Military Range Use:

An investigation and summary of what we have learned after 12 years at Massachusetts Military Reservation (MMR) and implications for the continued use of military ranges in the United States.

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Pictures From Previous Page - Clockwise from Top Left

PICTURE 1 - Soil sampling on a military range[1]

PICTURE 2 - Low-order bomb found on the impact range at Camp Guernsey, Wyoming.[2]

PICTURE 3 - Bullets and casings of small arms ammunition.[3]

PICTURE 4 – Residue collection chamber.[4]

[1] (Thomas F. Jenkins T. A., 2004)
[2] (Thomas F. Jenkins S. T., 2005)
[3] (Jay L. Clausen, 2010)
[4] (Jay L. Clausen, 2010)

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Environmental Impacts of Military Range Use:

An investigation and summary of what we have learned after 12 years at Massachusetts Military Reservation (MMR) and implications for the continued use of military ranges in the United States.

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Abstract

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The Massachusetts Army National Guard operates the Massachusetts Military Reservation (MMR), located on Cape Cod. In 1997, MMR received the first of four Administrative Orders (AO) from the Environmental Protection Agency (EPA) due to concerns over potential groundwater contamination in the training area and range complex. The second AO issued in April of 1997 prohibited the use of the artillery, mortar, and small arms ranges at MMR. This was the first time that military training on an active military range had been stopped by the EPA. The ARNG has spent upwards of $350 million over the last 12 years to study and remediate contamination as stipulated by the EPA. As of this date the AOs have not been closed and the ARNG still cannot use the ranges at MMR. Would MMR set a precedent that would threaten training on other military ranges? This study will review what the Army has learned about the impacts of military ranges on the environment. This knowledge has important implications for the continued use of the Army's ranges to conduct realistic live-fire training.

TABLE OF CONTENTS

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Introduction

Military ranges contribute significantly to our national defense. The Army must work to ensure that it can continue to use its ranges to train soldiers on critical tasks that will help save lives and protect our soldiers in combat environments. When the Environmental Protection Agency (EPA) initiated enforcement actions at Massachusetts Military Reservation (MMR) in 1997 on the grounds that military training and other activities on the military ranges were contaminating the groundwater under Cape Cod and later stopped the training on military ranges, it was a serious threat to national security that many thought could threaten the training occurring on other military installations across the United States. EPA "contended" that the potential impacts of the activities occurring (or that had occurred in the past) on the ranges at MMR constituted a 'substantial' and 'imminent' threat to the groundwater. What was significant is the military did not have any information to prove otherwise. The military did not have sufficient data for the ranges there or, for the most part, at other ranges to show the impacts of military ranges on the environment. It would have been beneficial for all affected parties to proceed without enforcement, but that was not to be. Perhaps the Army did not move fast enough, or enforcement was a result of the combination of community activism and regulatory pressures surrounding the contamination and cleanup efforts at Otis Air Base (the southern portion of MMR) after it became a Superfund site in 1989 due to extensive groundwater contamination from fuel spills and aircraft maintenance. This paper focuses less on why the enforcement actions occurred and how they have progressed and more on what we have learned in the 12 years since EPA issued the first Administrative Order (AO) which spurred the Army to accelerate its study of the environmental impacts of military ranges. The ensuing investigations required by the enforcement action at MMR and the studies it spawned throughout the Army, have provided the military with valuable lessons about the impacts of military range training on

the environment and the implications for other military ranges. This information will demonstrate to the public and regulators that the Army has an improved understanding of the impacts of military ranges on the environment. The knowledge gained will help to provide assurances that military activities and their impacts to the environment can be managed appropriately to ensure minimal risk to human health and the environment and strike a balance between acceptable risk and national security.

The Importance of Military Ranges

The United States maintains a strong national defense to defend its territory and the valuable natural resources that surround us. The military must have the ability to train to meet their national defense missions. The military must maintain critical skills in a wide variety of tasks and missions and maintain a level of readiness to respond to a wide range of crises. The majority of military training occurs on military installations here in the United States. One of the most important venues for military training is on our military ranges. The Army, because of its land-based mission, relies heavily on training conducted on military ranges, that includes critical tasks for individuals and collective training for units.

> "The need to train as we fight is fundamental to our armed forces. Ranges are some of our most valued assets for they provide contiguous, unencumbered space to replicate, as closely as possible, the operational environment of an assigned mission. Installations and ranges are the foundation of our security because they are critical to maintaining the readiness and mission effectiveness of the United States (U.S.) military. These assets must be available when and where needed, with the capabilities to support current and future military mission requirements." [5]

The use of military ranges is critical to the readiness of our soldiers as they train to meet the wide variety of missions they face worldwide, especially in Iraq and Afghanistan. The conflicts in Afghanistan and Iraq and the requirements of counterinsurgency (COIN) operations and stability

[5] (Sustainable Range Report , 2009)

operations underscore the importance of small arms proficiency. The Army's 'clear, hold and build' strategy requires close contact with the community, the protection of civilians and prevention of collateral damage that necessitate the use of small arms and not the reliance on our major advanced weapons platforms. The ability to train with the equipment they will use in war and to maintain proficiency in the use of small arms is critical to our soldier's survival on the battlefield. Nothing can be more elemental to the mission of the Army. The focus of this paper is on the need for the military to be able to train on military ranges while at the same time understand the potential impacts of training on the environment and the risks of potential off-range impacts.

> The Army Strategy for the Environment states that: "It is our obligation to ensure that our Soldiers today – and the Soldiers of the future – have the land, water, and air resources they need to train; a healthy environment in which to live; and the support of local communities and the American people."[6]

Massachusetts Military Reservation (MMR)

MMR is a 22,000 acre installation located on upper Cape Cod and includes parts of Bourne, Sandwich, Mashpee townships and is adjacent to the town of Falmouth. [7] MMR has a long history as a military installation for the Army, the Air Force, the Army and Air National Guard, and the Coast Guard. The boundaries and users of MMR have varied over the years and has shifted back and forth between the Army, Air Force, National Guard (Air and Army), and the Coast Guard. For the most part MMR is on land owned by the Commonwealth of Massachusetts that is leased to the Department of the Army/Air Force. Essentially MMR has three distinct areas that are managed separately; Camp Edwards, run by the Massachusetts Army National Guard (MAARNG) which consists of the northern 15,000 acres of military ranges and training areas; Otis Air National Guard Base; and the Coast Guard's Air Station Cape Cod. The focus of

[6] (Army Strategy for the Environment, 2004)
[7] (MMR IRP Website, 2010)

this study is on the Camp Edwards section of MMR; the northern 15,000 acres that is run by the MAARNG and the enforcement actions taken by the Environmental Protection Agency (EPA) related to the activities on the military ranges there. For consistency, MMR will be used throughout this document to refer to the Camp Edwards portion of MMR. This is not meant to be a definitive technical review for environmental professionals, but more a general treatise for Army staff and others to understand the limited applicability of the enforcement actions at MMR to other ranges, but at the same time, and more importantly, to review what we have learned from MMR and other range studies about the impacts of military ranges on the environment that can apply to all military ranges.

A brief history of environmental issues related to Otis Air National Guard Base is warranted. The upper Cape Cod area is no stranger to environmental problems. In the early eighties the Air National Guard began investigating potential contamination in soil and groundwater. Contaminants detected included volatile organic compounds, polychlorinated biphenyls, poly-nuclear aromatic hydrocarbons, semi-volatile organic compounds, and waste oils and metals.[8] The contaminated areas found were the result of historic chemical/fuel spills, fire training activities, landfills, and drainage structures and effluent from the former sewage treatment plant. Monitoring had also detected contaminants in several hundred private wells (all of which are now on municipal water) and in one town well (which is shut down).[9] In 1989, Otis Air National Guard Base was listed on the Environmental Protection Agency's (EPA) National Priorities List (NPL) or Superfund list and a Federal Facility Agreement (FFA) was signed in 1991 (and subsequently amended in March 2000) governing the Superfund cleanup. [10]

[8] (Installation Restoration Program (IRP), 2010)
[9] (EPA Waste Site Cleanup & Reuse in New England, 2010)
[10] (EPA Waste Site Cleanup & Reuse in New England, 2010)

The Superfund investigations at Otis Air Base led to increased concerns from EPA and the public over the potential of even more groundwater contamination coming from the training activities on the northern 15,000 acres or Camp Edwards. In response the National Guard Bureau (NGB) formed the Impact Area Ground Water Study Program (IAGWSP) and began investigations under their Installation Restoration Program (IRP). The IAGWSP found contamination in the soils and groundwater just outside the training areas. Despite NGBs early investigation efforts, the EPA took action against the NGB, fearing there was a potential threat of contamination of groundwater from both past and current activities on the military ranges and training areas.

Of particular significance is the EPA's designation of the Cape Cod Aquifer underlying MMR as a sole source aquifer under the Safe Drinking Water Act in 1982.[11] The Cape Cod aquifer provides drinking water for 200,000 year-round and 500,000 seasonal residents of Cape Cod.[12] The ranges at MMR lie directly over the Sagamore Lens, a major groundwater recharge area for the aquifer. The apex of the Sagamore Lens lies under the southeast corner of the Impact Area from which groundwater flows radially in all directions. Except on extreme slopes, surface water runoff at Camp Edwards is virtually nonexistent due to the highly permeable nature of the soils and aquifer material. [13]

Administrative Orders

In 1997, the EPA issued the first of four Administrative Orders (AOs). The first AO issued in February 1997 ordered the National Guard to conduct a study of the effects of military training

[11] (Cape Cod Acquifer FR, 2010)
[12] (EPA Waste Site Cleanup & Reuse in New England, 2010)
[13] (Judith C. Pennington, 2004)

on groundwater.[14] There was minimal evidence showing that residues from the ranges were getting into the groundwater. The military had not at the time, done any significant sampling on ranges, so therefore did not have the data to refute the contention that the ranges were a threat to groundwater at MMR. EPA's first AO (February 1997) essentially required the ARNG to do the necessary investigation to determine the impacts of military training on the groundwater. Unsatisfied with the progress of the military, EPA issued a second AO in May of 1997. EPA took the unprecedented step of "suspending most military training at Camp Edwards, including all use of live explosives, propellants, flares and lead bullets" - the first time in our country's history that military training activities had been halted by the EPA due to environmental and public health concerns. [15]

In January of 2000, EPA issued AO #3, which required the National Guard Bureau and the Massachusetts National Guard to conduct rapid response actions, feasibility studies and remedial actions to address contamination in certain areas of the training ranges and Impact Area. It required the NGB to undertake a feasibility study to address unexploded ordnance (UXO) and munitions, which have been disposed of or fired at the training ranges and impact area. It also required the NGB, upon approval from EPA, to implement remedial measures relating to UXO and munitions. AO #4 was issued on January 4, 2001 under the Resource Conservation and Recovery Act (RCRA) to the National Guard Bureau. This order requires that munitions found subsurface or in burial pits be properly stored and disposed of in a Contained Detonation Chamber (CDC), or by other means which prevent the release of explosives, metals and other contaminants into the environment.[16] "All four AOs were issued under the agency's emergency powers to prevent imminent and substantial endangerment to public health. The first three

[14] (Waste Site Cleanup & Reuse in New England, 2010)
[15] (Waste Site Cleanup & Reuse in New England, 2010)
[16] (Administrative Orders , 2010)

orders were issued under the Safe Drinking Water Act (SDWA), the fourth under the Resource Conservation and Recovery Act."[17]

Groundwater Study and Cleanup Overview

Although not specifically about the enforcement actions and clean-up at MMR, a brief overview of the cleanup at MMR is warranted. The location of MMR in a densely populated area over a sole-source aquifer, and the adjacent Otis Air Base Superfund Site make it a unique site. The EPA's use of the SDWA, the heightened sensitivity of the community and heavy political involvement has created a unique regulatory situation at MMR. This unique situation and the inexplicable fact that after 12 years of investigation and clean-up, none of the AOs have been closed or resolved make the enforcement action/cleanup of limited applicability for other ranges. The following is a brief description to show the scope of the project. Over $350 million has been spent at MMR, which makes it the most expensive environmental efforts the Army has ever undertaken using operations and maintenance (O&M) funding. This means that the cost of MMR has come at the expense of other ARNG O&M requirements, whereas most environmental cleanups are funded through the Defense Environmental Restoration Account. This additional factor adds to MMRs uniqueness and further limits its applicability. The following is an extract from the IAGWSP Overview and Update (2007).[18] For additional details see Appendix A.

Investigations to Date

- 14 sites are being investigated based on historical activities.
- 950 groundwater monitoring well screens have been installed in 470 locations.
- 50,000 soil samples and18,000 groundwater samples have been analyzed to look for contamination.
    - 2 primary groundwater contaminants have been identified - RDX and perchlorate.
    - Primary soil contaminants include RDX, other explosives, propellants, metals and perchlorate.
- 9 sites with groundwater contamination have been identified.

[17] (Waste Site Cleanup & Reuse in New England, 2010)
[18] (Impact Area Groundwater Study Program Overview and Update, 2007)

    - 8 areas of groundwater contamination contain both RDX and perchlorate.
    - 2 areas of groundwater contamination contain only RDX.
    - 1 area of groundwater contamination contains only perchlorate.
- 12 areas of soil contamination have been identified. Rapid Response Actions conducted at several sites have resulted in:
    - 50 tons of lead being removed from 16 small arms range berms.
    - 48,000 tons of soil being removed from 7 source areas and treated using thermal desorption. 700 tons of soil were removed and disposed of off-site.

Cleaning Up Groundwater

- Pump and treat systems are in place at the three places with the highest levels of groundwater contamination – Demolition Area 1, the J-2 Range North, and the J-3 Range.
- Systems are treating more than 765 million gallons of groundwater per year.
- It is expected to take 11 to 16 years to return groundwater to health-based levels.
- **None of these areas of groundwater contamination are impacting public or private drinking water supplies. The contamination is being addressed to ensure drinking water supplies are not impacted in the future.**

The investigations and clean-up at MMR continue, as of this date, none of the AOs have been closed or resolved. Other than the limited use of a single small arms range as part of a pilot study, the ban on most military training remains in effect almost 12 years later. Although the story is still unfolding, MMR and the research it spawned across the Army have had a tremendous impact on the military's understanding of the impacts of military ranges on human health and the environment. Because the enforcement actions at MMR were based on the SDWA and specifically on the threat to human health from contamination of drinking water, the work at MMR and other studies are focused mainly on the threat to groundwater and (therefore human health), not the overall impacts to the environment.

<u>What we have learned</u>

In general, the Army has learned a great deal about specific impacts of military ranges on the environment since EPA issued its first AO in 1997. This knowledge puts the military in a much better position to assess the impacts of military ranges on the environment than in 1997. We

know that the use of military ranges can lead to the deposition of residues onto the ground and that the amount and distribution of those residues are dependent on a number of variables. We also know more about the 'fate and transport' of those residues in soil and or groundwater. We know that these complex interactions are influenced by a variety of factors that can vary greatly for different types of residues. The Army has also learned there is a need for additional research and study on the impacts of military ranges.

Military Munitions Rule

Two consequential events happened in 1997 within the same month that were at opposite ends of the spectrum for military training and oddly enough shared the same acronym. One resulted in historic cooperation between the EPA and the DOD in developing likely the most important environmental regulation for military ranges, while the other saw the EPA take aggressive enforcement action resulting in the first military range ever shut down by the EPA.

The Military Munitions Rule (MMR) was published in the Federal Register on 12 February 1997 as an amendment to the Resource Conservation and Recovery Act (RCRA). The most important contributions of the munitions rule include:

- Definitions of military range, military munitions and unexploded ordnance (UXO)
- Definitions of when the two subsets of "used" and "unused" military munitions would become a waste under the Resource Conservation and Recovery Act (RCRA) especially as it applied to active military ranges.
- It also defined certain activities on active ranges that constitute training activities and not "waste disposal" activities subject to RCRA.
- Provided a framework that promotes reuse and recycling of military munitions that may have had to be treated or disposed of as "hazardous waste" previously.

The Munitions Rule represented a tremendous leap forward in responsible regulation. The EPA worked closely with the Department of Defense to craft a regulation that was protective of the environment, but did so in a way that recognized the role of the military and the importance of

national security. Of particular significance for military training and range management as explained in the preamble of the Munitions Rule:

> "Military munitions are not a solid waste for regulatory purposes: 1) when a munition is used for its intended purpose, which includes when a munition is used for the training of military personnel and of explosives and emergency response specialists: when a munition is used for research, development, testing and evaluation; and when a munition is destroyed during certain range clearance operations; and (2) when an unused munition, including components thereof, is repaired, reused recycled, reclaimed or disassembled reconfigured, or otherwise subjected to materials recovery activities."[19]

Additionally, the definition for unexploded ordnance (UXO) was codified in federal regulation as:

> "Unexploded Ordnance (UXO) –means military munitions that have been primed, fused, armed, or otherwise prepared for action, and have been fired, dropped, launched, projected, or placed in such a manner as to constitute a hazard to operations, installation personnel, or material and remain unexploded by malfunction, design, or any other cause.[20]

UXO continues to be one of the most difficult concerns to deal with on military ranges. The Munitions Rule has helped shape or limit the impact of the enforcement actions at MMR. AO#2 was originally issued under the SDWA and RCRA, but RCRA was removed after it was challenged based on an inconsistency with the Munitions Rule. The Munitions Rule also helped limit the scope of AO#4 in paragraph 59 - "this order does not apply to military munitions (including UXO) which have been used for their intended purpose and have not been subsequently disposed of or buried on the training ranges and Impact areas."[21]

Prior to 1997 detailed records were not kept on what was fired on military ranges. As part of the AOs the EPA compelled the ARNG to do extensive archive search reports to help collect information on the number and types of munitions that were used on the ranges. The Military Munitions Rule Implementation Policy made it a requirement to keep detailed records on the

[19] (Military Munitions Rule, 1997)
[20] (40 CFR 266.201, 2010)
[21] (Administrative Order As Modified For Use of Controlled Detonation Chamber for Waste Munitions, 2001)

number and type of munitions fired on military ranges.[22] To determine or research potential impacts of military ranges it is essential to know what and how much you are firing on specific ranges.

Past Practices

Most of the military's ranges have been operating since at least the WWII era and some much longer. Similar to other environmental problems, the military must address and re-examine what they did prior to environmental regulations. So as the military tries to determine the impacts of military training on land that has been used for over 50 years, they have to account for the impacts related to past practices and actions that the military no longer engages in. For example, burial of unused or excess munitions, and certain testing practices that occurred in the past on the same range areas in use today may have or be contributing to the residues or compounds found in the soil and groundwater. This makes it difficult to determine if the residues you are finding or the "plume" came from recent or current activities or from "past practices". From a "clean-up" perspective, it may not matter where the substances came from, but from a range use perspective and military mission this distinction can be very important.

The archive search reports revealed a number of disposal and treatment activities associated with weapons testing conducted by contractors on MMR. Specifically actions by Textron Systems Corporation (TSC) that led to perchlorate contamination of the J ranges:

> "From 1968 to 1999, Textron Systems Corporation (TSC) or its predecessors, under contracts with the Department of Defense conducted munitions testing in the area of the J-Ranges at MMR. Excess explosives, off specification propellants, unexploded ordnance, excess munitions and scrap metal were open detonated or burned in an unlined detonation pit and burn box in the J-1 and J-3Range areas."[23]

[22] (Military Munitions Rule Implementation Plan, 1997)
[23] (Energy and Environmental Affairs, 2008)

Precedence

One of the biggest worries after MMR received the AOs and military training was stopped by the EPA for the first time, was that a dangerous precedent was being set that would jeopardize military training across the country. Conversely, the ensuing 12 years has shown that the enforcement action at MMR has not set a precedent that would lead to the closing of other ranges across the country by the EPA.

Terminology

The discussion of impacts of military ranges on the environment requires an understanding of munitions and range terminology. Energetic compounds are those chemicals used in both military explosives and propellants.[24] Propellants propel or push the round down range to its intended target. In addition to propellants, artillery or mortar rounds also contain explosives within the round designed to detonate on contact or are fused to explode at or near a target in an impact area. For most small arms, a propellant is used to fire an inert projectile that will go down range. The majority of the projectiles are lead or copper-jacketed lead. Projectiles land in the target area, in a berm, or on the ground, in front of or beyond the target. In general, propellants are found at or near firing points and firing lines and explosives are found at target areas throughout the impact area and on demolition ranges.

What to Look For

The Army began to look at the types of residues that might be deposited based on the different types of military ranges. An Engineer Research and Development Center (ERDC) study identified the following energetics for the majority of military ranges; Explosives - 2,4,6-trinitrotoluene (TNT), 1,3,5-hexahydro-1,3,5-trinitrotriazine (RDX), 1,3,5,7-tetrahydro-1,3,5,7-

[24] (Thomas F. Jenkins, 2005)

tetranitrotetrazocine (HMX) and Propellants - Nitrocellulose (NC), 2,4-dinitrotoluene (DNT), Nitroglycerin (NG), and Nitroguanidine (NQ)[25] The study compiled the data from 27 ranges. The potential residues and how they were distributed varied based on the weapon system used, the types of munitions, and specific areas of the ranges. For example, at an artillery range you may have residue around the firing points and around the impact area, but the majority of the total acreage of the range may be free of residues. The study linked the energetic compounds with the type of munition used as follows:

- Antitank range impact areas - HMX - firing points – the propellant is NG
- Artillery and mortar impact areas - TNT and/or RDX - firing points - 2,4-DNT or NG
- Hand grenade ranges - RDX and TNT
- Bombing ranges - TNT
- Demolition ranges – RDX and NG and 2,4-DNT (from the burning of excess propellant.)[26]

In a 2003 study, based on data for more than 200 analytes from over 15,000 environmental samples taken at MMR found that assessment of groundwater and soil contamination at military ranges can be narrowed down to RDX, HMX, perchlorate, TNT, and their transformation products. Testing for volatile organic compounds, semi-volatile organic compounds, and tentatively identified compounds can be avoided. [27]

Factors Affecting Deposition

Having ascertained what has been used on a range and what residues to look for the next step is to begin to look at factors that may affect deposition and distribution. MMR was the impetus for a large number of studies that have been conducted on other military installations across the United States.

[25] (Thomas F. Jenkins, 2005)
[26] (Thomas F. Jenkins, 2005)
[27] (Clausen, Robb, & Korte, 2003)

Prior to MMR the predominant paradigm for artillery and mortar rounds was that the explosives in the munitions were consumed in the explosion. The initial data from MMR challenged that assumption. Subsequent studies have shown that for properly functioning munitions, the original paradigm was essentially true. A series of studies conducted on snow, that helped to isolate residues from previous range usage have revealed:

> "Findings show that the high-explosives filler in the main charge of howitzer rounds, mortar rounds, and hand grenades is efficiently consumed during live-fire operations that result in high-order detonations. Analysis of detonation residues collected on snow following the live-fire detonations of three different mortar rounds, one type of howitzer round, and one type of hand grenade, all filled with Composition B, shows that on average 99.997 percent or more of the RDX and TNT were consumed. " [28]

There are additional factors that affect distribution. As mentioned above, when a munition operates as intended and explodes – a high order detonation – more of the explosive is used up in the blast, while a low order detonation may result in incomplete explosion that "consumes" less of the explosive material. A round may hit the ground and not explode, or may crack open, allowing residues to be deposited in the ground. "Incomplete or low order detonations or rounds that crack open are most likely the greatest contributors of explosives residue on ranges. Additionally, any unexploded ordnance (UXO) that is on the range may be hit by subsequent rounds that result in a low order detonation.[29]

Demolition ranges are where engineers and EOD personnel use explosives to train on a number of critical tasks that include creating obstacles, destroying obstacles, other counter-mobility tasks and range clearance operations that could potentially include blow-in-place (BIP) for training in the destruction of enemy captured munitions, or for UXO that may be too dangerous to move

[28] (Judith C. Pennington, 2004)
[29] (Alan D. Hewitt, September 2003)

off-range. Range clearance operations or other BIP operations may contribute residues if an "insufficient" charge is used resulting in a low order detonation.

> "The most important factor controlling residues is the incidence of low-order or incomplete detonations, which varies among weapon systems. Low-order detonations from fired rounds, from incomplete detonations during blow in place (BIP) of UXO, and as a result of UXO detonation from metal fragments of incoming rounds are the greatest sources of residues on the ranges. [30]

Another area of work that was initiated, or at a minimum was accelerated, by MMR was in terms of UXO investigations. The EPA contended that UXO contributes significantly to soil and GW contamination at MMR. Although often treated as the same on ranges it is important to keep in mind the difference between UXO (see definition) and low order detonations. Low-order detonations are partial detonations that may result in incomplete consumption of the explosives and potential release of those explosive to the ground. On the other hand, UXO that did not crack open upon contact with the ground, are not likely to contribute significantly to contamination of soil or groundwater. In a study of UXO corrosion that covered fourteen sites, 161 UXO items were analyzed for soil characteristics, climate data and extent of corrosion found that only rainfall correlated with extent of corrosion. The majority of UXO in the study had been there for 50-80 years with a maximum of .25 cm of corrosion, which indicate that only thin-cased munitions would be expected to be perforated in that time frame. Of the 161 samples only three were thin-cased. "The UXO studied in this effort were not a significant source of explosives to the unsaturated soil environment."[31] EPA also contends that buried munitions are also a significant source of contamination at MMR. Although not specifically addressed in the study, these findings on corrosion could be extrapolated to apply to buried munitions.

[30] (Thomas F. Jenkins, 2005)
[31] (Chendorain, Stewart, & Packer, 2005)

Understanding of dud rates and low order detonations for different types of munitions could help range managers in trying to limit the amount of residues deposited on a range. This idea is behind the directive by Congress in 2009 to the Department of Defense to "review live fire practices for the purpose of reducing UXO and munitions constituent contamination without impeding military readiness." [32]

Fate and Transport

We now know much more about the fate and transport of those residues in the environment and the range of factors that influence their movement in soil and water or their 'fate and transport.' These factors include the physical properties and geochemistry of soils and groundwater, climate, and the depth to groundwater. The sandy soils of Cape Cod help to accelerate the movement of some residues through the soil and into the groundwater. The depth to groundwater is around 100 feet over most of MMR. Once the residues and where to look for them were determined, studies began to look at what happens to them after they are deposited (fate) and to determine if they are mobile (transport) in soil and/or groundwater.

Small Arms Ranges and Lead

The first thing to examine is small arms ranges because the Army has so many of them and due to the importance of small arms in the current conflicts. In preparation for deployment all soldiers must train on and qualify with their assigned weapon. One of the most surprising and well-documented findings to come out of the studies at MMR is the understanding or knowledge we have of the fate and transport of lead in the ground at MMR. Despite the sandy soils and the mobility of some residues that move quickly through the soil and into the groundwater, lead does not move through the soil more than a few feet, and does not seem to pose a threat to groundwater. Lead was identified as a potential threat to groundwater in the first AO based on

[32] (Public Law 111-84 Section 316, 2009)

its use in most of the small arms training conducted at MMR and its presence in soils across the ranges. Lead, a naturally occurring element is found in the ground with background levels up to 50 parts per billion (ppb) in areas of Massachusetts. The ubiquity of lead in the environment is also related to its widespread use in a variety of products, such as gasoline, plumbing products and paint before it was banned or eliminated from products manufactured in the U.S. Lead can have serious health impacts when it is consumed or ingested by humans especially young children. The dangers of lead are directly related to exposure. The exposure to lead that has been deposited on ranges set aside for military training is very minimal.

The potential for lead getting into surface water runoff is a possible concern in some locations, but has not been as extensively reviewed as the threat to groundwater. The same physical properties of the Cape Cod soils that are responsible for accelerating the movement of RDX and perchlorate through the soil are the same ones that help reduce surface runoff on the ranges at MMR. At ranges where there is surface water runoff, additional measures should be pursued to channel or control the runoff before it leaves the range or enters streams, wetlands or other surface waters. The presence of lead in surface water and in wetlands has been shown to cause problems, so ranges that include surface waters and wetlands must address that concern. Studies from Tango Range at MMR show that nitroglycerin (NG) residue was found in the soil at or near the firing line. The studies show that the NG residue degrades or breaks down within a few meters and is not a threat to groundwater. So the main concern from small arms ranges is lead which is the primary material in most small arms ammunition.

One of the ironies of the investigations at MMR and the identification of lead as a main concern in the AOs is that despite the near perfect conditions for movement of a contaminant through the sandy soil straight into the aquifer, it was found that lead was not getting to the groundwater at

MMR. Even though lead was found throughout the range complex at high levels in the soil, it was not found in groundwater even directly below some of the most heavily used ranges at MMR. A study by Cold Regions Research and Engineering Laboratory (CRREL) assessed the fate of lead on the small arms ranges (SARs) at MMR and specifically if lead was getting into the groundwater at MMR. With over 9,000 soil samples analyzed for lead at MMR concentrations were highest at target areas and firing lines, but with almost no migration downward in the soil. The principle findings of this study are:

- Lead is a relatively immobile element in the terrestrial environment. In addition to forming a range of stable mineral phases in both oxygen-rich and oxygen-poor environments, lead can bind to mineral surfaces directly and can from adsorption complexes on surfaces of quartz, humus, iron oxides, aluminum oxides, manganese oxides, and virtually any mineral with oxygen or sulfur atoms at the surface.

- The principal conclusions are corrosion, dissolution processes are sufficiently slow, and mechanisms for attenuation, such as precipitation and adsorption, sufficiently robust, that lead has not migrated to groundwater.

- It is the conclusion of this study that, lead has not contaminated the groundwater in any significant way based on the absence of lead plumes and only one groundwater monitoring well associated with the small arms ranges had a single low lead detection less than 2 ppb. [33]

Groundwater data collected to date from across Camp Edwards demonstrated no lead contamination from the small arms training, despite the use of lead at the ranges for more than 60 years.

Energetics

Some energetics degrade or disappear fairly quickly in the soil. A recent study at MMR has shown that migration of the propellants NG and DNT beyond the immediate surface area are unlikely and are not a threat to groundwater.

[33] (Clausen, Korte, Bostick, Rice, Walsh, & Nelson, 2007)

> "Overall, the results from this study indicate that residual NG and DNT in weathered, fired propellants are not likely to be mobile below the near-surface layers in the environment at Camp Edwards. But the lack of migration of NG/DNT in the column experiments, coupled with similar field observations, suggests that NG and DNT are not likely to be mobile at this or other military installation.[34]

Although TNT had been identified in AO #2 as a threat to groundwater based on a single sample result found outside the training range and impact areas, TNT has been shown to be a much lower risk than previously indicated.

> "The significant decrease in TNT and aDNTs in groundwater relative to soil is a function of their susceptibility to degradation processes and sorption onto shallow surface soils. Even when the TNT and aDNTs overwhelm the natural microorganisms in the soil, these compounds are rapidly degraded within several hundred feet of where they are introduced into the aquifer."[35]

The bulk of the investigations and cleanup at MMR focus on RDX and perchlorate due to their presence in groundwater. The presence of these in groundwater itself tells us something about the fate and transport of these residues in the conditions present at MMR. Once dissolved, RDX and HMX are the most mobile of the organic energetic compounds deposited on ranges, both vertically, in the soil profile, and horizontally, across the surface. [36]

As RDX and perchlorate are the primary residues of concern at MMR that are reaching the groundwater they continue to be the focus of the continuing investigation and clean-up at the following locations:

- Demolition Area 1 – a groundwater plume of RDX and perchlorate contamination migrating west from the site.
- Demolitions Area 2 – a groundwater plume of RDX is migrating north from the site.
- J-1 Range has two plumes (J1 North and South) of RDX and perchlorate.
- J-2 Range – a groundwater plume of RDX and perchlorate.
- J-3 Range – a groundwater plume of RDX and perchlorate.
- Central Impact Area - a series of finger-like groundwater plumes of mostly RDX and limited amount of perchlorate.

[34] (Jay L. Clausen)
[35] (Judith C. Pennington, 2004)
[36] (Thomas F. Jenkins, 2005)

- Northwest Corner – a groundwater plume of perchlorate with a narrow RDX plume underneath. [37]

The investigation of perchlorate at MMR added significantly to the groundwater study program and elevated the controversy over perchlorate, its risk to the environment and how it would be regulated.

> "Perchlorate (ClO4-) is a soluble anion that forms solid salts with various cations, including ammonium, potassium, sodium, lithium, and magnesium. Once dissolved in water, perchlorate is very stable. It resists degradation in the subsurface and does not readily adsorb to mineral surfaces."[38]

The military uses for perchlorate include solid propellant for rockets, explosives, smoke-producing compounds, simulators and signal flares while non-military uses include pyrotechnics, fertilizers, black powder, air bag inflators, and road flares. Perchlorate also occurs naturally in minerals and can be produced atmospherically.[39]

Prior to 2001, perchlorate was not a concern at MMR, but quickly gained prominence after being found in numerous soil and groundwater samples. The preponderance of perchlorate in groundwater can be attributed to its high mobility relative to the other contaminants.[40] After perchlorate was found at MMR, DOD instituted new guidelines for investigating and sampling for perchlorate and ultimately developed a handbook on perchlorate.[41]

Perchlorate is controversial due to the lack of agreement over the risks to human health that it poses and in setting appropriate regulatory action levels. The EPA does not have a maximum contaminant level (MCL) for perchlorate, but has a drinking water equivalent level (DWEL) of 24.5 ppb, while the Massachusetts Department of Environmental Protection (MADEP) is

[37] (Areas of Concern, 2010)
[38] (DOD Perchlorate Handbook, 2007)
[39] (DOD Perchlorate Handbook, 2007)
[40] (Judith C. Pennington, 2004)
[41] (DOD Perchlorate Handbook, 2007)

promulgating a state MCL for perchlorate of 2 ppb.[42] As a result of the interest and concern over perchlorate and the wide discrepancy in action levels the EPA's Inspector General conducted an impartial review of the research and toxicology behind the perchlorate DWEL of 24.5 ppb and found it to be protective of human health. The review went even further in stating that "potentially lowering the perchlorate drinking water limit from 24.5 ppb to 6 ppb does not provide a meaningful opportunity to lower the public's risk".[43] Despite this finding the cleanup is still being driven by the MADEP level of 2ppb.

The Army's Operational Range Assessment Program (ORAP) likely grew out of MMR and is helping the Army to answer some of the questions raised about the impacts of military training on the environment. The actions at MMR helped the Army focus its ORAP program on the risk of "off-range" impacts that may occur at Army ranges and the assessment of potential exposure pathways and potential receptors for those impacts. The Army has completed its initial assessments for all its ranges and is working on a second phase of assessments for those ranges that required additional assessment.

Conclusions

In 1997, EPA issued AO #1 contending that activities occurring on the military ranges at MMR were causing groundwater contamination that was an "imminent and substantial" endangerment to human health. Now after 12 years of study, it appears that the impacts of the military ranges are not substantial and not imminent. More importantly for the rest of the military, MMR and the research it spawned across the Army has provided valuable information about the impacts of military ranges on the environment that can be applied to all military ranges across the

[42] (Perchlorate fact sheet for Public Water Suppliers, September 2006 , 2006)
[43] (Wilson, 2010)

Department of Defense. The unique conditions at MMR bred a regulatory interaction that is unlikely to occur anywhere else and fortunately has not set a precedent for other ranges.

The Army now has a better idea of what residues are deposited on ranges, what activities and factors affect distribution of those residues and the fate and transport of those residues on the ranges. This information will help the military make decisions about specific types of range uses, where those range uses should occur, and with the development of management practices to reduce or eliminate impacts where possible.

The widely held assumption that the presence of a residue in soil will eventually lead to it getting into the groundwater is not valid for all residues. Of particular significance for the rest of the Army due to the number and widespread use of small arms ranges and their importance to military readiness are the findings from the investigations of lead at small arms ranges.

In light of the studies showing that lead has not impacted the groundwater below MMR and is not likely to for several hundred years, it is difficult to comprehend why the EPA has not lifted the prohibition on the use of the small arms ranges at MMR or modified the AOs to reflect this.

The greatest impacts observed were most likely related more to past practices like disposal, open detonation of excess munitions and contractor use, than from normal range operations.

The scientific data from studies at MMR and across the Army has helped to narrow the concerns over the impacts of military ranges on the environment, with respect to human health. Studies show that there is less to be concerned about in terms of environmental impacts or impacts to human health. The primary residues of concern are RDX and perchlorate due to their presence in groundwater. There is significant debate as to the risks they pose, based on lack of exposure (if not in groundwater being used for drinking water) and in terms of the health risks they pose and the challenge of setting appropriate regulatory standards.

After 12 years of investigation and cleanup at MMR there has been no closure or resolution to any of the AOs. The significant outlay of O&M funding for MMR at the expense of other important ARNG requirements, with no closure or resolution of the AOs, must be closely scrutinized as this does not reflect sound management or responsible stewardship of government resources.

Key Findings

- In 1997 MMR did not have sufficient data to show what impacts the military ranges were having on the groundwater.
- 12 years of study have provided a significant amount of data from sampling, analysis and modeling to determine the impacts military ranges are having on the groundwater at MMR and other military ranges in the United States.
- None of the contamination from MMRs ranges has impacted public or private drinking water supplies.
- Past practices contribute to the deposition of residues on ranges, including burial of unserviceable munitions, excess munitions, and open burning/detonation of waste military munitions.
- The Military Munitions Rule provided necessary clarification as to what types of activities can occur on military ranges, what activities are unlawful and what activities are subject to regulation under RCRA.
- Properly functioning munitions do not significantly contribute to the deposition of energetics' residue on ranges, that the explosives are almost completely consumed in the blast.
- Low-order detonations and UXO that crack open upon contact with the ground have been shown to be a source of residues.
- Similarly BIP operations used in range clearance operations can contribute residues if insufficient charges lead to a low-order detonation of the UXO.
- The activities of contractors engaged in research, development and testing of munitions contributed to the residues found on ranges.
- The problems found at MMR drove the Army to revise their policy on the use of military ranges by contractors engaged in research, development and testing.

- An extensive lead assessment at MMR has shown that lead from the small arms ranges has not impacted the groundwater at MMR, even though it shows up in the soil in high concentrations.

- Residues, like RDX, HMX and perchlorate that were deposited on the ground can get to the groundwater.

- Residues like NG, DNT and TNT that are deposited on ranges and show up in the soil do not show up in the groundwater.

Recommendations

- The Army must ensure that MMR does not drive what the Army does on other ranges. The enforcement actions and the progression of cleanup activities at MMR are a unique situation with limited applicability for other locations.

- Conversely, the Army Environmental Command should ensure that the extensive knowledge and data produced by the investigation and studies at MMR and other ranges is used to inform the development and review of range operations and range management policies and procedures.

- The Army Environmental Command should revise its guidance on the removal of lead from range berms based on the findings on lead's relative immobility and adsorption to soil. The studies bring into question the utility of projects to periodically remove lead from berms, or at least the frequency of those projects.

- The ARNG should seek to have the AOs revised to reflect that after 12 years of study they have not found lead in the groundwater at MMR and petition the EPA to lift the prohibition on the use of small arms ranges.

- The Army should assess compliance with the Military Munitions Rule at all ranges for the handling and storage of military munitions, excess munitions and explosive ordnance disposal personnel training.

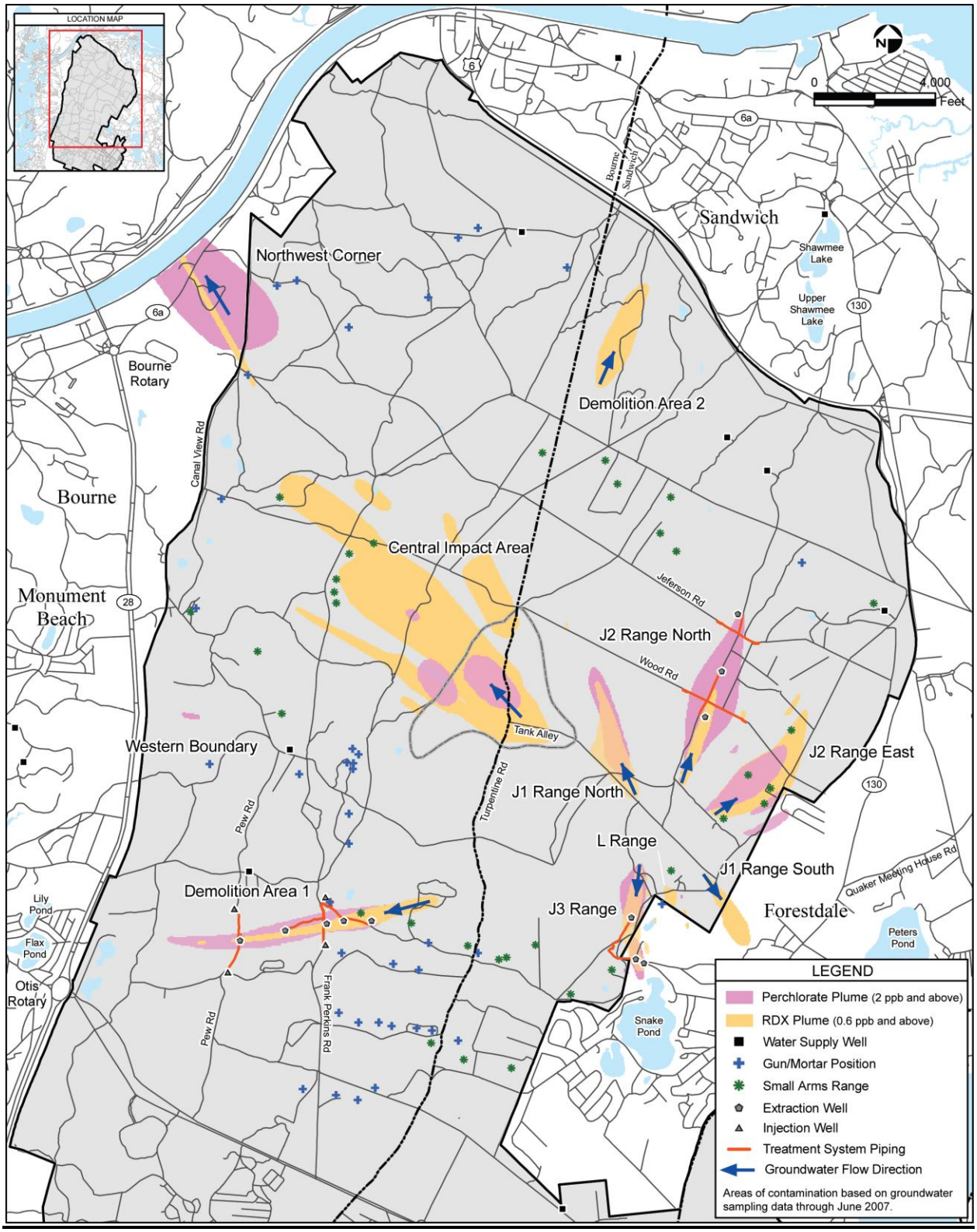
- The Army must ensure information from studies on demolition ranges and BIP operations is used to modify procedures for training demolition and EOD personnel and range clearance operations.

- The Army should continue to study the impacts of military ranges on surface water, because MMR drove the last decade of research to focus mostly on the threat to groundwater.

- The Army should push to incorporate a sustainability approach to the cleanup of groundwater with limited contamination; it would be more efficient and more effective to treat water when it is withdrawn appropriate to the intended use of the water.

- The Army must begin to apply a sustainability review of clean-up projects that assesses environmental and energy consumption impacts of pumping millions of gallons of groundwater a day that is not currently being used for drinking water to remove miniscule amounts of residues (ppb).

Appendix A



Impact Area Groundwater Study Program — Site-wide Map — From IAGWSP **Investigation and Cleanup Update - 2007**

NORTHWEST CORNER

The Northwest Corner site is located along Canal View Road in Bourne and extends from 2,700 feet inside the installation west to the Cape Cod Canal. Past activities included off-post fireworks displays and on-post pyrotechnics use, both of which involved items containing perchlorate, the primary site contaminant.

- Groundwater sampling identified a shallow perchlorate plume and a deeper, smaller RDX plume.
- Area residents are connected to town water.
- More than 250 soil samples were collected. A continuing source area was not identified.

CENTRAL IMPACT AREA

The Central Impact Area site covers 330 acres near the center of the base. It has 49 targets that were used for artillery, mortar and other firing until 1997.

- Multiple finger-like RDX and perchlorate plumes are migrating northwest.
- RDX, other explosives, propellants and perchlorate were detected in soil at various targets.
- This soil and unexploded or partially-exploded munitions are considered potential groundwater contamination sources.
- A soil action removed 800 tons of soil from two targets in 2004

WESTERN BOUNDARY

The Western Boundary site is located on the western side of the installation and extends into the Monument Beach area of Bourne.

- Concentrations near the 2 parts per billion (ppb) state standard for perchlorate were detected in monitoring wells on the installation.
- Intermittent perchlorate detections below 1 ppb were found in four water supply wells and in Monument Beach monitoring wells.
- Perchlorate is currently below detectable levels in the water-supply wells and most of the Monument Beach monitoring wells.
- Only one monitoring well on the installation currently has detections of perchlorate near the state standard.

DEMOLITION AREA 1

The Demolition Area 1 site is a 7.4-acre natural depression that was used from the mid-1970s until 1997 for training and disposal of munitions, fireworks and other items.

- A 2004 source area removal excavated and treated 28,000 tons of contaminated or potentially contaminated soil.
- A groundwater treatment system has cleaned 170 million gallons of groundwater per year since 2004.
- An expanded groundwater system that will treat 476 million gallons per year will begin operation in mid-2007.
- The system is expected to restore groundwater in 11 years.

DEMOLITION AREA 2

Demolition Area 2, located in the northern portion of the installation, is a former demolition training site that was used for training with small explosives charges.

- Source removal, including excavation and treatment of 1,200 tons of contaminated soil, was completed in 2004.
- A plume with RDX is migrating northeast.
- A feasibility analysis is expected in late 2007.

SOUTHEAST RANGES

The Southeast Ranges are comprised of four sites located near the Camp Edwards/Sandwich boundary that were developed for military training in the 1940s. The J-Ranges were used from the 1950s to mid-1990s for a variety of defense contractor activities, including munitions testing and disposal.

J-2 RANGE

- Two areas of groundwater contamination containing RDX and perchlorate have been defined.
- The J-2 North plume, which is now being treated, had the potential to impact a drinking water supply well.
- A cleanup system is reducing contamination and limiting migration of the J-2 North plume by treating 190 million gallons of groundwater per year.
- 8,400 tons of soil were excavated from the J-2 Range in 2004, including source areas for the J-2 North and J-2 East plumes.
- Subsurface investigations being conducted to identify other potential source areas are removing additional soil contamination and metallic items.

J-1 RANGE

- The J-1 North plume, containing RDX and perchlorate, is migrating toward the impact area.
- The J-1 South plume, which contains RDX, is migrating into a residential area supplied by town water.
- A Rapid Response Action treatment system is planned to begin treating contamination from the J-1 South plume and limiting off-post migration.
- Potential source areas are being investigated and removed.

L RANGE

- Small areas of groundwater, contaminated by RDX and perchlorate, are migrating to the southeast from the installation.
- Contaminant concentrations appear to be declining.
- Soil and groundwater sampling indicates the source area is depleted.

J-3 RANGE

- An area of RDX and perchlorate contamination is migrating in groundwater to the south from the installation toward Snake Pond in Sandwich.
- Neither explosives nor perchlorate have been detected in Snake Pond.
- The J-3 source area was part of a 3,500-ton soil removal in 2004.
- A groundwater system is treating 92 million gallons a year.

Bibliography

Administrative Order As Modified For Use of Controlled Detonation Chamber for Waste Munitions. (2001, January). *EPA Docket No: RCRA 1-2001-0014* . Washington DC: Environmental Protection Agency.

Alan D. Hewitt, T. F. (September 2003). *Estimate of Explosives Residue from the Detonation of Military Munitions.* Vicksburg, MS: U.S. Army Engineer Research and Development Center.

Areas of Concern. (2010). Retrieved May 6, 2010, from Impact Area Groundwater Study Program: http://groundwaterprogram.army.mil/cleanup/areas/

(2004). *Army Strategy for the Environment.* Washington DC: U.S. Army .

Chendorain, M. D., & Stewart, L. D. (2004). *Corrosion of Unexploded Ordnance in Soil Environments.* Aberdeen Proving Ground, MD: U.S. Army Environmental Center.

Chendorain, M. D., Stewart, L. D., & Packer, B. (2005). Corrosion of Unexploded Ordnance in Soil - Field Studies. *ENVIRONMENTAL SCIENCE & TECHNOLOGY* , p. 2447.

Clausen, J. L., Korte, N., Bostick, B., Rice, B., Walsh, M., & Nelson, A. (2007). *Environmental Assessment of Lead at Camp Edwards, Massachusetts Small Arms Ranges.* Hanover, NH: Cold Regions Research and Engineering Laboratory, U.S. Army Engineer Research and Development Center.

Clausen, J., Robb, J., & Korte, N. (2003). *A Case Study of Contaminants at Military Ranges; Camp Edwards, MA.* Westford, MA: AMEC Earth and Environmental.

(2007). *DOD Perchlorate Handbook.* Washington, DC: THE DEPARTMENT OF DEFENSE ENVIRONMENTAL DATA QUALITY WORKGROUP.

Energy and Environmental Affairs. (2008). Retrieved May 16, 2010, from Executive Office of Energy and Environmental Affairs: http://www.mass.gov/natural resource damage assessments

(2007). *Impact Area Groundwater Study Program Overview and Update.* Camp Edwards, MA: Army Environmental Command .

Jay L. Clausen, C. S. *Adsorption/Desorption Measurements of Nitroglycerin and Dinitrotoluene in Camp Edwards, Massachusetts Soil.* Hanover, NH: U.S. Army Engineer Research and Development Center (ERDC).

Judith C. Pennington, T. F. (2004). *Distribution and Fate of Energetics on DoD Test and Training; Interim Report #4.* Vicksburg, MS: U.S. Army Corps of Engineers, Engineer Research and Development Center.

Military Munitions Rule. (1997, February 12). *Federal Register* . Washington, DC: US Government Printing Office.

Military Munitions Rule Implementation Plan. (1997, February). *Federal Register* . U.S. Government .

Perchlorate fact sheet for Public Water Suppliers, September 2006 . (2006). Retrieved May 6, 2010, from Massachusetts Department of Environmental Protection: http://www.mass.gov/dep/water/drinking/perchfs.htm#percmcl

Public Law 111-84 Section 316. (2009, October 28). *National Defense Authorization Act for Fiscal Year 2010* . Washington DC: U.S. Government.

(2009). *Sustainable Range Report* . Washington DC : US Army.

Thomas F. Jenkins, S. T. (2005). *Identity and Distribution of Residues of Energetic Compounds at Military Live Fire Training Ranges.* U.S. Army Engineering Research Center.

Wilson, M. (2010). *Office of Inspector General Scientific Analysis of Perchlorate Report No. 10-P-0101.* Washington, DC: Environmental Protection Agency.