Military Impact Areas as a Source of Environmental Contamination

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Submitted to the Department of Civil and Environmental Engineering on 7 May 1997, in partial fufillment of the requirements for the degree of Master of Engineering in Civil and Environmental Engineering at the Massachusetts Institute of Technology.

Abstract

In recent years, military impact and training areas have come under considerable scrutiny as possible contaminant sources. Concerns about the possibility of contaminants such as heavy metals, explosives, and explosives by-products leaching into the groundwater have resulted in remedial investigations at several closed installations. Until very recently, the study of explosives contamination from active installations has been avoided by the military community. As a result, very little is known about the fate and transport of ordnance residuals leftover from normal training operations. This project attempts to cover some of the issues surrounding this potential problem by (1) providing background information on explosives and how they work, (2) discussing the physical and chemical characteristics along with the fate and transport mechanisms of some of the most common explosive compounds, and (3) developing an approach for conducting an impact area study by addressing some of the specific problems such a study may encounter. Current investigations at the Massachusetts Military Reservation, Cape Cod, Massachusetts and the Marine Corps Air Ground Combat Center, Twentynine Palms, California are used as reference points throughout the thesis.

Such a study must be flexible and thorough. Any contamination caused by normal training operations will be extremely dispersed, non-quantifiable, and essentially non-existent. The contaminants of concern have a wide array of characteristics, which may make a comprehensive study very expensive as well as challenging. However, the uncertainty of past use of an area may combine with sensitive environmental issues like those found on Cape Cod to require an investigation. When dealing with an impact area, safety will be one of the most important considerations, primarily due to the physical hazards of unexploded ordnance.

The two studies used as references for this thesis are both scheduled to be completed this summer, with data available in the fall. This information will aid in decisions to conduct studies at other sites, but will not necessarily preclude any further studies, since every installation is unique.

Thesis Advisor: Peter Shanahan, Guest Lecturer, MIT

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Acronyms & Abbreviations

AAP	Army Ammunition Plant
AEC	Army Environmental Center
AFCEE	Air Force Center for Environmental Excellence
ANG	Air National Guard
ARNG	Army National Guard
ATSDR	Agency for Toxic Substances and Disease Registry
CAX	Combined Arms Exercise
CEC	Cation Exchange Capacity
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CESMU	Controlled Environment Soil-core Micrcosm Unit
CSM	Conceptual Site Model
DoD	Department of Defense
DIN	Dissolved Inorganic Nitrogen
DNT	2,6 or 2,4-Dinitrotoluene
EDB	Ethylene Dibromide
EIS	Environmental Impact Statement
EOD	Explosives Ordnance Disposal
EPA	Environmental Protection Agency
ESE	Environmental Science and Engineering
ETA	Engineering Technologies Associates
f_{oc}	Fraction of Organic Carbon in the soil
HE	High explosives
HMX	Cyclotetramethylenetetranitramine
HSDB®	Hazardous Substances Data Bank
IRP	Installation Restoration Program
K_d	Partitioning coefficient, ~ concentration sorbed/aqueous concentration
K_{oc}	Organic Carbon distribution coefficient
K_{ow}	Octanol-Water distribution coefficient
LRWS PAT	Long Range Water Supply Process Action Team
MAARNG	Massachusetts Army National Guard
MADEP	Massachusetts Department of Environmental Protection
MCAGCC	Marine Corps Air Ground Combat Center (Twentynine Palms, California)
MCL	Maximum Contaminant Level
MMR	Massachusetts Military Reservation
NEPA	National Environmental Policy Act
NGB	National Guard Bureau
OB/OD	Open Burn/Open Detonation
PETN	Pentaerythritol Tetranitrate
PPB	Parts per Billion
PPM	Parts per Million
RCRA	Resource Conservation and Recovery Act
RDX	Cyclotrimethylenetrinitramine (Cyclonite)

SOP	Standard Operating Procedures
SSG	Soil Screening Guidance (USEPA)
SSL	Soil Screening Level
Superfund	See CERCLA
SVOC	Semi-Volatile Organic Compound
TNB	1,3,5-Trinitrobenzene
TNT	2,4,6-Trinitrotoluene
USACE	US Army Corps of Engineers
USATHAMA	United States Army Toxic and Hazardous Materials Agency (now AEC)
USGS	United States Geologic Survey
USMC	United States Marine Corps
UXO	Unexploded ordnance
VOC	Volatile Organic Compound
WES	Waterways Experiment Station
WHPA	Well-head Protection Area (Zone II Area)

Section 1
Introduction

1.1 Background

In recent years, military impact and training areas have come under considerable scrutiny as possible contaminant sources. Concerns about the possibility of contaminants such as heavy metals, explosives, and explosives by-products leaching into the groundwater have resulted in remedial investigations at several closed installations. Until very recently, the study of explosives contamination from active installations has been avoided by the military community. As a result, very little is known about the fate and transport of ordnance residuals (Propellants, Explosives and Pyrotechnics [PEPs]) left over from normal training operations

Two open and operating (active) military installations are currently conducting studies of their live-fire impact areas as potential contaminant sources. These are the Massachusetts Military Reservation, on Cape Cod, Massachusetts, and the Marine Corps Air Ground Combat Center, located in the lower Mojave desert in California. Both bases face unique problems and have different approaches and methodologies for conducting a study and therefore provide a good comparison. The following sections outline the characteristics of each base, explains why they are conducting studies, and describes the regulatory framework within which the studies are being undertaken.

1.1.1 The Massachusetts Military Reservation (MMR)

The Massachusetts Military Reservation (MMR) occupies approximately 22,000 acres of western Cape Cod (Figure 1-1), of which approximately seventy percent, or 14,000 acres, consists of a live-fire impact area (Figure 1-2). The base is the home of both active and reserve military units from all branches of service. It is also the home of the only live-fire ranges in the New England area. The availability of these ranges has significantly increased in importance during the past 4-5 years. As each of the branches of service has down-sized its active component, they have developed total force concepts that rely heavily on reserve units in the event of a major conflict. The MMR is critically located for many New England reserve units, since travel to other ranges would be time and cost prohibitive.

During 1994, over 1.7 million small arms ammunition and over 3100 mortar rounds (Table 1-1) were expended on the live fire ranges at Camp Edwards (NGB 1996). Live-fire training is a crucial part of training combat troops, since no simulator can completely duplicate the feel, noise, and results of firing live ammunition. Simulators also fail to capture the weapons handling and maintenance requirements that accompany realistic live-fire training. The live-fire training that currently

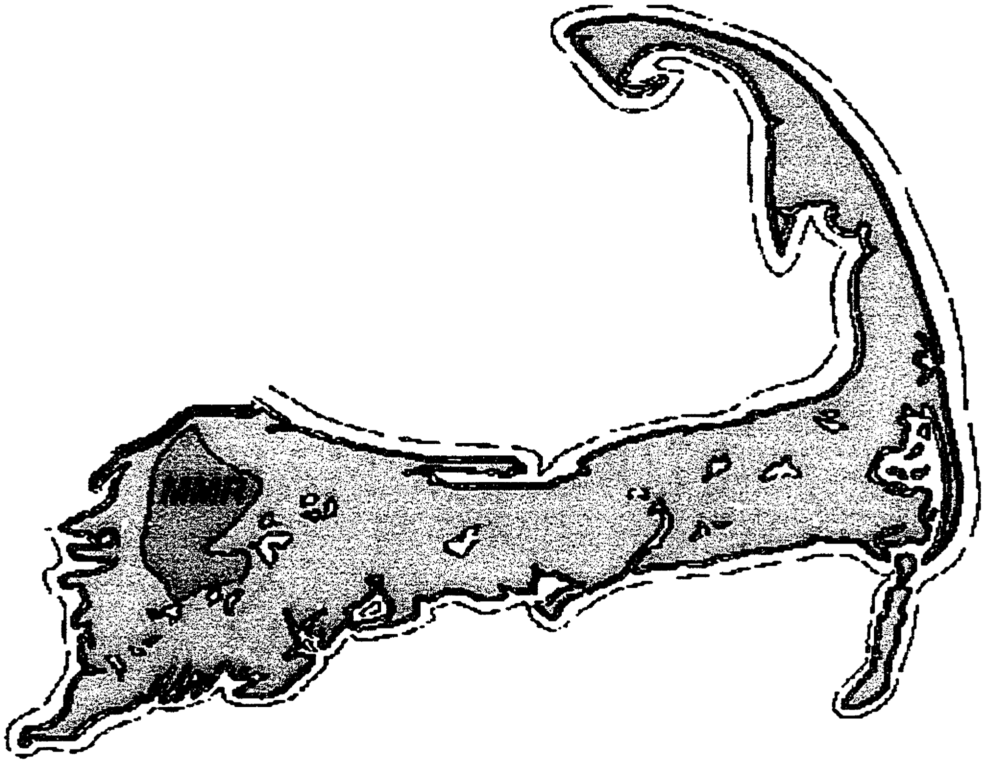

Figure 1-1
Location of the MMR on Cape Cod, Massachusetts.

takes place on the Cape consists of firing what are known as small arms, mortars, and 155 mm artillery. Small arms are every infantry weapon up to, and including, 50 caliber machine-guns. These weapons fire mostly copper-jacketed lead and steel ammunition, except for the shotgun, which fires lead pellets. Mortar rounds can either be high-explosive (HE), chemical illumination (illum), or chemically generated smoke. The typical HE mortar round consists of a steel casing packed with composition-B explosive, which is a mixture of TNT and RDX. The artillery rounds fired at the MMR are a training round called a Light Inexpensive Training Round (LITR). The LITR does not have any explosives in it, but is a solid metal projectile made of zinc, potassium, and aluminum (ETA 1996).

The live-fire impact area, where all of the projectiles land, sits directly on top of the highest part of the Sagamore Lens of the Cape Cod Sole Source Aquifer. Approximately 45% of the precipitation that falls in this area provides recharge to the aquifer, and as groundwater, flows radially from a point near the center of the impact area (Figure 1-2). Several of the municipal wells in the area have Zone II contribution areas, or Wellhead Protection Areas (WHPAs) that extend into the impact area. Several proposed well locations are currently under study that will also have WHPAs extending into the impact area. The primary concern at the MMR is that PEPs from past, current, or future training

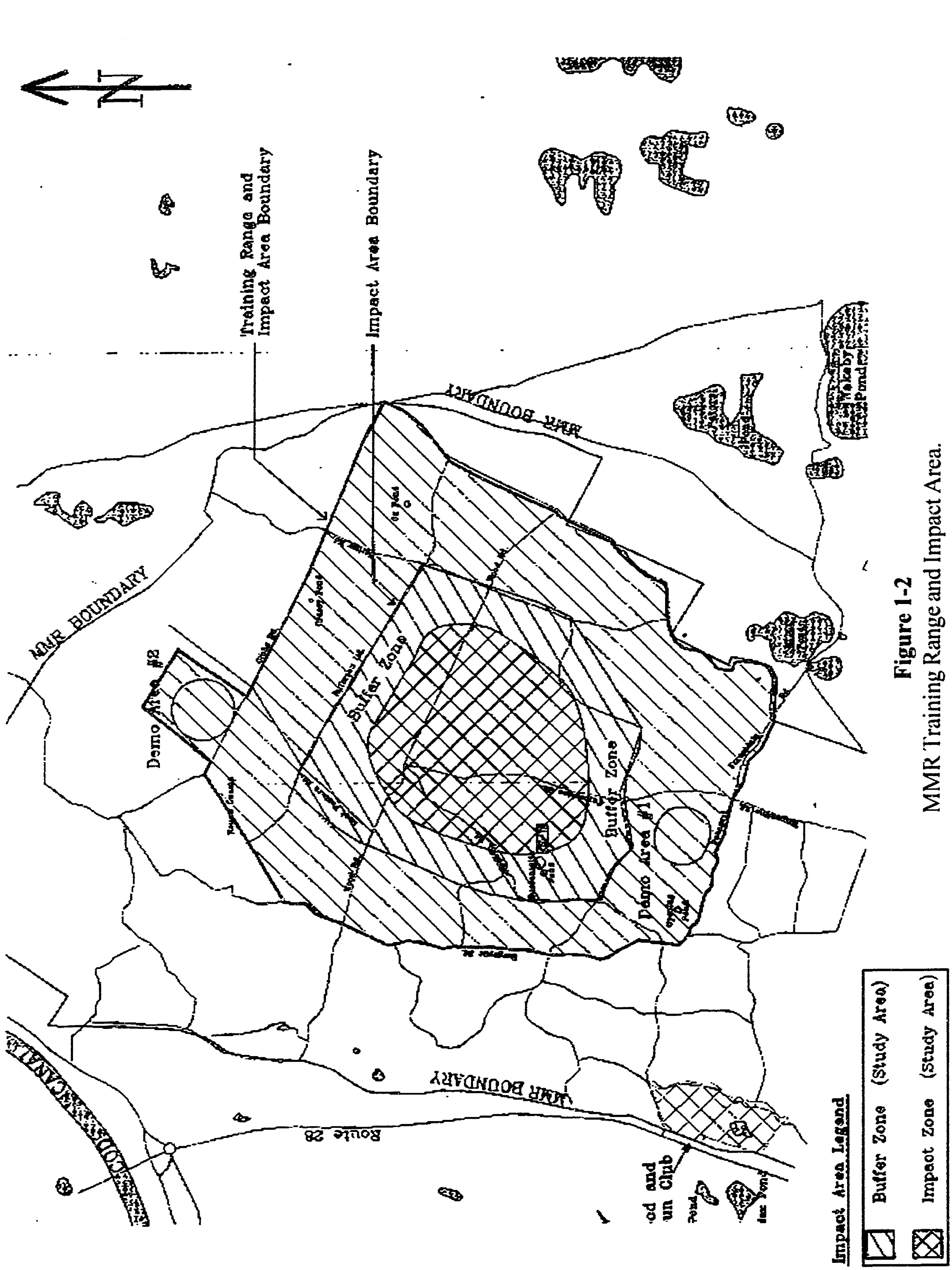

Figure 1-2
MMR Training Range and Impact Area.

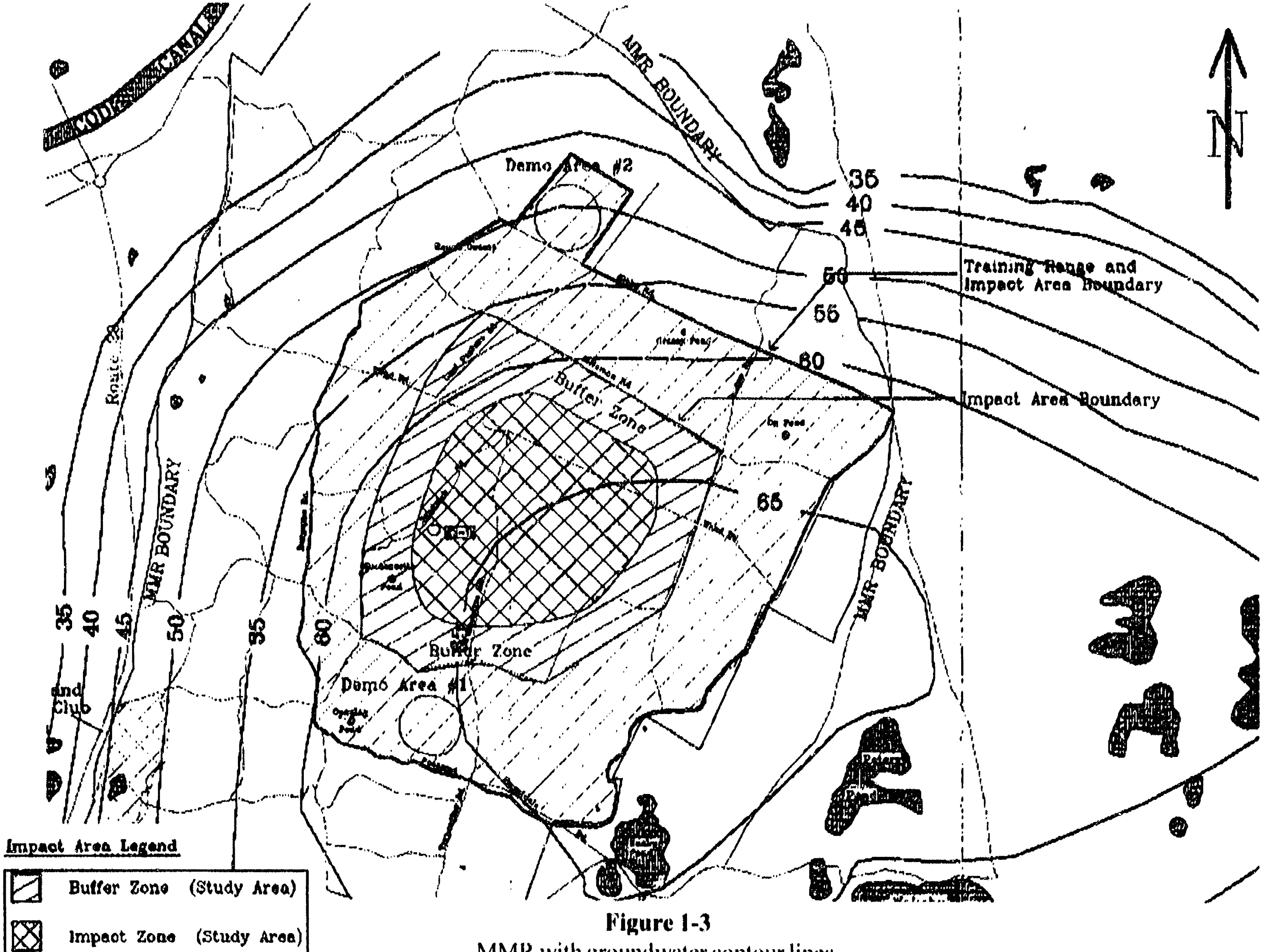

Figure 1-3
MMR with groundwater contour lines.

conducted in the impact area may further contaminate the aquifer below, affecting drinking water quality. The EPA issued drinking water guidelines of 2 µg/l for both TNT and RDX in 1993 (Federal Drinking Water Guidelines), and 0.011 µg/l for 2,4-DNT, for minimal cancer risk of 10^{-7} (IRIS, USEPA 1986). RDX has been found in the groundwater at a site designated by the Installation Restoration Project (IRP) as Chemical Spill (CS)-19, but it is not clear whether the contaminant emanates from CS-19 or from the impact area. Recently, Stone and Webster reported that TNT was found at one of the test well sites. Although that particular report was dismissed due to suspected laboratory contamination (subsequent testing and analysis found no TNT), concern remains that PEPs may be in the aquifer.

Table 1-1

Ammunition Expenditure Comparison

	MMR	MCAGCC
5.56 mm (rifle)	785,009	2,687,708
7.62 mm (machine gun)	285,762	2,410,500
9 mm (pistol)	461,138	350,000
50 cal (machine gun)	38,830	1,496,140
40 mm grenades	9,578	139,200
60 mm mortars (HE)	259	19,328
81 mm mortars (HE)	2205	11,022
155 mm artillery (HE)		29,526
155 mm artillery (LITR)	363	

Data obtained from MMR EIS and NREA, MCAGCC

As a result of contaminant plumes emanating from other sources at the MMR, the neighboring communities of Bourne, Sandwich, Mashpee and Falmouth have been forced to close a number of public supply wells and are seeking new well sites within or close to the MMR boundaries. The prime sites for such wells, however, are located close to or down gradient from the live-fire impact area, and a land use conflict has ensued. Additionally, citizens of the surrounding communities are concerned about the possibility of contaminants such as heavy metals, explosives, and explosives by-products leaching into the groundwater of the aquifer and contributing more pollution problems. A combination of these concerns, along with the prodding of the EPA and local activists, have provided a catalyst for this investigation.

1.1.2 The Marine Corps Air-Ground Combat Center (MCAGCC)

Also known as Twentynine Palms, this base, situated in the Southern California desert just north of Palm Springs, is the Marine Corps' premier training area. The base covers approximately 936 square miles, almost all of which is active impact area. Table 1-1 shows the average quantities of ammunition expended during exercises aboard MCAGCC, as compared to the 1994 expenditures aboard the MMR (MCAGCC 1997; NGB 1996). This comparison reflects the quantitative difference in volume of ammunition fired at the two facilities. In addition to the ammunitions listed in the table, however, MCAGCC also receives several tons of bombs on the aircraft bombing ranges each year, along with rockets and many other types of ordnance items.

MCAGCC faces numerous complex issues regarding the environment and the ecological systems and subsystems unique to the desert. During live-fire Combined Arms Exercises (CAXs) conducted several times each year, thousands of Marines receive realistic and invaluable training. During a typical CAX, an event consisting of Marines on foot or in trucks maneuvering through an area that has just been fired upon by live artillery, mortar fire, and aerial bombardment takes place. There is a possibility that PEP contaminants remaining from HE may pose a threat to human health and/or the environment. This, along with a desire to establish a precedence for this type of investigation are the primary reasons for the study that is to be conducted there.

1.1.3 Regulatory Framework

Current regulations do not address contamination caused by munitions used in normal training. A Proposed Munitions Rule that the EPA is due to finalize this Spring states that "... the use of munitions in the training of troops and EOD personnel is not regulated under RCRA ...because such training constitutes the normal use of a product, rather than waste disposal" (USEPA 1995). Under RCRA, the normal use of a product does not constitute waste management, and is not subject to regulation (USEPA 1995). The Department of Defense (DoD) is also in the process of promulgating a Range Rule that will address the cleanup of closed and transferred military ranges. Under the proposed EPA Munitions Rule, this Range Rule will supersede RCRA regulations of munitions as solid waste and will be the sole basis for inactive or closed range cleanup. Neither the EPA nor the DoD rules address active ranges, except to reiterate that munitions used for their intended purpose are not considered waste.

At MCAGCC, one of the concerns being addressed is: What happens when an ordnance item lands outside of the active impact area? Normally, as long as such an item detonates, no further consideration is necessary (as long as it lands in a remote area). In the past, if such an item did not detonate, an Explosives Ordnance Disposal (EOD) team was dispatched to either render the item safe for subsequent removal and disposal, or to detonate the item in place. Either way, consideration of the item as hazardous waste or a contaminant source was not an issue. Under the new and proposed rules, however, such an item may very well be considered as either hazardous waste or a source if detonated in place. Part of the reason for the study at MCAGCC is to determine if an in-place detonation will require a subsequent removal of contaminated soil and treatment as a hazardous waste site.

Under the National Environmental Policy Act (NEPA), an Environmental Impact Statement (EIS) is required to be prepared when any "... major Federal actions significantly affecting the quality of the human environment..." are proposed (42 U.S.C.A. §4332.C). Section 4332.C of the NEPA goes on to describe in detail what must be described in the EIS:

i) the environmental impact of the proposed action,
ii) any adverse environmental effects that cannot be avoided should the proposal be implemented,
iii) alternatives to the proposed action,
iv) the relationship between local short-term uses of man's environment and the maintenance and enhancement of long-term productivity, and
v) any irreversible and irretrievable commitments of resources that would be involved in the proposed action should it be implemented.

At the MMR, the EIS process is being used by the USEPA to drive the groundwater quality study. The National Guard Bureau (NGB), as one of the lead Federal agencies, has prepared an EIS that encompasses ten proposed projects aboard the MMR. The proposed projects include five range improvement/construction projects, and five cantonment area projects (NGB 1996). In order to aid in the acceptance of the EIS, the NGB has agreed to conduct a thorough investigation of the live-fire impact area and associated training ranges to determine if current or past training methods have introduced PEP or heavy metal pollutants to the soils or groundwater in the area. While no regulatory requirement exists for the impact area study to be conducted, it has been linked to the EIS as a requirement to meet the spirit and intent of NEPA. Even if contaminants are found in the soils or groundwater, it is unclear how that will affect the proposed projects or current training, since active ranges are not currently regulated.

1.2 Scope

The purpose of this project is to address some of the issues surrounding the potential problem of PEP contamination by (1) providing background information on explosives and how they work, (2) discussing the physical and chemical characteristics along with the fate and transport mechanisms of some of the most common explosive compounds, and (3) developing an approach for conducting an impact area study by addressing some of the specific problems such a study may encounter. Extremely technical aspects of actually conducting such a study are not addressed in detail.

Section 2
The Nature of the Problem

2.1 The Contaminants

2.1.1 Heavy Metals

In addition to the chemicals in explosive shells, the lead, copper, and other metals found in solid munitions (bullets) could feasibly be a source of contamination. The great majority of the bullets fired on training ranges are trapped in earthen berms built behind the target area, and this seems a likely source of any potential contamination. Figures 2-1 and 2-2 are photographs of a typical firing range at the MMR, and Figure 2-3 shows the typical density of spent projectiles in an impact berm. Studies previously done at the MMR have investigated the migration of lead under the impact berms of some of the most heavily used ranges, and have found significant concentrations of lead only as deep as 6 feet, with traces down to 20 feet (NGB 1996). The water table under most of the impact area is more than 60 feet below ground surface, so there does not appear to be an immediate risk from these metals in the density associated with the impact berms. The NGB is taking measures to reduce or halt the introduction of more lead into the soil though the use of bullet traps and other technologies. The bullets that do not impact into the berms are much more dispersed, and should not contribute any significant metal contamination to the remainder of the area.

2.1.2 The Chemicals

The by-products of munitions expended for their normal purpose are not considered hazardous waste or pollutants under current EPA regulations. However, many pyrotechnics, explosives, and propellants (PEPs) and their constituent compounds have been identified as toxic and/or possible carcinogens (HSDB® 1996; ATSDR 1996). These compounds include 2,4,6-Trinitrotoluene (TNT), Cyclotrimethylenetrinitramine (RDX), Cyclotetramethylenetetranitramine (HMX) which is an impurity in RDX, 2,4-Dinitrotoluene (DNT), and 2,6-Dinitrotoluene. All of these chemicals are listed in the Agency for Toxic Substances and Disease Registry's (ATSDR) Minimal Risk Levels (MRLs) for hazardous substances.

2.1.3 Explosives Reactions

Explosives react in three different ways: high-order, low-order, or degradation. High-order is when the explosive reacts as it was designed to react, and burns (detonates) at an extremely high rate of speed. Explosives are divided into two categories based on their designed rate of burn. Low explosives include black and smokeless powder and most propellants, and burn slower than the speed of sound. High Explosives (HE) include TNT, RDX, HMX, and most other military explosives that

Photo by Author

Figure 2-1
Range G at the MMR.

Photo by Author

Figure 2-2
Typical Impact Berm, Range G at the MMR.

are used for demolition training, artillery shells, mortar rounds and hand grenades. Military explosives are designed to be extremely stable due to the range of environments and situations they are used in. Since they are designed not to explode until needed, all military explosives require an initiator or fuse of some type. Fuses usually contain a small amount of a relatively unstable explosive compound (such as Mercury Fulminate) that will detonate when mechanically acted upon; this explosion produces a high velocity shock wave that in turn initiates the detonation of the main charge.

Photo Courtesy of Leon Bowling, MCAGCC

Figure 2-3

Typical density of spent bullets in an impact berm.

2.1.4 Duds

Duds occur when a round fails to operate as it is designed to and are typically caused by a failure of the fuse to initiate. The acceptable rate for duds, depending on the type of ammunition, is approximately 10%. This does not mean that a given type of ammunition will actually fail to operate 10% of the time. What it does mean is that if this dud rate is experienced, then that "lot" of ammunition is removed from service. On any training range, the detonation of the rounds fired downrange is counted, and compared to the number of rounds fired. If duds are recorded, then an EOD team will perform a range sweep and attempt to find them and detonate them. The spotter who adjusts the artillery or mortar fire is also required to record the location of any identified duds for subsequent EOD disposal. When dud ammunition impacts the ground, it will penetrate to a depth that is determined by the type of round, the velocity on impact, the angle of impact, and the soil type. Under most conditions, penetration should not exceed 12 feet (Peternel 1997). These rounds do not break open on impact, and are, in fact, seldom damaged (see UXO, below).

2.1.5 High-Order Detonation

When an explosive "high-orders", it detonates, or reacts, at the rate it was designed to react. In a high-order reaction, virtually all of the explosive compound is instantaneously volatilized into high pressure gases, and its constituents are destroyed by the extreme heat and pressure. These gases are what give the explosive its power. The constituents that remain (usually a fine powder) quickly degrade into nontoxic compounds or volatilize further.

2.1.6 Low-Order Detonation

A low-order explosion is when the explosive does not react as it was designed to, but instead detonates at a much lower rate, often leaving considerable residue and explosive compound behind. The cause of a low-order reaction is typically an inadequate initiating reaction; however, they can also be the result of impurities or discontinuities in an explosive compound. If a munition "low-orders", it is not really a "dud" and may not even be recognizable as a low-order reaction from a distance. A low order detonation may be strong enough to cause the projectile to rupture, allowing it to become a source of contamination. The frequency of low-order detonations is nearly impossible to quantify, but is extremely small (Peternel 1997; Shaw 1997).

Another type of low-order explosion is when an explosive compound is ignited by a normal flame, and does not detonate at all. In this type of reaction, all of the original compound may be consumed, but the constituents formed are often just as harmful. This is the type of contamination that may be found at artillery and mortar firing positions. Each artillery and mortar round is packaged with a number of propellant bags, called charges or increments. A specified number of these bags are required to propel the round the required distance. Since most training takes place at distances far less than the maximum range of the weapon system, after each training event, there are numerous charges remaining that must be disposed of. Until recently, it was common practice and considered essential training to burn the extra bags of propellant packaged with each round in open pits dug at the gun positions.

2.1.7 Degradation

The third means of reaction is through degradation or transformation, which occurs once an explosive compound is exposed to the environment. All of the studies done on PEPs to date have been at ammunition manufacturing plants, storage facilities, or open burn/open detonation (OB/OD) activities. At these locations, raw explosives have either been burned, dumped directly on the ground, or placed into unlined waste lagoons and ditches (ESE 1985). In one study, soil contaminant levels from these types of operations were measured as high as 482 ppm (TNT) at one site, and groundwater levels were measured as high as 36 ppm (RDX) at another (ESE 1985). The highest possible levels of contaminant that could be expected in the impact area will not be nearly as great, since the great majority of the explosives are consumed during detonation, and hot spots from fractured projectiles will most likely be isolated and unusual.

2.2 Unexploded Ordnance (UXO)

2.2.1 What It Is

Unexploded ordnance is any munition that does not operate as it is supposed to, and the main explosive charge does not detonate, commonly referred to as duds. The failure to function may be caused by a number of factors: a faulty fuse, the fuse functions but fails to ignite the booster or main charge, or the fuse may break off on impact. Almost all fuses are designed to arm once a munition is fired, and most detonate either on impact, at a small time after impact (to allow a small penetration into the ground) or at a pre-designated height above the ground. If the fuse fails to function, it must still be considered armed, and could detonate the ordnance item if disturbed. Regardless of the cause of failure, all UXO is extremely dangerous, and should only be approached or handled by highly trained EOD personnel.

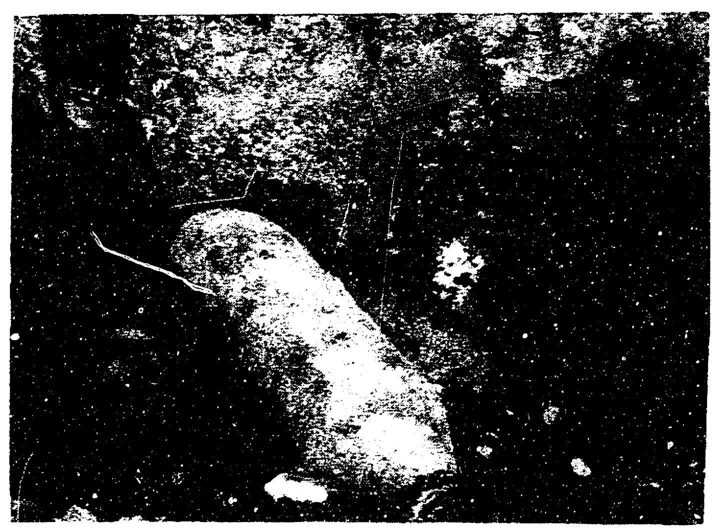

Photo Courtesy of Captain Ed Peternel, USMC

Figure 2-4 Typical UXO, a WW II era 500 pound bomb. EOD has prepared special charges to explosively remove the fuze so that the bomb may be safely moved.

2.2.2 UXO as a Contaminant

As a source of contamination, UXO is not a very likely candidate. When artillery or other projectiles land without detonating, they do not break open (Figure 2-4). Numerous observations have been made of artillery and naval gunfire projectiles that often struck solid rock and coral during the Island campaign in the South Pacific during World War II over 50 years ago and were barely dented. These same projectiles, along with those found at the bottom of the ocean, show remarkably little corrosion, and are easily cleaned. One extreme case of artillery rounds of World War I vintage that were buried in a swamp in New Jersey and showed almost no corrosion 70 years later was also reported (Shaw 1997).

2.3 Propellants, Explosives and Pyrotechnics (PEP) Characteristics

2.3.1 2,4,6-Trinitrotoluene (TNT)

2.3.1.1 Fate & Transport

The physical characteristics of TNT are summarized in Table 2-1. The K_d of TNT depends heavily on the percent of organic carbon (f_{oc}) in the soil, but ranges from 0.31 up to 56 ml/g (Townsend et al. 1996; ESE 1985). The soil in the Camp Edwards impact area can be expected to have a low organic carbon content, and a correspondingly low K_d. TNT usually adsorbs readily, whether the soil has a high organic content or not. In tests done as a part of the Army's investigation and remediation efforts at Army Ammunition Plants (AAPs), TNT was shown to be almost completely trapped within the top 3-6 inches of soil (Checkai et al. 1993a,b,c).

Table 2-1

Physical and Chemical Characteristics of TNT

Property	Value	Source
Molecular Weight	227.13 g	HSDB® (Merck Index 1983)
Density	1.654 @ 20 °C	HSDB® (Merck Index 1983)
Henry's Law Constant	9.8 x 10^{-6} @ 20 °C	ESE (Spanggord 1979)
Solubility in Water	130 mg/l @ 20 °C 110 mg/l @ 10 °C	WES (Urbanski 1964)
log K_{ow}	2.06 1.86 1.90 1.60	WES (Rosenblatt 1989) WES (Jenkins 1989) ESE 1985 HSDB® (Hansch 1987)
log K_{oc}	2.72 2.28 2.48	WES (Rosenblatt 1989) ESE (Spanggord 1979) ESE (Kenaga & Goring 1978)
K_d	Varies Greatly	
Diffusion Coefficients	Water: 6.71 x 10^{-6} cm^2/s Air: 0.064 cm^2/s	WES (Rosenblatt 1989)

The experiments done by Checkai et al. were conducted using a controlled environment soil-core microcosm unit (CESMU) chamber. In this process, soil cores are harvested using a steel penetrator with a high density polyethylene (HDPE) pipe liner. The penetrator is pressed hydraulically into the soil so as to obtain as undisturbed a sample as possible; the HDPE pipe, with sample enclosed, is then placed into the CESMU chamber. Specially designed end caps are placed on the lower end of the pipe, and a vacuum, calculated to simulate the normal movement of groundwater, is applied (Checkai et al. 1993a,b,c). In some experiments, contaminated water was allowed to flow through the samples, and in others, clean water was used to flush contaminants out. Townsend et al. (1996) concluded that the reductive transformation of TNT is both pH and redox sensitive, occurs at the highest rates anaerobically, and is a major process affecting its subsurface fate and transport. Pseudo-first order rate constants for the transformation of TNT in groundwater have been determined in the range of 0.0017 - 0.14/hr, corresponding to a half-life of 4 weeks to 12 months (Myers et al. In Preparation; Townsend et al. 1995) Townsend et al. (1996) also indicate that TNT transformation probably involves ferrous-ferric iron cycling, which may be significant for the iron-rich soils on the MMR.

2.3.1.2 Toxicity

TNT is highly toxic, and can cause death if high enough concentrations are ingested. It is classified as a C carcinogen, which means it may possibly cause cancer, but not enough data exists to confirm whether it does or does not (HSDB®, 1996). Three possible routes of exposure to TNT from the impact area exist: migration to the aquifer, surface runoff, and aerial transport. Although aerial transport is possible, (TNT in the atmosphere has a half-life of approximately 110 days [HSDB®, 1996]) as covered in the next paragraph, such insignificant quantities of explosives remain after a detonation that it would be pointless to pursue this aspect. Other routes of exposure, such as dermal contact, are highly unlikely due to the restricted access of the impact area.

2.3.1.3 Sources

TNT is a primary component of almost all military high explosives. Different sized "sticks" of ¼, ½, and 1 pound are used in a variety of ways for demolition work in both training and live military exercises. Sticks of TNT consist of the molded compound encased in a cardboard wrapper with thin metal end caps, one of which has a fuse well in it. To use TNT, it is either fused directly or wrapped in another explosive called det-cord (consisting of PETN in a flexible plastic wrapper), placed as desired, and detonated. Tests conducted by the Air Force Air Combat Command in 1994 with selected munitions established emission factors on a weight/weight basis. These tests, also known as the "Bang Box" or "BB" tests, found a maximum emission factor of 1.02×10^{-5} for bulk TNT (U.S.

Air Force 1994). With this factor, approximately 216 pounds of TNT would need to be detonated to have just 1 gram remaining. In turn, that one gram would be completely dispersed from the explosion; therefore, it can be stated that, effectively, no TNT remains after the normal detonation of an HE munition.

TNT is also combined with RDX or other explosives to produce various compounds such as Composition B (Comp-B), which is used in artillery and mortar shells, antitank and antipersonnel mines, bangalore torpedoes, and grenades. All of these common munitions are used extensively in training exercises.

2.3.2 Cyclonite (RDX) and HMX

2.3.2.1 Fate & Transport

The physical characteristics of RDX are summarized in Table 2-2 and HMX in Table 2-3. Both RDX and HMX behave similarly in the subsurface environment, and, unlike TNT, they do not sorb as readily. The partitioning coefficient K_d appears to depend heavily on the clay content and cation exchange capacity (CEC) of the soil. The soil on the Cape typically has a low clay content and CEC, therefore, RDX and HMX will not be expected to sorb. Tests at the various AAPs have shown that these contaminants are highly mobile (Checkai et al. 1993a,b,c) and that little transformation occurs, unless the soil has a high clay content and CEC (Townsend et al.1996).

Table 2-2

Physical and Chemical Characteristics of RDX

Property	Value	Source
Molecular Weight	222.26 g	HSDB® (Merck Index 1983)
Density	1.82 @ 20 °C	HSDB® (Merck Index 1983)
Henry's Law Constant	1.1×10^{-11} @ 20 °C	ESE (Spanggord 1979)
Solubility in Water	42.3 ± 0.6 mg/l @ 20 °C	WES (Sikka et al. 1980)
	28.9 ± 1.0 mg/l @ 10 °C	
Log K_{ow}	0.87 ± 0.028	WES (Banerjee et al. 1985)
	0.81	WES (Major 1984)
	1.1	ESE 1985
	0.87	HSDB® (Hansch 1987)
Log K_{oc}	2.00	WES (Rosenblatt 1989)
	2.62	ESE (Spanggord et al. 1979)
	2.73	ESE (Kenaga & Goring 1978)
	0.89, 1.87, and 2.43	WES (Sikka et al. 1980)
K_d	Varies Greatly	
Diffusion Coefficients	Air: 0.074 cm^2/s	WES (Rosenblatt 1989)
	Water: 7.15×10^{-6} cm^2/s	

First order rate constants for the transformation of RDX have been quantified in the range of 0 - 0.1/hr (Myers et al. In Preparation; Pennington et al. 1995). Rate constants for HMX have been reported in the range of 0 - 0.09/hr (Myers et al. In Preparation; Pennington et al. 1995). These transformations have only been detected in anaerobic conditions, and neither compound is expected to degrade aerobically. Hydrolysis is not a significant factor, but photolysis in surface waters is, with a half-life of about 5 days in river water (Spanggord et al. 1982).

Table 2-3

Physical and Chemical Characteristics of HMX

Property	Value	Source
Molecular Weight	296.2 g	WES 1996
Density	1.90	WES (Rosenblatt et al. 1989)
Henry's Law Constant	1.1 x10^{-13} @ 20 °C	WES (Rosenblatt et al. 1989)
Solubility in Water	2.6 ± 0.01 mg/l @ 20 °C	WES (Spanggord et al. 1982)
	1.21 ± 0.04 mg/l @ 10 °C	
Log K_{ow}	0.26	WES (Major 1989)
	0.06	WES (Jenkins 1989)
	0.13	ESE (Atl Research Co. 1979)
Log K_{oc}	0.54	WES (Rosenblatt et al. 1989)
	2.71	ESE (Kenaga & Goring 1978)
K_d	8.87-13.25	WES (Leggett 1985)
	0.0-1.2	WES (Myers et al.)
Diffusion Coefficients	Air: 0.063 cm^2/s	WES (Rosenblatt 1989)
	Water: 6.02 x 10^{-6} cm^2/s	

2.3.2.2 Toxicity

RDX is toxic, but only in extremely high concentrations. Studies on both animals and humans have shown no tendency to produce chronic effects. Acute effects observed at extremely high doses include convulsions and muscle spasms, but complete recovery after removal from the source (HSDB® 1996). In one study, 15 of the 35 rats fed high doses (100 mg/kg) of RDX every day for 10 weeks died (HSDB® 1996, Indus Hyg & Tox 1981-82). In another case, a person who intentionally swallowed approximately one tablespoon of RDX developed severe muscle spasms, but recovered completely (HSDB® 1996). RDX is a class C (possible) carcinogen (IRIS 1996). Little to no information exists on the toxicity of HMX, but it can probably be expected to have effects similar to RDX. HMX is a class D carcinogen, which means that it is not classifiable as to human carcinogenicity, due to a lack of available data (IRIS 1994).

2.3.2.3 Sources

RDX is a primary constituent of plastic explosives (C-4), and is also combined with TNT to create other explosive compounds (see par 2.3.1.3 above). Because it is easily initiated, it is often used as a booster charge for other explosives such as ammonium nitrate. C-4 is used extensively in demolitions and EOD training, due to its capacity for being easily molded and shaped. Like TNT, C-4 can be detonated either with det-cord or with a blasting cap once it is placed. The Bang Box tests for RDX indicated a maximum emission factor of 6.93×10^{-5} (U.S. Air Force 1994) for a 40mm grenade (these grenades typically hold approximately 1.5 ounces of explosive). If this worse case emission is extrapolated for pure RDX, approximately 32 pounds of explosive would be required to leave 1 gram remaining. Again, all RDX can be considered as consumed during normal detonations.

2.3.3 2,4-Dinitrotoluene (DNT)

2.3.3.1 Fate & Transport

The physical characteristics of 2,4-DNT are summarized in Table 2-4. Based on the reported values of K_{ow} and K_{oc}, DNT can be expected to behave much the same as TNT as far as subsurface transport. In the various studies conducted at Army Ammunition Plants (AAPs), DNT was found to concentrate within the top 2-6 inches of the soil, with little transformation (Checkai et al. 1993a,b,c).

Table 2-4

Physical and Chemical Characteristics of 2,4-DNT

Property	Value	Source
Molecular Weight	182.14 g	HSDB® (CRC 1991-'92)
Density	1.321 @ 71 °C	HSDB® (CRC 1991-'92)
Henry's Law Constant	1.8×10^{-4} @ 22 °C	ESE (Spanggord et al. 1979)
Solubility in Water	270 mg/l @ 22 °C	ESE (AMC 1971)
	299.5 mg/l @ 22 °C	HSDB® (Kirk 1981)
log K_{ow}	1.98	ESE (Hansch 1979)
	1.98	HSDB® (GEMS USEPA 1984)
log K_{oc}	1.94	ESE (Spanggord et al. 1979)
	2.30	ESE (Kenaga & Goring 1978)
K_d	Not Found	
Diffusion Coefficients	Not Found	

Biodegradation of DNT can occur both aerobically and anaerobically, and DNT has measured and theoretical photolytic half-lives ranging from 2.7 hours to 1.7 days in a variety of surface water conditions (HSDB® 1996).

2.3.3.2 Toxicity

Considerable data exists to confirm the high toxicity of DNT. Studies of factory workers exposed to high concentrations associated with the manufacture of DNT have shown excessive mortality rates over the long term (HSDB® 1996). Various acute effects such as cyanosis, nausea, dizziness, and numbness of the extremities were also reported (HSDB® 1996). Non-human toxicity studies have been numerous and varied, but all confirm the toxicity of DNT, and several have produced results that make it a suspected carcinogen (HSDB® 1996). 2,4-DNT is a class B2 (probable) carcinogen, based on non-human studies (IRIS 1996).

2.3.3.3 Sources

2,4-Dinitrotoluene is used in both smokeless powders and as a plasticizer in high explosives (HSDB® 1996). Since it is a principal component of smokeless powder (a propellant) it may be found where open burning of propellant bags occurred. Concentrations as high as 9.2 ppm in the soil, and 8.7 ppm in the groundwater have been found at some AAPs (ESE 1985). The Bang Box studies show extremely low emission factors for 2,4-DNT in normal circumstances, on the order of 10^{-6} (U.S. Air Force 1994).

Section 3
An Investigative Process

3.1 Overview

The investigation of an active live-fire impact area must be approached with careful thought and planning. Like any such endeavor, it must begin with a decision to take action and should have, as a minimum, the following components:

1) A clear concept of what is being investigated
2) A clear idea of the parameters of the investigation
3) A concise and feasible plan for accomplishing the investigation
4) The means and the will to complete the investigation
5) A plan for action based on the results of the investigation

While these components are a good starting point, the process cannot be thought of as entirely linear. As the plan is developed, and as more information becomes available during the course of the

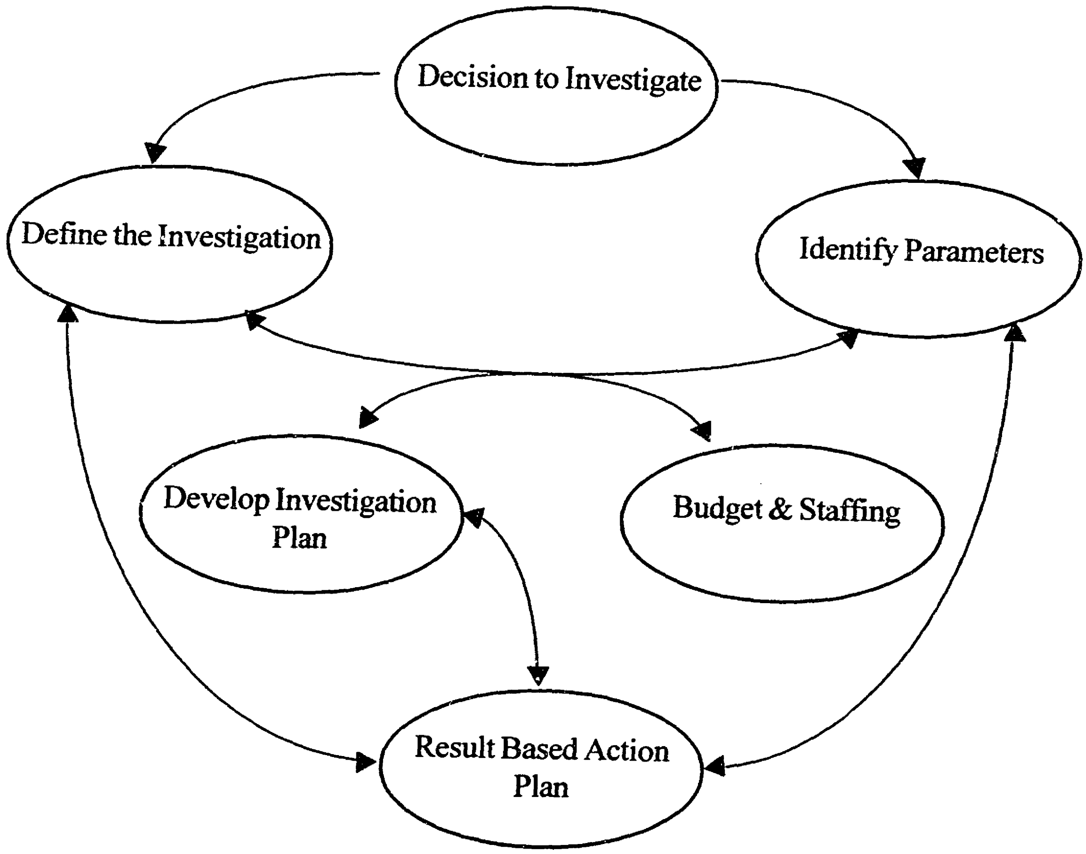

Figure 3-1
The Investigative Process

investigation, the problem may grow or shrink, or change altogether. These steps cannot be executed in a vacuum, nor in perfect sequence. The plan for action must be initiated along with the plan for the investigation, and will grow and evolve as the investigation is conducted. Figure 3-1 is a graphical representation of these concepts and their interaction. In addition to the decision to investigate, this section will examine all five components individually by using the two ongoing impact area studies at the MMR and the MCAGCC as reference points.

3.2 The Decision to Investigate

3.2.1 History

In the past, active live-fire impact areas have not been thoroughly investigated as a source of chemical contamination. A few investigations of the soils under and around impact berms have been conducted, but these were concerned primarily with the leaching of lead and heavy metals. Most investigations for PEPs in soils and groundwater have been done at AAPs and other explosive manufacturing locations, where the concentrations of pure and nearly pure contaminants in effluents from process operations were extremely high. At these locations, contaminants were often deposited directly on the ground in disposal lagoons and trenches or in OB/OD pits. While PEP contaminant levels in impact areas cannot be expected to be present at near the levels found at these sites, any possible contamination should be investigated if it is a threat to human health or the environment.

3.3 Defining the Investigation

3.3.1 What is the Problem?

The key to defining an investigation is a clear understanding of the problem, perceived problem, or potential problem. For example, it would not make sense to investigate an impact area for EDB, any more than it would make sense to investigate a fuel spill for PEPs, *unless there is a suspicion that the contaminant is present*. The investigation must address the primary perceived problem, and be flexible enough to change as new problems are encountered. A clear problem or purpose statement defining the objective of an investigation is a good way of identifying exactly what is to be investigated. The MMR has identified the purpose of their study thus:

> The goal of the Impact Area Groundwater Study is to determine the effects of range training on the groundwater beneath the impact area, the small arms ranges, and the demolition ranges (MMR Fact Sheet 1996).

The MCAGCC study has a different purpose, and is stated as follows:

The purpose of this project is to assess human health and environmental risks quantitatively. The project has the following specific objectives:

Quantify the potential risk that ordnance residuals at MCAGCC pose to human health and the environment.

Establish a baseline risk screening protocol that can be transferred and adapted for use at other DoD installations (MCAGCC Scoping Paper 1996).

3.4 The Parameters of the Investigation

3.4.1 General

Briefly, this can be considered the scope of the investigation, or the where, when, what and how much. Included in this stage needs to be decisions on how large an area the investigation is to encompass, what media the investigation will look at: soils, groundwater, plants, surface waters, wetlands, etc. and what is to be looked for. If the investigation is being prompted by a regulatory agency, then these parameters may be dictated, but they may also change as the scope of the investigation is continually defined.

3.4.2 Where

Around any impact area, there are ancillary sites that may also need investigation. On the MMR, gun positions and demolition ranges are such sites, but they are in close proximity to the actual impact area itself, and may easily be included in an investigation (Figure 3-2). At Twentynine Palms, however, the impact area is so vast that only parts of it can be feasibly investigated (Figures 3-3 and 3-4), which will be a critical consideration. The approach the MCAGCC is using to overcome the area consideration is to divide the impact area into parcels, and classify each parcel as to the level of contamination probable, based on the usage pattern for that parcel. At the MMR, key sites such as the demolitions ranges and high usage target areas have been identified as likely contaminant sources. Both approaches are reasonable and necessary in order to keep the investigation manageable.

3.4.3 When

The schedule for conducting an investigation may become a critical driving factor. If, as in the case of the MMR, the schedule is tied by the regulators to another project or group of projects, then time

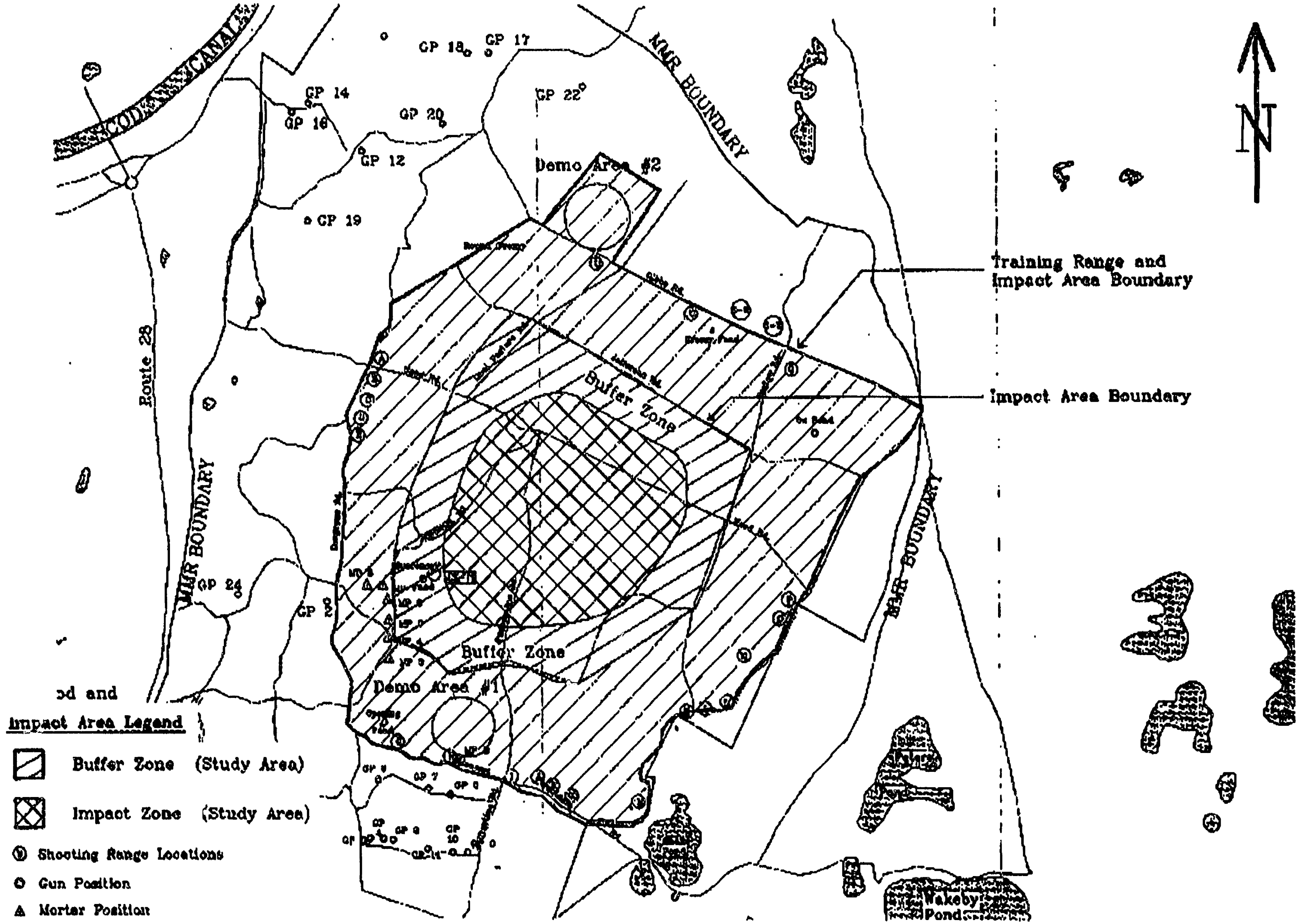

Figure 3-2
Training Range at the MMR, depicting Gun Positions (GPs) Mortar Positions (MPs) and Demo ranges.

Photo by Author

Figure 3-3

View of MCAGCC. Rifle ranges are in the foreground, a maneuver range known as the Delta Corridor is in the background.

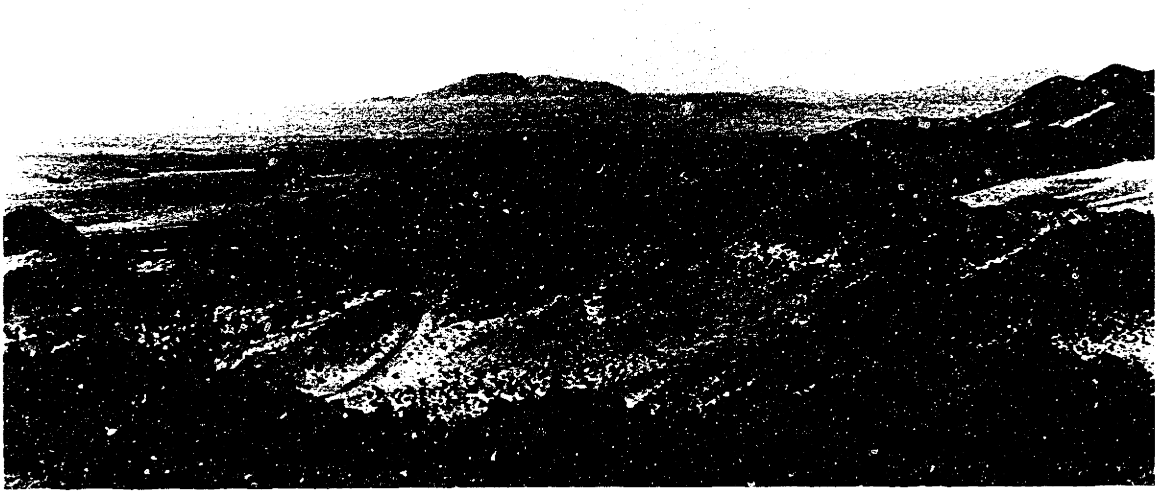

Photo by Author

Figure 3-4

The impact area begins at the foot of the mountains in the foreground and extends beyond the horizon.

may dictate what is to be accomplished. The investigation plan must still be flexible enough to allow for unforeseen problems and changes to the basic plan. If the impact area will continue to be used during the investigation, as is planned for both the MMR and the MCAGCC, then range firing schedules will need to be coordinated with the investigation schedule, with safety as an always overriding concern. An initial schedule should be developed in order to coordinate the planning process, public meetings, comment periods, etc. A detailed schedule, including a timeline of major events milestones and deliverables, can (and should) be started early and incorporated into the detailed plan later.

3.4.4 What

It will be necessary to determine as closely as possible which chemicals and compounds are to be looked for. PEPs are not chemicals that are analyzed for in most groundwater and soil sampling analysis, and special analyses must be conducted that only certain laboratories offer. Specifically, either EPA Method 8321 or Method 8330 must be used (EODTECHDIV 1997, ETA 1997). The most significant difference between the two is that 8321, which is a newer process that uses mass spectrometry, also detects PETN and nitroglycerin. The minimum detection levels should be low enough to ensure that the levels detected are consistent with levels that may pose a hazard, as determined through a preliminary risk assessment. The cost of laboratory analysis, which increases as detection limits become lower, should be minimized, while at the same time, no potential contaminant that exists in detectable amounts can be overlooked. A thorough literature search and preliminary investigation into the following factors will be necessary in order to identify the parameters of what to look for and also where it may be found.

3.4.4.1 History of the Site

In order to define the problem, some concept of past usage of the site must be developed. It is a common practice to place wrecked or obsolete vehicles, such as trucks, tanks, etc., into the impact area as targets (Figure 3-5). Until fairly recently, the various reservoirs on these vehicles were not drained. As a result, PEPs may be the primary contaminants of concern in an impact area, but other chemicals, such as hydrocarbons, antifreeze, and solvents may also be present. Another item to consider is whether the impact area was used for another purpose before it became an impact area. While this may not be a very common situation, it is feasible that parts of current training areas may have been used as ammunition or even trash dumps in the past.

3.4.4.2 Future of the Site

If an impact area is due to be closed as a result of a Base Re-alignment and Closure (BRAC) decision, then it may not make sense to conduct the investigation until it is closed. Not only may this

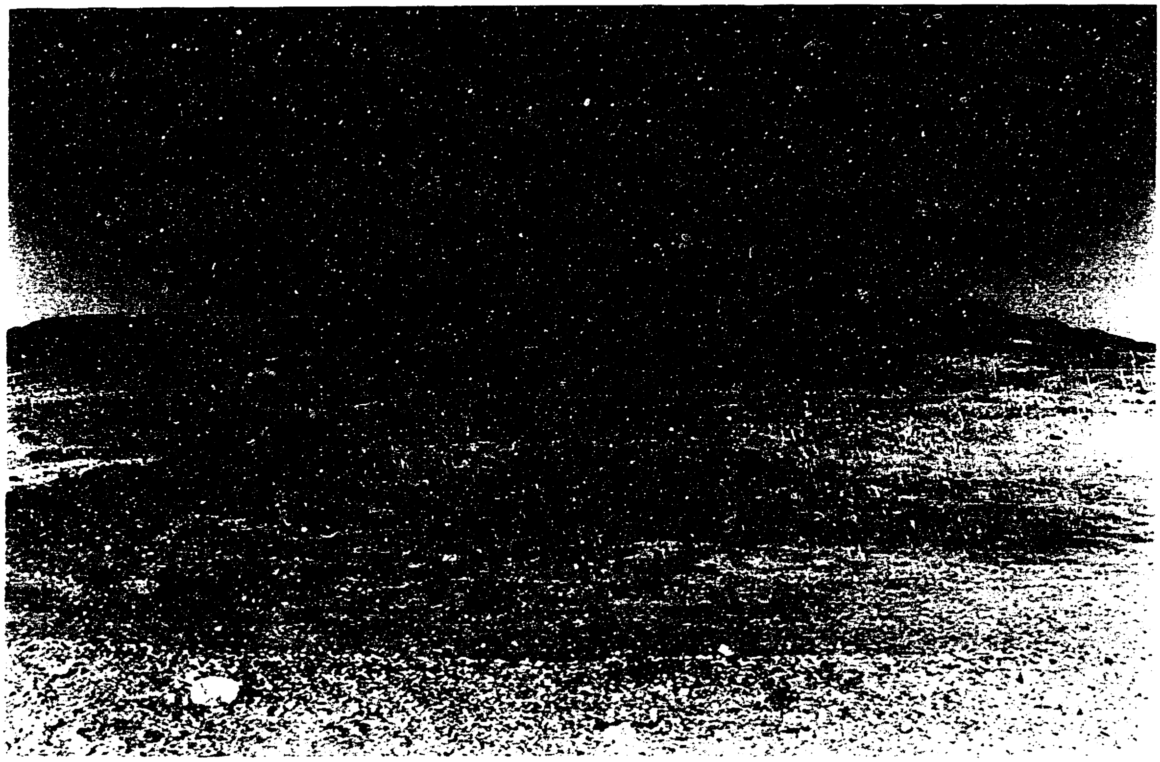

Photo by Author

Figure 3-5
A typical fixed range at MCAGCC. Note target hulks throughout impact zone.

Photo by Author

Figure 3-6
A grenade impact area at MCAGCC.

change the problem entirely due to the regulatory requirements that may apply to closed ranges, but the future use of the range may affect what is being looked for, and where.

3.5 Developing the Plan

3.5.1 A Baseline Plan

An action plan for the investigation should follow accepted and commonly endorsed practices. The EPA's Soil Screening Guidance (USEPA 1996) is probably a sound starting point for developing a workable and acceptable plan. If the investigation is being driven by regulatory requirements, this is probably the preferred method to follow. In the Soil Screening Guidance User's Guide, a seven step process is outlined as follows:

Step 1: Develop a Conceptual Site Model (CSM)
Step 2: Compare the CSM to the Soil Screening Level Scenario in the Guidance
Step 3: Define Data Collection Needs for Soils
Step 4: Sample and Analyze Site Soils & Data Quality Analysis (DQA)
Step 5: Calculate Site-Specific Soil Screening Levels (SSLs)
Step 6: Compare Site Soil Contaminant Concentrations to Calculated SSLs
Step 7: Address Areas Identified for Further Study

Following these guidelines would be the first phase of a phased approach to investigating possible contamination. If no significant concentrations were found during soil screening, then it would be likely that none would be found in the groundwater either, although it would not be prudent to take that for granted. Part of the Soil Screening Guidance also deals with determining whether contaminants have progressed to the water table or not.

3.5.2 A Conceptual Site Model

The development of a conceptual site model for an impact area investigation can follow the same general scheme as any other site, with a few additional considerations as outlined below.

3.5.2.1 UXO

UXO presents a unique problem in that it is a direct hazard, in addition to being a potential source. The US Army Corps of Engineers has developed a detailed protocol for conducting investigations in impact areas (Shaw 1997). A generalized description of this protocol, which should only be conducted under the supervision of qualified EOD personnel is as follows:

1) A vehicle/pedestrian lane must be clearly marked through the impact area to all potential sampling sites. The lane must be wide enough for any potential traffic, and will be swept by EOD to ensure that it safely bypasses any potential UXO.
2) An area around each sampling site must also be swept and cleared, to a depth that ensures that no vehicle traffic on the surface will affect buried UXO.
3) If only soil sampling is to be conducted, then EOD will check every two feet for UXO, to the depth that samples will be taken from.
4) If a monitoring well is to be installed, then it must be started with a hand auger with the bore hole checked for UXO every two feet to a minimum depth of six feet. At that depth, a drilling rig may then be brought onto the site to drill the remainder of the well, with stops to check for UXO every two feet until the maximum possible depth of projectile penetration is reached (Shaw 1997).

In addition to these precautions, all personnel who are to work in the impact area should receive formal training from EOD regarding the hazards of working in the impact area, and the importance of not disturbing any potential ordnance items.

3.5.2.2 Other Ordnance Hazards

During the review of the history of the range, any use that would indicate the presence of depleted uranium (DU) or chemical weapons should be noted. DU is used as the projectile portion of armor penetrating ammunition in a number of modern weapons systems, to include aircraft and light armored vehicles. While the radiation levels of the actual projectiles is extremely low and not considered a hazard, if subjected to open burning, the oxidation components (dust) that results can be hazardous if inhaled or ingested. Therefore, any potential DU presence must be addressed in the safety portion of a plan. Another serious concern would be the potential presence of chemical weapons UXO or residue. Although lethal chemical weapons are not currently used (and have not been used for many years), they may be present as UXO on some sites. Many ranges, however, allow the use of nonlethal (tear gas) weapons. The presence of these chemicals is often only an irritation, but should be addressed nonetheless.

3.5.2.3 Dispersed Source

The concept of a source takes on a different meaning when considering the site model of an impact area. At a conventional site, sources are typically a true point source in that the chemical of concern is introduced in high concentrations over a relatively small area. This does not hold true in an impact area that may consist of hundreds or even thousands of acres. The closest possibility of a source as thought of normally would be demolition training areas, where relatively large (40 pound limit per shot at the MMR) amounts of explosives are detonated in a small area. In the general impact area, where the contaminants have been delivered at a maximum of 15 pound increments (for a 155 mm artillery shell), the great majority of which is consumed at detonation, the potential source contribution begins to take on minuscule proportions.

3.5.2.4 Hot Spots

In a normally used impact area, the most likely source area will be where the greatest potential for low-ordered ammunition exists. This should equate to the most often used target areas, which would also be the most difficult area for a spotter to see a round that malfunctioned. These areas then are probably the key areas to identify when developing a sampling plan. Additional potential hot spot areas may be identified through the use of aerial photographs, particularly if there is concern that an ammunition or propellant dumping site exists.

3.5.3 Exposure Pathways

This is a relatively simple consideration for active impact areas. Since most impact areas are off-limits due to the dangers of UXO, exposure to contaminated soils is not likely to happen. For the same reason, PEPs are not likely to be an inhalation problem either. Surface water runoff is a potential pathway, however, due to the rapid photodegradation of PEP constituents in surface waters, this is not a likely pathway except in severe circumstances. Since it is a possible pathway, surface runoff should not be ignored, and drainage patterns from an impact area should be included in the CSM. The primary candidate for exposure pathway, particularly at the MMR (though less so at other locations) will be through groundwater ingestion. Since the aquifer underlying the impact area on Cape Cod is the sole source of drinking water for residents of that area, any chemical contaminants introduced into it have the *potential* of being ingested at some point in time. At MCAGCC, one potential pathway that is being examined is the transport of contaminants via dust clouds. Strong winds coming across the desert often pick up tremendous quantities of dust from the ranges and carry it over populated areas, providing a likely conduit if contaminants are present.

3.5.4 Other Considerations

While the items outlined above are primarily for determining if soil contamination exists, other aspects of an investigation may need to be included while developing a thorough plan. If the past usage of a range is unknown, or there is a possibility that it was used for the dumping of ammunition in the past, then a water sampling scheme should be developed along with the soil screening plan. At the MMR, the long history of use suggests that if PEPs are present in the soil, then they may also be in the underlying aquifer. The high mobility of RDX and the low mobility of TNT, combined with the extremely small size of a potential source (single projectiles) translates into any potential plume being so small as to defy detection unless burial or other concentrated sites exist. However, because of the uncertainty of whether or not unknown burial sites exist, it will be important to also examine the groundwater flowing from an impact area. This part of a plan, however, must be approached carefully, and with a maximum of flexibility built in.

3.6 Staffing and Budgeting

This is an important part of any project that is subject to the politics of government budgets and requirements. The command that initiates a study of this type must ensure that adequate levels of both budgeting and staff are available to complete the study in a timely fashion. If, as is the case at the MMR, the study is being driven by a regulatory requirement, then this may be one of the more difficult aspects of the investigation, since the study and what it might find may be politically unpopular. One of the lessons learned from the IRP process at the MMR is that it is critical to have the project manager on-site, and devoted to that project only, instead of trying to manage from afar (Public Meeting 1997). It is also important that the project manager be given enough budgetary leeway to allow them to adjust the plan rapidly if it is required. They should also have the necessary authority to make changes to the basic plan without the normal bureaucracy, in order to maintain flexibility.

3.7 Developing A Results Based Action Plan

This is in all likelihood the most critical phase of the investigation, and the one that most involved parties will be most interested in. The action plan must also take into account the costs and benefits associated with any remediation scheme. Even if the soil screening stage of an investigation reveals contaminants present, the exposure potential or lack thereof must be strongly considered before developing an elaborate and expensive remediation plan. Likewise, a presence of contaminants in the groundwater may not require an immediate reaction, since the potential for human consumption may be extremely low or nonexistent. Flexibility is again the key to a successful action plan. Options to reduce the amount of PEPs and other contaminants introduced into an impact area should be considered as a part of any such plan. These include the use of "green ammunition" for training, and the installation of bullet traps at fixed ranges, where practicable. Simulator training may also be an option, but should not be relied upon as a sole answer, as outlined in Section 1.1.1.

3.7.1 Remediation Options

If enough contamination from PEPs is found to warrant cleanup operations, a number of options may be considered. Several technologies have been adopted for remediation schemes at various AAPs faced with considerable contamination. Some of the options considered have included phytoremediation, UV treatment, composting, and activated carbon processes. In addition, several new technologies are being developed, such as catalytic oxidation in fixed-bed reactors (Civil Engineering 1997), and bioremediation treatment in an anaerobic reactor (UCLA 1993). However, due to the dispersed nature of the possible contaminants, no contaminated groundwater plume as they are commonly recognized is likely to be found emanating from an impact area. Additionally, the hazards from UXO would make a typical cleanup operation nearly impossible. Therefore, the most economical and effective option for dealing with any groundwater contamination caused by PEPs from an impact area would most likely be well-head treatment with activated carbon filters.

Each site and situation must be approached differently, however, and no cookbook solution for addressing PEP contamination, if it is found to be a problem, should be attempted. As in most environmental issues, innovation and flexibility, not stifling regulation and rigidity will provide the best answers, regardless of the issues being faced.

Section 4
Conclusions

4.1 Uncertainty & Flexibility

Based on the data currently available, it is not likely that a live-fire impact area used for its normal purposes will be a source of PEP contaminants. However, due to the possibility that other activities have taken place in the impact area that may have included the burial of munitions in the past, it will be necessary to conduct an investigation whenever human health and the environment may otherwise be threatened. An investigation, when undertaken, should be thorough, and fully open to peer and, if required, public review. While the contaminants addressed in Section 2 are probably the most common compounds that might be found in a study, there are many more that might also be considered. Likewise the investigation should address all feasible pathways, since there remains a high level of uncertainty regarding how PEPs and the heavy metals associated with live-fire training interact with the various media. Although considerable data exists for major sources such as the AAPs, more study will be required to understand the threat, if it exists, from the dispersed, non-quantifiable sources associated with live-fire training. If live-fire training is shown to pose a serious threat to human health or the environment, the military community will need to respond with innovation and flexibility to both remediate past damage, and to prevent any future problems. The continued development of "green" ammunition, bullet traps, and other technology will go far towards addressing some of these concerns, but until more of the uncertainty is removed, the basic question of whether current training methods are environmentally unacceptable will remain.

Regardless of the final verdict on contamination caused by live-fire training, numerous closed and soon-to-be closed military installations have impact areas that will need to be investigated. Since most bases did not keep accurate records of types of ammunition fired and other operations that may have occurred, a thorough study of the type outlined in Section 3 will need to be conducted. Each installation is unique, with unique environmental considerations, and any proposed study must be approached with this idea in mind. The known history of a site may dictate the general direction of a study, but history cannot be relied upon exclusively to guide a successful plan. Finally, safety may well be the overriding concern of any investigation. The physical hazards of UXO and other dangers that may be encountered in an impact area can not be taken lightly. An inclusion of EOD professionals in a study from the start will help mitigate the danger, but will not eliminate it. As in all other aspects of an investigation, flexibility to meet the situation will go far towards ensuring success.

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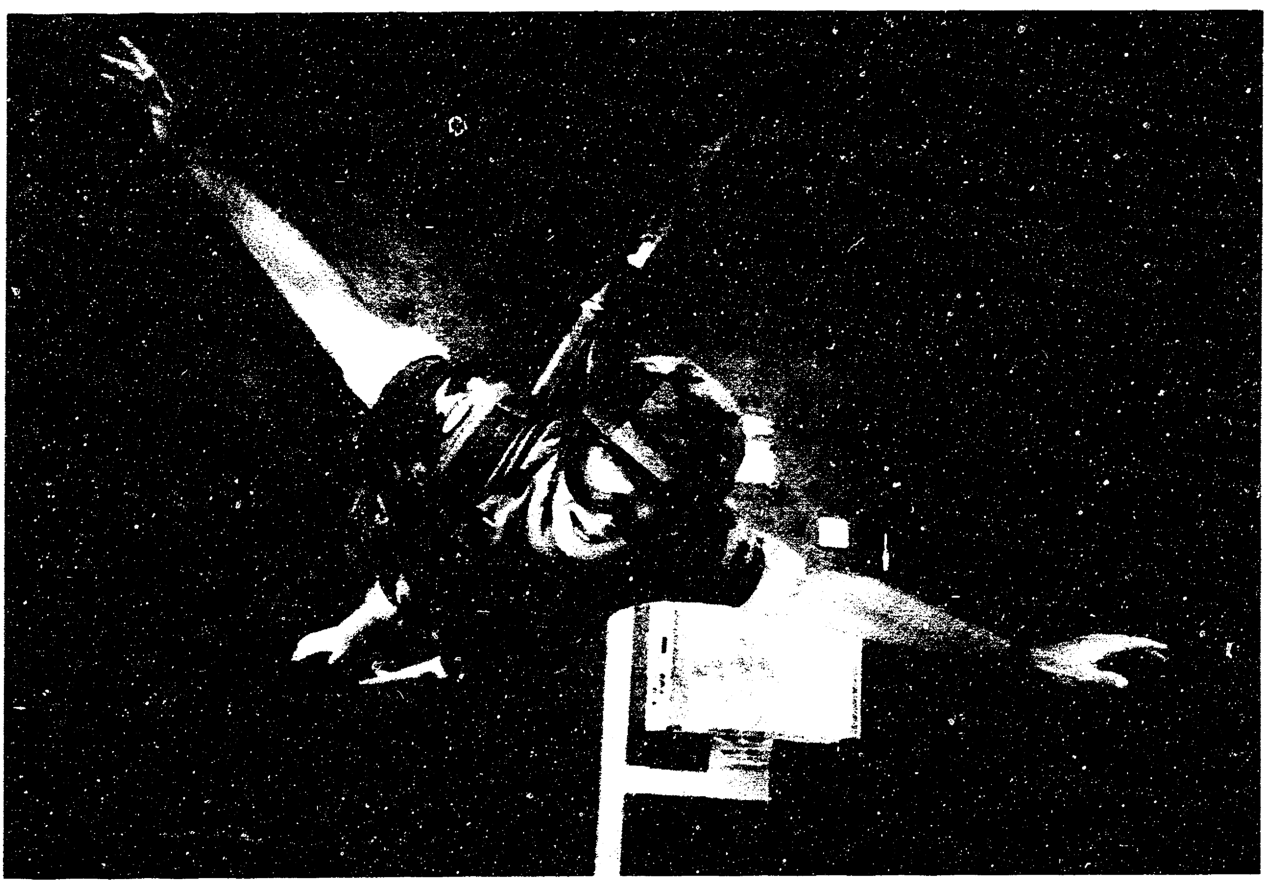
Biography

David Cook is a native of Florida and an active duty Captain in the US Marine Corps. He graduated first in his class and received a B.S. in Civil Engineering from The Citadel, Charleston, SC in 1992. While at The Citadel, he was awarded Citadel Development Foundation scholarships, American Consulting Engineering Council scholarships at both the state and national level, and the Loring K. Himmelright Civil Engineering scholarship. He was a member of the Semper Fi Society and Phi Kappa Phi. He was the secretary of the ASCE chapter, was named freshman of the year by the South Carolina Gamma Chapter of Tau Beta Pi and was president of the chapter his senior year.

Prior to attending The Citadel, he served as a Marine Drill Instructor at Parris Island, SC, and was an avionics technician on A-4 aircraft before that. Since receiving his undergraduate degree, he has served as a combat engineer platoon commander and bulk fuel company commander in Okinawa Japan, with deployments to Korea, Hong Kong, and Thailand. His future assignment is at Headquarters Marine Corps, Washington, DC, as the Environmental Compliance Officer for the Marine Corps.

He is supported in all of his endeavors by his wonderful wife Cecilia of Canton, North Carolina, and their two children, Maegan and Shane.



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