Impact Area Groundwater Study Program

Final
Central Impact Area
Source Investigation Summary Report

Massachusetts Military Reservation
Cape Cod, Massachusetts

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ACRONYMS AND ABBREVIATIONS

2,4-DNT	2,4-dinitrotoluene
2A-DNT	2-amino-4,6-dinitrotoluene
4A-DNT	4-amino-2,6-dinitrotoluene
AEC	United States Army Environmental Command
AFCEE	Air Force Center for Engineering and the Environment
AFRL	Air Force Research Laboratory
AIRMAG	airborne magnetometer
APC	Armored Personnel Carrier
bgs	below ground surface
BIP	blown-in-place
CRREL	Cold Regions Research Engineering Laboratory
CS-19	Chemical Spill 19
EPA	U.S. Environmental Protection Agency
g/yr	grams per year
HE	high explosive
HMX	octahydro-1,3,5,7-tetranitro-1,3,5,7-tetrazocine
HUTA	High Use Target Area
Kg	Kilograms
µg/Kg	micrograms per kilogram
µg/L	micrograms per liter
LITR	low intensity training round
MEC	munitions and explosives of concern
mg/Kg	milligrams per kilogram
mm	Millimeter
MMR	Massachusetts Military Reservation
RDX	hexahydro-1,3,5-trinitro-1,3,5-triazine
SCAR	Sub-caliber Aircraft Rocket
SVOC	semivolatile organic compound
TNT	2,4,6-trinitrotoluene

EXECUTIVE SUMMARY

The Central Impact Area Source Investigation Summary Report provides a summary of activities conducted and data gathered for characterization of source areas at the Central Impact Area. The Central Impact Area is among several training areas, ranges, and other sites evaluated by the Impact Area Groundwater Study Program for potential groundwater impacts. The investigations, studies and response actions were conducted under the authority of the United States Environmental Protection Agency Safe Drinking Water Act Administrative Orders SDWA 1-97-1019, and SDWA 1-2000-0014 and in consideration of the substantive cleanup standards of the Massachusetts Contingency Plan.

The Central Impact Area has been used as an impact area for artillery and mortar firing from the late 1930s until 1997 (Ogden 1997). During the late 1940s, the Central Impact Area also contained Navy air-to-ground rocket ranges that utilized inert 2.25-inch rockets. Various types of munitions, including 37mm, 40mm, 75mm, 90mm, 105mm, and 155mm artillery projectiles and 50mm, 60mm, 70mm, 81mm, and 4.2-inch mortars, have been fired into the Central Impact Area (USACE 2001). These munitions include HE charges designed to explode upon impact, and practice rounds, which do not contain an HE charge but may contain a spotting charge designed to emit smoke upon impact.

The primary groundwater contaminants in the Central Impact Area, RDX and perchlorate, are present in co-located plumes. Other explosives compounds, including HMX, TNT, 2A-DNT and 4A-DNT, have also been detected, but in a relatively few isolated monitoring wells. The RDX plume is comprised of multiple parallel and overlapping plumelets and is oriented in a southeast to northwest direction consistent with the regional groundwater flow direction.

The apparent irregular shape of the plume edges reflects its complex internal structure and origin from individual contaminant sources distributed over the Central Impact Area. The contamination within this region is not continuous and many of the component plumelets appear to be detached from historic source areas, while others correlate to continuing shallow detections. The furthest downgradient extent of the plume is located about two miles from its presumed origin. The highest RDX concentrations and center of mass appear at deeper intervals within the aquifer in downgradient portions of the plume supporting the interpretation that the active source is progressively depleting and the plume is migrating advectively with groundwater flow.

As part of the source investigation in the Central Impact Area, approximately 3,800 soil samples were analyzed for explosives and 671 for perchlorate. The total number of samples analyzed for each analyte includes discrete, composite, and multi-point composite samples. The highest frequencies of detection were observed for perchlorate (19.2%), RDX (5.0%), 2A-DNT (4.6%), TNT (4.0%), 4A-DNT (3.9%), and HMX (2.5%). Detections of explosives are scattered throughout most of the areas sampled. Most of the detections for explosives are located adjacent to non-detects, i.e., contaminant particles are scattered and heterogeneously distributed in soil. The types and frequencies of explosives compounds observed in soil reflect the munitions fired into the Central Impact Area.

The results of multi-point composite samples collected upgradient of drive points with water table RDX detections indicated only low levels of explosives detected in a few samples. The results suggest that the current source of the Central Impact Area plume is likely contamination still flushing through the unsaturated zone or low-order/breach munitions items and not a broad area of soil contamination.

Several major geophysical investigations have been conducted in the Central Impact Area to evaluate the distribution of unexploded ordnance including an airborne magnetometer survey (AIRMAG), the SCAR site, the Eastern Test site, the High Use Target Area (HUTA) Phase I, HUTA Phase II, unexploded ordnance density estimation test plots, and the robotics technology demonstrations. Several soil response actions have also been undertaken to reduce levels of contamination from certain areas identified during the investigation of the Central Impact Area. These include soil removals at the APC (Target 25), Mortar Target 9, and Targets 23 and 42. Information on the distribution of unexploded ordnance was also collected during these actions.

The distribution of unexploded ordnance within the Central Impact Area has been documented through the results of the numerous geophysical investigations and removal actions. Approximately 68 percent of the high-explosives filled unexploded ordnance items found in the Central Impact Area consist of 81mm mortars and 105mm and 155mm artillery projectiles. The three next most common items include 60mm mortars, 4.2-inch mortars and 37mm projectiles. However, within the CS-19 disposal area, small arms ammunition was the dominant item found. Results indicate that unexploded ordnance items are predominantly located near targets and other high use areas. Densities of unexploded ordnance items decrease significantly in other portions of the Central Impact Area. Investigation results indicate that the large majority (90%) of unexploded ordnance are located within three feet of the ground surface. The majority (317 out of 356) of the unexploded ordnance items found in the Central Impact Area were intact. The intact category includes items that were fully intact or dented and/or bent but not cracked or breached. Approximately 39 items (out of 356) were identified as cracked or beached. Partial items are included in the low-order/breached category. The determination on which category an item fits into was made by unexploded ordnance technicians based on visual inspections of the areas that are visible. However, since many items cannot be moved, a thorough inspection is not possible.

Because of the inconsistency of soil detections, potential groundwater plume source areas were identified through water table detections. Source areas were inferred from the extent of water table detections as of April 2007. For each source area, starting with the observed water table concentration, a range of RDX concentrations in aquifer recharge was iteratively simulated using the groundwater fate and transport model (MT3DMS) until a satisfactory match to interpreted plume extent and maximum RDX concentration at the water table was achieved. The source areas inferred from water table detections are consistent with other potential source area indicators such as target locations, unexploded ordnance density, cratering on aerial photographs and particle backtracks from wells with explosives detections. More recent (post-2007) RDX water table data shows declining concentrations, indicating depletion of the current source from 2007 to 2010.

To address soil contamination and potential sources areas, removal actions have been conducted or are ongoing at several locations and approximately 15,200 tons of soil has been excavated and treated on-site, disposed of off-site, or is awaiting final disposition. Munitions have also been removed to depth under various investigations (HUTA I, HUTA II, unexploded ordnance test plots) from an area of approximately 4.3 acres. Thus complete (100%) removal of all detected munitions has been completed over an area of approximately 10 acres (5.5 acres from the soil removals and 4.3 acres from the above investigations).

Surface clearance and major EM anomalies investigations have been conducted over an area of approximately 14 acres (Figure 6-2). Future investigations will be conducted using a modified EM-61 MK2 survey methodology over an additional 8-acre area and significant anomalies (i.e. the signal strength of 60mm mortar at 1 foot depth) will be excavated. This method has been developed to maximize the potential to identify unexploded ordnance in areas where significant fragmentation is present and involves the reconfiguring of the EM-61 MK2 time gates to collect later time data, similar to that which is collected using an EM-63. The ratio between an early time gate and a late time gate has been assumed to best differentiate between UXO targets (with thicker walls) and fragmentation. Based on the results of a modified EM-61-MK2 geophysical survey and excavation program conducted on a ¼-acre grid identified as CIA Grid 002(48_55), anomalies where the ratio of the 15th time channel to the 1st time channel is equal to or greater than 0.028 will be recommended for excavation. While this technique appears promising, it will be further evaluated throughout the project.

Based on the professional judgment of unexploded ordnance technicians and the findings of the depth studies, it is estimated that, when completed, approximately 75 percent of the munitions will have been removed from an area of approximately 22 acres. Munitions have been cleared to a minimum depth of two feet from an area of approximately 16 acres to allow vehicle access on drill pads, roads, and the CS-19 support area. These actions have removed an estimated 85 percent of munitions from these areas. Surface clearance has been performed on approximately 8 acres, which has resulted in an estimated 25 percent munitions removal.

A potential long-term source of groundwater contamination exists as a result of remaining unexploded ordnance. The magnitude and impact of this long-term source on groundwater cannot be accurately predicted or modeled due to the number of uncertainties. However, given the length of time for metal casings to corrode and the explosives filler to dissolve, release rates are likely to be slow. Land use controls will be in place to ensure there is no exposure and no health risk. In addition, continuation of current extensive long-term groundwater monitoring and an active treatment system could be used to address this future contamination if it occurs.

1.0 INTRODUCTION

This Central Impact Area Source Investigation Summary Report provides a summary of activities conducted and data gathered for characterization of source areas at the Central Impact Area. The Central Impact Area is among several training areas, ranges, and other sites evaluated by the IAGWSP for potential groundwater impacts. The investigations, studies and response actions were conducted under the authority of the United States Environmental Protection Agency Safe Drinking Water Act Administrative Orders SDWA 1-97-1019 and SDWA 1-2000-0014, and in consideration of the substantive cleanup standards of the Massachusetts Contingency Plan.

1.1 Purpose of Report

The purpose of this report is to present the scope of source area characterization activities conducted at the Central Impact Area, including the results of investigations and response actions. This report includes an evaluation of source areas and their potential relationship to the groundwater plume at the Central Impact Area.

1.2 Report Organization

Section 2.0 of this report provides a site description of the Central Impact Area and presents the history of past activities conducted at the range and describes the physical characteristics of the site. A summary of characterization activities, including those defining the nature and extent of soil and groundwater contamination and an examination of unexploded ordnance is presented in Section 3.0. Section 4.0 discusses the delineation of source areas. The conceptual site model is presented in Section 5.0. Response actions conducted at the Central Impact Area are discussed in Section 6.0. Section 7.0 presents the investigation findings. Section 8.0 provides the references.

2.0 SITE BACKGROUND

The Massachusetts Military Reservation (MMR) includes Camp Edwards, Otis Air National Guard Base, United States Coast Guard Air Station Cape Cod, Cape Cod Air Force Station, and the Veteran's Affairs Cemetery. It is located on the western side of Cape Cod, Massachusetts (Figure 2-1). The Central Impact Area is located in the central portion of Camp Edwards.

2.1 Site Description

The Central Impact Area is a 330-acre portion of the Impact Area where targets were concentrated. The delineation of the 330 acres was based on historical and current site use, a review of historical aerial photographs, airborne magnetometer (AIRMAG) results, firing fans and unexploded ordnance discoveries, groundwater plumes and particle backtracks, and explosives detections in soil.

Locked gates restrict vehicle access to the Central Impact Area. However, trespassing is an ongoing issue. The site is generally comprised of scrub oak barrens (*Quercus ilicifolia*), reforestation of previous cleared areas, and the remnants of burned areas. The remainder of the Impact Area that surrounds the site includes vegetated pitch pine (*Pinus rigida*) and scrub oak forest. The ground surface is relatively flat and generally slopes from the northwest to the south and east.

2.2 Site History

The Central Impact Area has been used as an impact area for artillery and mortar firing from the late 1930s until 1997 (Ogden 1997). During the late 1940s, the Central Impact Area also contained Navy air-to-ground rocket ranges that utilized inert 2.25-inch rockets. Various types of munitions including 37 millimeter (mm), 40mm, 75mm, 90mm, 105mm, and 155mm artillery projectiles and 50mm, 60mm, 70mm, 81mm, 3-inch, and 4.2-inch mortars have been fired into the Central Impact Area (USACE 2001). These munitions include high explosive (HE) charges designed to explode upon impact, and practice rounds, which do not contain an HE charge but may contain a spotting charge designed to emit smoke upon impact.

The predominant HE charge used in pre-World War II munitions contained 2,4,6-trinitrotoluene (TNT). Post World War II artillery and mortar munitions used Composition B for the HE charge, which is a mixture of hexahydro-1,3,5-trinitro-1,3,5-triazine (RDX) and TNT. The low-intensity training round (LITR) is an artillery practice projectile that was introduced in 1982 to reduce the noise associated with HE explosions. The 155mm M804 LITR includes a spotting charge containing 190-195 grams of smoke mixture that is 20 percent perchlorate and the 155mm M804A1 contains a small explosive charge containing 20 grams of RDX. The use of HE artillery projectiles ceased in 1989, and the firing of all munitions into the Central Impact Area was discontinued in 1997.

HE munitions that did not explode or that partially functioned (low order) have accumulated within the Central Impact Area during its use. Unexploded ordnance located along roadways or at other locations that presented a safety hazard due to human access have historically been blown-in-place (BIP) using an explosive donor charge. BIP operations were also used to clear areas for site investigation starting in 1997. Post-BIP soil sampling and removal of soil contaminated by BIP activities have been conducted since 1999.

Historical information indicates that in the past, several portions of the Central Impact Area have undergone a variety of uses and in some cases have been mechanically cleared of vegetation (Figure 2-2). Among the previously developed areas within the Central Impact Area are the following:

- Sub-caliber Aircraft Rocket (SCAR) Sites – two approximately 10-acre sites used by Naval aircraft in the 1940s for target practice with inert 2.25-inch rockets.
- Eastern Test Site – an area in the northern portion of the Central Impact Area believed to have been used for artillery and mortar targeting.
- Tank Alley – a cleared area developed around 1965 and afterward used extensively to locate tanks and other targets.
- Chemical Spill 19 (CS-19) – an area in the west-central region of the Central Impact Area where ordnance testing and disposal activities occurred.

Investigations of the CS-19 area were conducted under the Installation Restoration Program by the Air Force Center for Engineering and the Environment (AFCEE).

2.3 Environmental Setting

2.3.1 Geographic Setting

MMR is situated adjacent to the towns of Bourne, Sandwich, Falmouth, and Mashpee. The northern, non-cantonment area is a wooded area on the Upper Cape that is largely undeveloped, but fringed with highways, homes, and other development (Cape Cod Commission 1998).

2.3.2 Cultural Setting

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

MMR contains a cantonment area that includes a housing area for approximately 2,000 year-round residents. Areas of the MMR are used as airfields and other military support facilities. The MMR resident population increases by as much as several thousand people during the summer training activities.

The northern area in which the Central Impact Area is located is used for military training. As such, it is a restricted area surrounded by fencing and guarded gates. The land is controlled by the U.S. Army under a lease from the Commonwealth of Massachusetts running until at least 2051. Therefore, the potential for human exposure to on-site soil contaminants is limited to occasional trespassers, site workers, and military personnel. It is anticipated that the land use at the Central Impact Area will not significantly change over time.

An archaeological survey covering 72 percent of Camp Edwards was conducted in 1987 to assess its archaeological sensitivity. One historic site and 26 prehistoric sites were identified within Camp Edwards. Findings from these surveys indicate that humans inhabited the Camp Edwards area up to 10,000 years ago.

2.3.3 Ecological Setting

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

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

2.3.4 Climate

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

Mean annual rainfall and snow meltwater range from 45 to 48 inches. The average net recharge to groundwater of this annual rainfall is 27 inches per year. Occasional tropical storms that affect Barnstable County may produce 24-hour rainfall events of 5 to 6 inches (NGB 1990). Average snowfall is 24 inches (MAARNG 2001).

2.3.5 Geology

The Central Impact Area is situated within the Mashpee Pitted Plain, a thick wedge-shaped deposit of unconsolidated Late Pleistocene outwash sands and gravels. The Mashpee Pitted Plain is bounded to the west and north by the Buzzards Bay and Sandwich moraines, respectively (Figure 2-3). The Mashpee Pitted Plain is an outwash plain formed by streams that drained the Buzzards Bay and Cape Cod Bay lobes of retreating glaciers. Depositional environments of the Mashpee Pitted Plain range from glaciofluvial for the coarser deposits to glaciolacustrine for the finer deposits. In the Mashpee Pitted Plain, the glaciolacustrine deposits are discontinuous and commonly overlie basal till or bedrock. Coarse textured basal till, consisting of poorly sorted sands and gravels, occurs sporadically across the top of the bedrock surface. Coarser grained sands and gravels, deposited in glaciofluvial environments, usually overlie the glaciolacustrine deposits and are more continuous across the plain. Overlying these glaciofluvial deposits is a thin veneer of eolian silt. A general description of the geology of Cape Cod and the geology of the Central Impact Area is provided in the *Draft UXO/Source Investigation Report for the Central Impact Area* (AMEC 2008).

Soils encountered during installation of the numerous borings and monitoring wells within the Central Impact Area are consistent with the descriptions of the Mashpee Pitted Plain stratigraphy, and depths to the bedrock surface. The top 260 feet consists predominantly of poorly graded medium to coarse sands with intervals of fine gravelly sediments and is classified using the Unified Soil Classification System as SP. Between 260 and 330 feet, soils are principally classified as finer sands and silts. These deposits are representative of a sandy basal till. Crystalline bedrock was encountered at a depth of approximately 320 to 380 feet below grade.

2.3.6 Hydrogeology

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

The aquifer system is unconfined (i.e., it is in equilibrium with atmospheric pressure and is recharged by infiltration from precipitation). The sole source of natural fresh water recharge to this groundwater system is rainfall and snow meltwater that averages approximately 48 inches per year. Except on extreme slopes, surface water runoff at Camp Edwards is virtually nonexistent due to the highly permeable nature of the sand and gravel underlying the area.

The top of the groundwater mound within the western Cape Cod groundwater system is located beneath the ranges on the southeast side of MMR (Figure 2-4). Groundwater flows radially outward: north to either the Cape Cod Canal or the Cape Cod Bay, east to the Bass River, south and southeast to Nantucket Sound, and west and southwest to Buzzards Bay (ANG 2001). The height of the water table in and around the MMR can fluctuate up to 7 feet annually due to seasonal variations in groundwater recharge and pumping demand (USGS 1996). Groundwater levels are highest in the spring when recharge rates are high and pumping demand is low; levels are lowest in the late summer/early autumn when rainfall is minimal and pumping demand is at its maximum. The total thickness of the aquifer varies from approximately 80 feet in the south to approximately 350 feet in the north. The variation in thickness is due to the episodes of glacial advance and retreat, the underlying bedrock geology, and the presence of fine-grained materials in the deeper sediments beneath the southern portion of the aquifer (ANG 2001).

The groundwater flow direction from the Central Impact Area is predominantly to the northwest (Figure 2-4) and the hydraulic gradient steepens with increasing distance from the top of the regional potentiometric groundwater mound. Within the Central Impact Area, groundwater elevations typically range between 65 and 70 feet National Geodetic Vertical Datum, and depth to groundwater ranges from approximately 100 to 140 feet below ground surface (bgs). Based on the observed response of the water table relative to recharge events, the hydraulic travel time through the vadose zone is expected to be three to six months. The thickness of the saturated zone varies between 180 and 280 feet.

A hydraulic conductivity value of 155 feet per day for the saturated zone was calculated from the results of an aquifer test performed within the Central Impact Area on well P-1 (AMEC 2003a). This value is consistent with the estimated range of 125 to 350 feet per day based on grain size (Masterson et al. 1996) and is approximately double those calculated in the moraine material. The hydraulic conductivity of the 5- to 20-foot thick basal till on top of bedrock is estimated at one foot per day (Masterson et al. 1996). Bedrock occurs at a depth of approximately 320 to 380 feet bgs beneath the Central Impact Area and can be considered impermeable. Therefore, the bulk of regional groundwater flow is transmitted through the upper outwash units. The effective porosity of the saturated zone, which was determined from several past MMR studies (AMEC 2003b; AFCEE 2003; LeBlanc et al. 1991; Barber et al. 1988; Morrison and Johnson 1967), is assumed to be 0.39.

Groundwater flow calculations for different Central Impact Area well pairs using measured gradients and assuming relatively constant hydraulic conductivity and effective porosity values yield mean and median velocities of 0.32 and 0.29 feet per day, respectively, and compare well to the aquifer test derived groundwater flow velocity of 0.48 feet per day (AMEC 2003a).

3.0 SUMMARY OF INVESTIGATIONS

This section briefly summarizes investigations of the nature and extent of soil and groundwater contamination and munitions at the Central Impact Area. This summary is based upon the detailed evaluation presented in the *Draft UXO/Source Investigation Report* (AMEC 2008) augmented by groundwater data collected after the issuance of the 2008 *Draft UXO/Source Investigation Report*. As discussed in the investigation report, there have been numerous previous soil, groundwater and geophysical investigations at the Central Impact Area.

3.1 Groundwater Characterization

The addendum to the Final IAGWSP TM 01-06 Central Impact Area Groundwater Report (AMEC 2007a) and the *Central Impact Area Feasibility Study* (Tetra Tech 2011) provide a comprehensive compilation of groundwater results for the Central Impact Area and a detailed discussion of the nature and extent of groundwater contamination. The primary groundwater contaminants, RDX and perchlorate, are present in co-located plumes. Other explosives compounds, including HMX, TNT, 2-amino-4,6-dintrotoluene (2A-DNT) and 4-amino-2,6-dintrotoluene (4A-DNT), have also been detected, but in a relatively few isolated monitoring wells. The RDX plume shape has changed somewhat over time, while the perchlorate plume shape has changed more significantly, principally because it has been reinterpreted based on the more recent sample results rather than maximum historical concentration.

RDX is the most widespread groundwater contaminant at the Central Impact Area. The RDX plume, which is comprised of multiple parallel and overlapping plumelets, is oriented in a southeast to northwest direction consistent with the regional groundwater flow direction. The region of likely contamination is illustrated in Figure 3-1. Monitoring wells are shown in Figure 3-2. The apparent irregular shape of the plume edges reflects its complex internal structure and origin from individual contaminant sources distributed over the Central Impact Area. The contamination within this region is not continuous as depicted in plan view. Many of the component plumelets appear to be detached from historic source areas, while others correlate to continuing shallow detections. The furthest downgradient extent of the main plume is located about two miles from its presumed origin. The highest RDX concentrations and center of mass appear at deeper intervals within the aquifer in downgradient portions of the plume supporting the interpretation that the active source is progressively depleting and the plume is migrating advectively with groundwater flow.

RDX within the groundwater plume has been reported up to a maximum concentration of 44 micrograms per liter (µg/L) in 2005. Most values are below 10 µg/L and the overall mean of detectable concentrations in the plume in 2007 was approximately 3 µg/L. Higher RDX concentrations (i.e., greater than 10 µg/L) have historically been observed in samples collected from three locations: wells along Turpentine Road and nearby wells to the east; wells at the CS-19 site near the western edge of the Central Impact Area; and MW-207M1 located west of the Central Impact Area along Wood Road. Recent (post-2007) monitoring well data indicate that RDX concentrations in groundwater associated with the Central Impact Area have largely remained consistent with previous observations and expected trends. Within the core of the plume, declining RDX concentrations at MW-184M1 and increasing concentrations at MW-89M2 indicate that the apparent center of RDX mass is departing the Central Impact Area along the boundary defined by Pocasset–Sandwich Road and continuing to arrive at the Impact Area Boundary (Spruce Swamp Road). In addition, concentrations in shallow wells near the inferred source areas along Turpentine Road and Tank Alley have declined overall, suggesting the trailing edge of the RDX plume has begun to detach from its area(s) of origination.

Overall, only two water table wells (MW-91S and MW-1S) presently exceed 2 µg/L for RDX (based on data collected through July 2010). The source area RDX concentration at MW-91S has systematically declined from 24 µg/L in 2007 to 2.1 µg/L in 2010 and MW-235M1 located 35 feet below the water table within the source area has declined from a high of 45 µg/L in 2006 to 2.2 µg/L in 2010. At the same time, well screens further downgradient such as well MW-89M2, which is screened approximately 80 feet below the water table, have increased in concentration from 5.6 µg/L (2002) to 21 µg/L (2009). RDX concentrations in this well have subsequently begun to decrease (17 µg/L as of January 2010) as the area of higher concentrations moves further downgradient toward MW-209M1. MW-209M1 started with an initial RDX concentration of 2.4 µg/L in 2002 and experienced its historic maximum of 7.9 µg/L in 2009. RDX concentrations in this well are expected to increase in the future as the area of higher concentrations passes through. The plume has now reached MW-123M2 located approximately 1,700 feet downgradient from MW-209M2, which has recorded RDX concentrations below 1 µg/L. The total RDX plume mass (as estimated by interpolation of monitoring well concentrations across the interpreted plume footprint) is approximately 22.5 Kg (AMEC 2008).

The perchlorate plume in the Central Impact Area is significantly less extensive than that of RDX contamination. However, its downgradient extent was comparably similar at approximately 12,000 feet from the region where it initially enters groundwater. As with RDX, higher perchlorate concentrations were initially observed in groundwater samples collected from the water table at the source along Turpentine Road and Tank Alley. The highest concentration as of 2007, an estimated value of 5 µg/L, was detected in MW-91S (AMEC 2008). With the exception of that one sample, reported perchlorate concentrations were less than 4 µg/L, and the mean of detectable concentrations was approximately 1 µg/L. Total perchlorate plume mass above 2 µg/L as of 2007 was estimated to be 0.26 Kg.

Perchlorate concentrations appear to be following a similar trend as seen with RDX. In 2000, the highest perchlorate concentration (5 µg/L) was observed in a shallow monitoring well (MW-91S) located in the main source area along Turpentine Road. By May of 2007, perchlorate was non-detect in this well. As the perchlorate plume began to detach from its source and move downgradient, higher concentrations were observed at the Central Impact Area boundary in MW-38M3. MW-38M3 has exhibited a steadily declining concentration since 2007 and most recently has fallen below 2 µg/L. In 2009, the highest perchlorate concentrations were detected in MW-89M2, which is located at the Impact Area boundary downgradient of MW-38M3. Consequently, similar to RDX, the apparent center of mass of the perchlorate plume is departing the Central Impact Area along the boundary defined by Pocasset–Sandwich Road and arriving at the Impact Area boundary.

3.2 Source Characterization

Potential source areas in the Central Impact Area have been extensively investigated and sampled during numerous studies conducted since 1997. The primary investigations include the following:

1997-1998	Site-wide Sampling
2000	Land Features Investigation
2000	Airborne Magnetometer Survey
2000	Mortar Target Investigation
2000-2001	Target Investigations
2000-2001	HUTA I Investigations
2001-2002	HUTA II Investigations
2002	SCAR Site Investigation
2002	Eastern Test Site Investigations
1991-2003	CS-19 Remedial Investigation
2004-2005	Focused Investigations at Targets 23 and 42
2005	CRREL Multi-increment Soil Sampling
2006	Multi-Increment Sampling
2006	Post-screening Investigation UXO Density Test Plots
2009-2010	CS-19 Bunker Area Phase II Investigation
2010	UXO Density/EM-61 Modified Test Plot (CIA Grid 48-55)

These investigations cover the principal historical use areas within the Central Impact Area, including targets and test sites. Detailed summaries of the results of most individual investigations are presented in the *Draft UXO/Source Investigation Report* (AMEC 2008). A detailed summary of the 2009 CS-19 investigation is presented in the AFCEE *Chemical Spill 19 – Bunker Area Phase II Investigation Report* (AMEC 2010). The locations of the primary investigations are shown in Figure 3-3.

3.2.1 Soil Investigations

Approximately 3,800 soil samples were analyzed for explosives (not including semivolatile organic compound [SVOC] samples, which also have three explosive analytes reported) and about 671 were analyzed for perchlorate. The large majority of samples analyzed for explosives (>95%) were analyzed by EPA Method 8330. Approximately 304 samples were discrete samples, 3,420 were composite samples, and 76 samples were multi-point composite samples. Of the 671 samples that were analyzed for perchlorate, approximately 183 were discrete samples, 270 were composite samples, and 218 were multi-point composite samples. The composite samples were typically composed of either five subsamples collected from a 22 by 22-foot grid, eight subsamples collected from the inner and outer rings positioned 10 to 15 feet and 20 to 25 feet from the center of the targets, or from square grids spaced 50 feet apart. Multi-point composite samples were typically composed of 30 subsamples collected from several sizes of grids including 22 by 22-foot grids and 15 by 15-foot grids.

The highest frequencies of detection were observed for perchlorate (19.2%), RDX (5.0%), 2A-DNT (4.6%), TNT (4.0%), 4A-DNT (3.9%), and HMX (2.5%). The types and frequencies of contaminants observed reflect the munitions fired into the Central Impact Area and munitions release mechanisms, contaminant fate and transport, and soil characterization methods. Perchlorate is an ingredient in the spotting charge used in LITR projectiles fired from 1982 to 1997. RDX and TNT are the main ingredients in HE charges used after World War II. 2A-DNT and 4A-DNT are breakdown products of TNT, and HMX is an impurity in RDX.

Detections of total explosives, RDX and perchlorate appear to be scattered throughout the Central Impact Area and relatively higher detected concentrations are frequently co-located with non-detects. The maximum RDX detection and a series of smaller co-located detections were observed at a low-order mortar with exposed filler at High-Use Target Area 2 Transect 2. RDX was also detected at Mortar Target 9 and Target 11. Apart from these detections, RDX was primarily observed in areas near Turpentine Road and Tank Alley. Therefore, RDX was determined to be most prevalent in soil in the area most of the targets are located and where groundwater impacts have occurred.

The U.S. Army Cold Regions Research and Engineering Laboratory (CRREL) of Hanover New Hampshire is credited with developing the multi-point composite soil sampling methodology in order to overcome spacial and particle-size heterogeneity inherent on military ranges. CRREL performed limited multi-point composite sampling at MMR in 2005. This sampling is shown in Figures B-12 and B-13 in Appendix B. As can be seen, CRREL utilizes a variety of decision unit sizes to determine an average concentration across the sample area.

Under the 2006 Post Screening Investigation, an extensive multi-point composite soil sampling program was implemented within the Central Impact Area. Thirty-point multi-point composite samples were collected throughout the Tank Alley and Turpentine Road area, the SCAR site, and HUTA II Transect 2. Most of the multi-point composite samples were collected upgradient of drive-points installed to delineate the extent of water table RDX detections along Tank Alley and Turpentine Road. The goal of these samples was to try to establish a correlation between surface soil and shallow groundwater contamination. These results were reported in the 2008 *Draft UXO/Source Investigation Report*; however, they were included in the overall discussion of the nature and extent of contamination and were not separately identified. These sample results however are more representative of surface soil conditions.

The results of the multi-point composite sampling program are summarized in Figure 3-4. The results of the samples collected upgradient of the drive points with water table RDX detections indicated only low levels of explosives detected in a few samples. Thus no clear connection was established between explosives detections in soil and shallow groundwater contamination. The results suggest that the current source of the Central Impact Area plume is likely contamination still flushing through the unsaturated zone or low-order/breach munitions items and not a broad area of soil contamination.

Explosives were not detected at the SCAR or HUTA II Transect 2 sites. Some explosives were detected in samples from the suspected source area along Tank Alley and Turpentine Road. This data is consistent with previous composite sample results that showed more frequent and higher explosives detections in the immediate vicinity of this and other targets.

3.2.2 Geophysical Investigations

3.2.2.1 Investigation Phases

Major geophysical investigations conducted in the Central Impact Area include: an airborne magnetometer survey (AIRMAG), the SCAR site, the Eastern Test site, the High Use Target Area (HUTA) Phase I, HUTA Phase II, unexploded ordnance density estimation test plots, and the robotics technology demonstrations. Geophysical surveys and munitions clearance have also been conducted at geophysical equipment test areas, drill pad sites, roads, buffer areas around investigated areas and removal actions, and the CS-19 support area.

AIRMAG

An airborne magnetometer survey was conducted over the entire 330-acre Central Impact Area in 2000 (Figure 3-5). The survey identified many large ferrous anomalies particularly along Tank Alley and Turpentine Road. Field verification was conducted on 134 anomalies and 23 were excavated. One potential HE 105mm projectile was discovered and blown-in-place. Based on the field verification and aerial photography, the vast majority of the anomalies were categorized as cultural, geologic, target-related, and signal noise. AIRMAG was useful at identifying areas with significant surface or near surface metal but not useful at identifying individual munitions.

High Use Target Area I

HUTA I was a square, 4-acre area within the Central Impact Area selected for investigation in 2000 based primarily on AIRMAG results (Figure 3-3). The objectives of the HUTA I investigation were to characterize the physical distribution of munitions items and characterize soil contamination. The area was cleared of vegetation and surface cleared for munitions. Successive 1-meter lifts of soil were removed from each of the test plots, while munitions, munitions debris, and range-related debris were catalogued. The most common munitions items found were 81mm mortar and 155mm projectiles (Table 3-2). An analysis of the distribution and condition of munitions found in the Central Impact Area (including HUTA I) is provided in Section 3.2.2.2.

High Use Target Area II

HUTA II consisted of five 7 by 200-meter (0.35 acre) transects positioned across suspected target areas based on AIRMAG survey anomalies (Figure 3-3). The objectives of the HUTA II investigation were to determine the density of munitions items near targets and attenuation away from targets; catalogue munitions items and munitions debris by type and condition; and characterize soil contamination. Sampling and survey methods were similar to those used for the HUTA I investigation, except that test plots were not excavated. Transects 2 through 4 were located inside the Central Impact Area while Transects 1 and 5 were located outside the limits of the Central Impact Area. Predominant munitions types varied between transects; for example, 81 mm mortars were most common in Transects 1 and 5, while 155mm and 105mm projectiles were most common in Transects 2 and 3 (Table 3-2). Munitions conditions varied from "good" to "heavily corroded." With the exception of inert SCARs around the southern SCAR target, no pattern of munitions items was apparent throughout the five transects. An analysis of the distribution and condition of munitions found in the Central Impact Area (including HUTA II) is provided in Section 3.2.2.2.

Sub-caliber Aircraft Rocket Site

The SCAR site is located in the northern part of the Central Impact Area and is approximately 10 acres in size (Figure 3-3). This is one of two sites located in the Central Impact Area where inert 2.25-inch rockets (SCARs) were fired from airplanes at targets located on the ground. SCARs are unfused metal tubes that contain 1.75 pounds of ballistite propellant which is consumed during firing. Ballistite is composed of nitrocellulose (51%) and nitroglycerine (43%) blended with small amounts of plasticizers, stabilizers, wax, and blackening agents.

The entire site was cleared of vegetation and surface-cleared for unexploded ordnance in 2002. SCARs were the most common item discovered during the surface clearance. In addition, five 105mm and thirteen 155mm projectiles were also discovered on or near the ground surface. An EM-61 survey was then conducted and 15 anomalies were investigated. In addition, one test trench was excavated through a large centrally located anomaly. Finds during the intrusive investigation consisted mostly of inert SCARs; however, three HE 155mm projectiles were also discovered.

Eastern Test Site

The ground scar in aerial photographs where the Eastern Test Site was located is approximately 3 acres in size and is located in the northeastern portion of the Central Impact Area (Figure 3-3). The site was identified based on historic aerial photographs but its exact use is not known. The site was cleared of vegetation and surface cleared for munitions in 2002. The majority of items discovered during surface clearance were 155mm LITR projectiles; however, one HE 155mm projectile was also discovered. An EM-61 survey was conducted over an area somewhat larger than the ground scar (4.5 acres) and nine anomalies were investigated. Most of the items discovered during the intrusive investigation were 155mm LITR projectiles. One live M51 PD fuse was also discovered.

2006 Post Screening Investigation UXO Test Plots

Nine 0.22-acre test plots were investigated to further characterize munitions density in the Central Impact Area (Figure 3-6). Three test plots were located in areas believed to have high (H-1 to H-3), medium (M-1 to M-3), and low (L-1 to L-3) munitions densities. At each location, anomalies were investigated in one foot lifts down to approximately 4 feet.

The most frequently detected munitions in the test plots were 81mm mortars and 105mm projectiles (Table 3-2). Other items encountered included 60mm and 4.2-inch mortars, 37mm and 155mm projectiles. The vertical distribution of munitions indicated that almost all of the items were found in the top one meter. The initial characterization of low munitions density was validated by the investigation. The remaining medium and high density test plots had similar numbers of finds, which suggest that initial characterization overestimated the number of munitions in the high density test plots. An analysis of the distribution and condition of munitions found in the Central Impact Area (including the 9 test plots) is provided in Section 3.2.2.2. The initial classifications of high, medium and low for the test plots were based on predictions made using an unexploded ordnance density estimation model described in the *Draft UXO/Source Investigation Report* (AMEC 2008). This model was determined, based on the test plot results, to be an adequate predictor of gross unexploded ordnance density but could not achieve a level of accuracy greater than simple numerical averaging (see below).

<u>Target Areas</u>

Several soil response actions have been undertaken to reduce levels of contamination from certain areas identified during the investigation of the Central Impact Area. These include soil removals at the Armored Personnel Carrier (APC) (Target 25), Mortar Target 9, and Targets 23 and 42 (Figure 3-3). Munitions were intrusively cleared from these areas and geophysical surveys conducted. Results obtained during clearance work at these locations (except the APC where records were not sufficiently detailed) are presented in Table 3-2 and provided information on the distribution of munitions items near targets (Section 3.2.2.2).

3.2.2.2 Investigation Findings

<u>Ordnance Type and Condition</u>

The predominant high explosives charge used in munitions fired at MMR through World War II contained TNT. Post-World War II artillery and mortar munitions used Composition B for the HE charge, which is a mixture of RDX (~60%) and TNT (~40%). HMX is a common impurity in RDX and therefore is implicit in the formulations of Composition B. The 155MM M804/M804A1 LITR is an artillery practice projectile that was introduced in 1982. The LITR includes a spotting charge containing perchlorate or RDX. The use of HE artillery projectiles ceased in 1989, and the firing of all munitions into the Central Impact Area was discontinued in 1997.

Table 3-1 presents a summary of the numbers and types of unexploded ordnance items that have been found within the Central Impact Area. The overall distribution of these items is summarized in Figure 3-6 and discussed below. Nineteen different types of unexploded ordnance items have been identified, most being artillery projectiles or mortars. The most common items found were 81mm mortars (27% of all unexploded ordnance items and 30% of high explosives-filled items), 155mm projectiles (24% and 20%), and 105mm projectiles (15% and 18%). These three munitions types comprise more than 65% of all the items found and 68% of all HE items.

The next three most common items observed have been 60mm mortars, 4.2-inch mortars, and 37mm projectiles. The remaining items consisted of a range of munitions including: 2.36-inch, 2.75-inch, and 3.5-inch rockets; one 57mm recoilless rifle projectile; and 30mm, 75mm, 90mm, 7-inch, and 8-inch projectiles. Within the areas that were cleared to depth (HUTA I, HUTA II, Post Screening Investigation Test Plots and soil removal areas), unexploded ordnance item types generally reflect the cumulative statistics for the Central Impact Area as a whole with the 81mm mortar being the most common item and either the 105mm or 155mm projectiles being the second most common items found.

Results summarizing the condition of HE items identified in the Central Impact Area are presented in Figure 3-7. In Figure 3-7, the intact category includes items that were dented and/or bent but not cracked or breached. Cracked items have a physical crack in the metal. Breached items include broken open rounds with exposed filler likely due to a low-order detonation or the fuze shearing off from impact. These observations were determined by the UXO teams working at MMR. The likelihood of a particular type of munition remaining intact varies somewhat depending on the type of munition. In general, the larger caliber items were more likely to be intact, although relatively few (39 out of 356) projectiles were found to be cracked or breached.

These results suggest that approximately 11 percent of the total number of residual HE unexploded ordnance items at the Central Impact Area may constitute a current source of RDX to the groundwater.

The United States Army Environmental Command (AEC) evaluated corrosion of a 155mm LITR discovered during the HUTA I investigation (AMEC 2004a). Additional detailed metallurgical studies of the degree of corrosion of selected items were conducted as part of the Post Screening Investigation (Thielsch Engineering 2007). In both cases, time frames predicted for perforation due to pit formation were estimated to be long, potentially decades to centuries from deposition. Since corrosion of unexploded ordnance in the field is dependent upon many factors (including soil chemistry, weather, unexploded ordnance item type and condition), accurate prediction of corrosion rates and times until specific items may fail are difficult. Results from the UXO HE database indicate that approximately 168 items (out of 356) were either in good condition or only slightly corroded. Approximately 161 items were indicated as being heavily corroded and approximately 27 were not characterized.

However, corrosion of the casing is only one component in determining potential future releases. Both TNT and Comp B are hard solid materials which would not “leak” once the casing has been perforated. Studies conducted by Taylor et al. in 2004 on a 5-inch bare lump of Comp B suggest that complete dissolution of this material would take decades to centuries. Releases of explosives from perforated munitions items are even slower and more complex. A number of factors control these releases including: the cumulative surface area of exposed filler; whether the item is buried in soil (limiting direct contact with precipitation); and the geometry and orientation of the perforation.

These studies provide information on the time it may take for munitions items to impact groundwater. However, specific predictions on the exact time are extremely difficult to accurately model. These studies demonstrate that impacts will not be immediate and will occur over time.

Unexploded Ordnance Distribution

The distribution of unexploded ordnance within the Central Impact Area has been documented through the results of the numerous investigations and removal actions. The location of HE unexploded ordnance finds are plotted on Figure 3-6. Table 3-2 presents a breakout of the total number of items identified in areas within the Central Impact Area that have been cleared to depth, including Mortar Target 9, Target 23, Target 42, HUTA I and HUTA II, and the Post Screening Investigation Test Plots. In some cases, the results presented in Table 3-2 differ from those presented in the *2008 Draft UXO/Source Area Investigation Report*. As discussed in Appendix A, minor differences in some areas can be attributed to: (1) data becoming available after the issuance of the 2008 report and (2) removal of data that was improperly included in the 2008 UXO database. Two significant differences are noted: Mortar Target 9 in the 2008 report was shown to have 30 munitions items but only 7 are shown on Table 3-2 and HUTA I was shown to have a total of 57 munitions items in the 2008 report and 79 on Table 3-2. These differences are the result of the area chosen for the munitions count. In 2008, the entire Central Impact Area was divided into 0.25-acre grids in support of the unexploded ordnance density estimation process. For Mortar Target 9, several items discovered in the support area around the excavation were included in the 0.25-acre grid and thus in the munitions count. Table 3-2 in this report includes only those items found in the actual excavation. Conversely, munitions discovered in the HUTA I test plots but outside the 0.25-acre grids were not counted in 2008. Table 3-2 in this report provides a count of all items found in each test plot.

Target 25 was cleared to depth and seven potential unexploded ordnance items were identified in this area: two 81mm mortars (later determined to be inert); one 4.2-inch mortar; two 155mm projectiles; one 8-inch projectile; and one 3.5-inch rocket. Records related to munitions discoveries from this action lacked sufficient detail to determine whether the items were located inside this APC or in the ground beneath it. Thus these results were not included in the following discussion.

The majority of the items that have been found are located within the central portions of the Central Impact Area in the vicinity of Turpentine Road and Tank Alley. A total of 102 HE items were found within the HUTA I, including the six test plots and adjacent areas. A number of items have been identified in the northern portions of the Central Impact Area during the SCAR and Eastern Test site investigations and clearance for access roads and drill pads. Approximately 54 HE items were located within the Post Screening Investigation Test Plots, which were scattered across the Central Impact Area.

At several locations in the Central Impact Area, complete munitions clearance to depth was performed in support of removal actions or munitions density investigations. Detailed information on the distribution of munitions items over an area of approximately 5 acres was collected. For each area, the number of items found and the size of the area investigated were compiled and the numerical average density was calculated in terms of items per acre. The results of this evaluation are shown in Table 3-3.

Table 3-3. Range of Item Densities

Location	HE Items Found (#)	Extent of the Investigated Area (acres)	Average HE Item Density (#/acre)
HUTA II Transects	15	1.05	14
PSI Test Plots (Low)	8	0.66	12
PSI Test Plots (Med/High)	46	1.32	35
HUTA I Test Plots	79	1.32	60
Target MT-9	7	0.09	78
Target T-42	11	0.18	61
Target T-23	17	0.18	94

The results presented in Table 3-3 generally support the conclusion that those portions of the Central Impact Area known to have had higher historical use have higher munitions densities.

Beyond these cleared areas, unexploded ordnance have been discovered during a range of investigation activities, including monitoring well pad construction, road/access path construction, and soil sampling. These discoveries account for approximately 42 percent of the HE items encountered in the Central Impact Area.

Generally target density is not representative of the Central Impact Area density since the targets represent such a small portion of the area (0.14%). The test plots better represent an average density since they are distributed throughout the Central Impact Area. The average density of these test plots is 27 (54 items/2 acres of test plots) HE unexploded ordnance per acre. This would represent a total number of HE unexploded ordnance within the entire 330-acre area of approximately 8,910. This is generally consistent with the density estimated in the *Draft UXO/Source Investigation Report* (AMEC 2008) of 7,467 from the unexploded ordnance density estimation model. In addition, the Central Impact Area is not necessarily the physical extent of UXO and UXO may remain outside the Central Impact Area boundary (Figure 3-8).

As of 2007, approximately 520 known or suspected HE UXO items had been removed. Approximately 250-300 additional items have been recovered during more recent investigations, including the robotics work. This represents approximately 10 percent of the HE.

Observed unexploded ordnance densities were found to be generally consistent with the working conceptual site model for the Central Impact Area, in which unexploded ordnance are expected to be clustered around targets. Extrapolation of unexploded ordnance distribution from the 5 acres of known munitions density to the entire 330-acre Central Impact Area is problematic considering the heterogeneous distribution of unexploded ordnance.

The vertical distribution of unexploded ordnance items found in the Central Impact Area was evaluated considering both the overall vertical distribution of items across the Central Impact Area, as well as the relationship between item depth and condition.

Table 3-2 presents a breakout of munitions items by depth and Figure 3-9 presents cumulative distribution of items by depth. As is indicated, almost 26 percent of HE items were on the surface while almost 60 percent of the items were reported within the top foot of soil and over 90 percent within the top 3 feet of soil. The deepest item reported was at a depth of 68 inches, although the number of items reported below 3 feet is very low (37 out of 356 items).

Figure 3-10 presents the distribution of unexploded ordnance items found in the Central Impact Area by both depth and ordnance type. As is indicated, most of the smaller ordnance types (less than 60mm) were found within the top one foot of soil. For the larger ordnance items, including 81mm mortars, 105mm and 155mm projectiles, a significant fraction was also found at or near the surface. For 105mm and 155mm projectiles, the majority of items were found within the top one foot. For 81mm mortar items, the largest number of items was identified at the 1 to 2-foot depth. Higher numbers of 81mm mortars were found at the 2 to 3-foot depth, as compared to 105mm and 155mm projectiles. Very few 81mm, 105mm or 155mm items were reported below 4 feet (12 out of 356 items).

The relationship between depth and the condition of unexploded ordnance items has been briefly examined in Figure 3-11. This figure presents the condition of the items found versus depth. The results suggest that at all depths the majority of items present consist of intact items. Most of the cracked items are present in the top foot of soil with only minimal numbers of cracked items deeper. The numbers of breached items is low (<6%) with no well defined distribution versus depth.

4.0 SOURCE AREA DELINEATION

This section summarizes principal aspects of the soil and groundwater contaminant distributions with respect to their implications for delineation of source areas in the Central Impact Area.

4.1 Contaminant Distributions in Soil

As indicated in Section 3.2, soil sampling in the Central Impact Area was generally focused on targets and ground features identified in historical documents and aerial photographs. Explosives compounds were detected at many of these areas; however, RDX was detected more frequently near targets located on Tank Alley and Turpentine Road.

The principal explosives detected in soils at the Central Impact Area include RDX, TNT, the two amino-DNTs, and HMX. Perchlorate has also been detected. The results of the extensive soil sampling efforts indicate that the horizontal distribution of explosives contaminants across the Central Impact Area is highly heterogeneous. Detections of both total explosives and RDX appear to be scattered throughout most of the areas sampled with relatively high concentrations frequently co-located with non-detects.

Most of the maxima and the other explosives detections are located adjacent to non-detects, i.e., contaminant particles are scattered and heterogeneously distributed in soil. Fundamentally, it is the nature of the mechanism of emplacement (projectile detonation) that results in a heterogeneous size and spatial distribution of particulate matter in soil. Further, as the source material is a soluble crystalline aggregate, these distributions change with time and are consequently very difficult to characterize. The multi-point composite sampling method provides a reasonable approach for characterizing soil. The incremental sampling methodology was developed based on studies conducted by USACE CRREL and implemented in 2006 (Method 8330b). These studies showed that the use of an incremental sampling methodology in sampling explosives residues at military ranges produced statistically more representative results when compared to traditional sampling procedures. In the incremental sampling approach, subsamples are collected within a defined area and combined to obtain a representative sample with a mass of 1 Kg or more in order to characterize the average concentration of explosives residues in the defined area. The entire sample mass is ground to a fine powder at the laboratory and subsampled for extraction and analysis.

RDX levels are higher and more frequently detected in target areas than in other areas. In the immediate vicinity of a target, RDX and other explosive levels declined and were less frequently detected moving away from the target. These results are consistent with a conceptual site model of contaminants occurring in the form of scattered HE particulate material that is heterogeneously distributed at the ground surface. Since most of the firing was from gun and mortar positions at targets in the Impact Area, HE particulate matter is present in higher densities in the vicinity of targets.

The extremely heterogeneous nature of the explosive particulates limits the usefulness of soil data to define groundwater source areas. The detection of extremely elevated explosives concentrations in discrete samples adjacent to samples showing no detections precludes the development of consistent concentration contours with which to reliably define specific source areas. As such, alternate approaches to defining source areas in the Central Impact Area were evaluated.

4.2 Groundwater Particle Backtracks

An initial groundwater-based approach used to define source areas within the Central Impact Area was to employ reverse particle tracking from contaminant detections in the aquifer using the regional and subregional groundwater flow models. This approach was based on the fact that the point of origin (source areas) could be calculated for contaminated groundwater, which has migrated downgradient both vertically and horizontally. The results of this approach assisted in defining the overall source areas. While this approach identified general areas, its accuracy was limited. Given the length of the groundwater plume, there was some uncertainty in particle tracking over long distances. In addition, it is not possible to distinguish between historical source areas, which are now depleted, and those areas which are still active. Consequently, it was determined that a modified approach involving mapping of contaminants at the water table within those areas suspected of being sources based on particle tracking provided the most reliable indicator of currently active contaminant sources.

4.3 Water Table Groundwater Contaminant Distributions

Groundwater RDX detections appear at deeper intervals within the aquifer in the downgradient portion of the plume, indicating that contaminants migrate advectively with groundwater flow. Based on this observation, consistent detections of RDX in water table wells located within the Central Impact Area is believed to be direct evidence of explosives leaching from an active source above that location. Mapping of these source areas and assigning a relative magnitude to them based on associated concentrations in groundwater was determined to be the most appropriate method for defining contaminant loadings within the Central Impact Area.

4.3.1 Source Area Mapping

As indicated above, the detection of RDX in water table wells located in the Central Impact Area is believed to be direct evidence of active source areas. As such, an investigation of the distribution of explosives at the water table was completed in accordance with the *Post Screening Investigation Central Impact Area Source Characterization Work Plan* (AMEC 2006). Analytical results for explosives and perchlorate from drive point groundwater sampling and from existing water table monitoring wells were used to refine RDX concentration contour maps within the Central Impact Area. Figure 4-1 shows the water table results used to characterize the primary RDX source areas.

Source area extents in the Central Impact Area were inferred from the extent of water table detections of RDX as of April 2007. For each source area, starting with the observed water table concentrations, a range of RDX concentrations in aquifer recharge were iteratively simulated using the groundwater fate and transport model until a satisfactory match to interpreted plume extent and maximum RDX concentration at the water table was achieved.

For the CS-19 Area and the Turpentine Road-Tank Alley Areas multiple wells or drive points were clustered and an irregular source extent was required to fit the data. Both of these areas were broken into “hot spot” and “halo” subareas over which different loading rates were applied.

4.3.2 Relationship to Targets

Based on the water table data and the evaluation described above, a total of 10 distinct source areas were identified as potentially contributing RDX to groundwater in the Central Impact Area. These areas are shown on Figure 4-2, while Figure 4-3 shows the location of monitoring wells relative to targets. As shown, source areas were located in several different portions of the Central Impact Area. These source areas correlated closely with locations where targets were located or specific activities occurred. The largest and most significant source was observed on Turpentine Road near the intersection with Tank Alley. This is also the area where multi-point composite sampling identified some explosives contamination. As discussed in Section 6.0, the most significant current source areas have subsequently been addressed through various response actions.

4.3.3 Trends in Source Area Loading

As discussed above, the water table evaluation approach considering areas of elevated RDX concentrations at the unsaturated/saturated zone interface was determined to be the best tool to identify source areas within the Central Impact Area. These areas of elevated RDX concentrations likely represent current loading rates; thus, this approach supports the estimation of trends in RDX source area loading rates.

Based on the delineation for RDX in shallow groundwater (e.g., water table) the active source areas within the Central Impact Area in 2007 were estimated to range from approximately three acres (RDX >2 µg/L) to 18.2 acres (RDX > 0.6 µg/L) in shallow groundwater. The cumulative total loading (mass flux) rate of RDX to the aquifer in 2007 for all sources was estimated to be approximately 152 grams per year. The method of estimating this mass flux rate is discussed in Section 4.2.2 of the 2008 *Draft UXO/Source Investigation Report* (AMEC 2008). Approximately 22,500 grams of RDX are estimated to be present in the aquifer based upon interpolation of monitoring well concentrations across the interpreted plume footprint. The results indicate that RDX loading rates have decreased significantly over the 60-year history of RDX usage at the Central Impact Area. More recent groundwater monitoring data also confirms that loading rates have continued to decrease since 2007.

4.4 Source Depletion

As discussed above, in 2007 the extent and magnitude of active RDX sources within the Central Impact Area were defined based on concentrations observed at the water table through a combination of existing monitoring wells and temporary drive point samples. Key monitoring wells used in this assessment included MW-90S, MW-91S, MW-1S, and OW-2 in the Turpentine Road-Tank Alley corridor, as well as MW-107M2, MW-37M2, MW-86S, MW-25S, and MW-59S in outlying areas. Among these wells only two, MW-91S and MW-1S, presently exceed 2 µg/L for RDX and two others, MW-90S and MW-107M2, presently exceed 0.6 µg/L (based on data collected through July 2010). Most notably the RDX concentration at MW-91S has systematically declined from 24 µg/L to 2.1 µg/L over the intervening three years, an order of magnitude decrease. Consequently, it is reasonable to infer that all of the current source areas are depleting or fully extinguished with respect to RDX loading to the water table. This reduction in RDX concentration is also occurring at depth with the hot spot areas moving downgradient (northwest) at greatly reduced or diluted concentrations and for the most part under 2 µg/L. One example of this is MW-235M1, screened approximately 35 feet into the water table. This well has dropped from a high concentration of 45 µg/L (the highest value recorded within the Central Impact Area groundwater) in 2006 to a concentration of 2.2 µg/L in 2010.

This is the result of depletion of the readily soluble unexploded ordnance filler exposed to atmospheric conditions. The map of currently active RDX sources within the Central Impact Area was redrawn in late 2010 using the most recent dataset (July 2010). As shown in Figure 4-4, the size and concentration of the Turpentine Road hotspot has decreased significantly since 2007.

5.0 CONCEPTUAL SITE MODEL

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

5.1 Source

The Central Impact Area is surrounded by a number of gun and mortar firing positions from which artillery and mortar rounds have historically been fired into the Central Impact Area. The predominant HE charge used in the earliest munitions fired into the Central Impact Area in the 1930s contained TNT. Starting in 1945, the predominant HE charge was a mixture of RDX and TNT. The use of HE artillery projectiles was discontinued in 1989, and the firing of all munitions into the Central Impact Area was discontinued in 1997. LITR projectiles, containing no HE charge but using a spotting charge containing perchlorate, were fired into the Central Impact Area between 1982 and 1997.

Data from the Central Impact Area and from several related investigations (Jenkins et al. 2000a, 2000b; Pennington and Brannon 2002; Hewitt and Walsh 2003) indicate that high-order detonations generally produce relatively small (smoke sized), widely scattered HE particles. In contrast, low-order detonations tend to produce larger HE particles and when found or excavated during clearance are accounted for as unexploded ordnance. At the Central Impact Area, both the explosives-related particulate material and unexploded ordnance tend to be concentrated in historical target areas, where the majority of munitions were fired. The particulate materials are typically scattered and are not homogeneously distributed in surface soils. Contaminants in surface soil are potentially accessible to groundwater through leaching and subsurface migration processes.

Fine particulate material from high order detonations likely constitute a depleted or rapidly declining source, based on several lines of evidence. The detonations producing fine particulate slowed with the conversion from HE artillery projectiles to LITR projectiles in the 1980s, and stopped with the cessation of all HE munitions firing at MMR in 1997. Fine particulate would be the quickest to dissolve. The highest RDX concentrations and greatest plume mass are not at the water table but rather several tens of feet below the water table, indicating that loading rates peaked sometime in the past. Groundwater modeling presented in the *Draft Feasibility Study Screening Report* (AMEC 2007b) suggests that the RDX loading for the current plume peaked in the early 1990s.

Groundwater detections in the source area have been steadily declining with only one water table level remaining above the EPA RDX Health Advisory of 2 µg/L (2.1 µg/L). The potential current RDX source area is shown in Figure 4-4. The highest model-predicted concentration was at Turpentine Road. As discussed in Section 6, a removal action has recently been completed in this area.

The exact number of unexploded ordnance items in the Central Impact Area is unknown. Available information from field observations and excavation results suggest that a total of several thousand items may remain. However, information (Section 3.2.2.2) also indicates that only 11 percent of these items may be breached and present a potential active source for groundwater contamination. There is considerable uncertainty in the release mechanism, timing and rate for unexploded ordnance.

5.2 Pathway

Following deposition onto the soil, precipitation passing through the upper soil profile can solubilize a fraction of any explosives-related particulate material or exposed explosives present. The quantity of solid phase that is dissolved is controlled by multiple factors, including the size and type of particulate material, surface area of exposed filler, intensity and duration of precipitation events, soil characteristics, ambient temperature, and drainage patterns. The aqueous solubility of an explosives-related contaminant is a key environmental chemical characteristic influencing dissolution rates. Perchlorate has a higher equilibrium water solubility than TNT or RDX. Also, a range of particulate sizes is expected in surface soils at the Central Impact Area, with the smaller sizes anticipated to dissolve fastest and having the most immediate impact on pore water. Individual breached unexploded ordnance would have release rates based on the amount of filler exposed to precipitation.

Once in solution, available environmental chemical data suggests that TNT is susceptible to degradation. Literature information also indicates that TNT is more strongly adsorbed to soil (higher K_{oc} value) than either RDX or perchlorate (AMEC 2008). In contrast, available information indicates that RDX and perchlorate are not strongly adsorbed to soil and may tend to migrate to the water table. RDX travel times through the unsaturated zone are expected to be on the order of five years based on SESOIL modeling and mass modeling through the unsaturated zone.

5.3 Receptors

There are no private or public water supply wells located within the Central Impact Area study area. There are no known municipal water supply wells located between the Central Impact Area and the Cape Cod Canal; the discharge point for Central Impact Area plume. There are two private residential water supply wells located to the northeast and downgradient of the Central Impact Area on Route 6A. The closest of these is located approximately three miles from the Central Impact Area boundary.

6.0 RESPONSE ACTIONS

This section summarizes response actions undertaken at the Central Impact Area. Included are summaries of past soil response actions and geophysical investigations where munitions were removed, and a detailed discussion of recent response actions.

6.1 Pre-2008 Response Actions

Several soil removal actions have been undertaken in the Central Impact Area to reduce levels of soil contamination from certain areas identified in the investigations described in Section 3.0. These include soil removals at the Armored Personnel Carrier (Target 25), Mortar Target 9, Targets 23 and 42, the CS-19 Disposal Area, and the CS-19 Bunker Area. The following is a summary of results from the response actions. Response action locations are shown in Figure 6-1. Detailed figures depicting response action excavation areas are presented in Appendix B. Response action information is summarized in Table 6-1. Additional information is discussed in the *Draft UXO/Source Investigation Report* (AMEC 2008).

For safety purposes, during a soil removal action, all unexploded ordnance must be removed from an area at least one foot below the planned excavation depth before digging can begin. However, as a practical matter, unexploded ordnance technicians dig until the source of the anomaly is discovered. Thus larger anomalies are excavated to a depth greater than one foot. Generally, unexploded ordnance specialists remove all munitions down to the depth of their equipment, generally 2 to 3 feet, followed by a foot of excavation, followed by additional unexploded ordnance clearance. Given the depth of the excavation, the depth of clearance below the excavation and the fact that nearly all munitions are found in the top 3 feet, excavated areas are considered to be cleared of all detected potential unexploded ordnance-related sources. Clearance activities are summarized in Table 6-2.

6.1.1 APC (Target 25)

Sampling at the APC detected RDX at a maximum concentration of 7 milligrams per kilogram (mg/Kg). Approximately 330 tons of contaminated soils were removed in 2000. The soil was treated on-site using the soil washing unit. Approximately 0.12 acre was excavated to depths ranging from 1 to 3 feet. Also, approximately 0.25 acre of support area was cleared of munitions to a depth of 3 feet.

6.1.2 Mortar Target 9

Detections at Mortar Target 9 during the 2000 mortar target investigation included RDX at maximum concentrations of 38 mg/Kg. Further delineation sampling was conducted in 2001, following which a total of 577 tons of soil was excavated. The soil from Target 9 was treated on-site using soil washing. Approximately 0.12 acre was excavated in a generally circular area. Soil was excavated to a depth of 2 feet. Also, approximately 0.18 acre of support area was cleared of munitions to a depth of 3 feet.

6.1.3 Targets 23 and 42

Soil investigations conducted at Targets 23 and 42 during the 2000 target area investigation included detections of RDX at a maximum concentration of 50 mg/Kg. The areas around these targets were further investigated in 2004 followed by a response action. Soil within a 50-foot radius of the targets was initially removed to a depth of 2 feet bgs. Post-excavation samples were collected from the bottom of both removal areas. Based on the presence of explosives in the post-excavation samples at both targets, additional areas within the original excavation footprints were identified and excavated to 3 feet bgs. A total of 1,100 tons of soil were excavated from Target 42, and 885 tons of soil was removed at Target 23. The soil was treated on-site using low-temperature thermal desorption. Approximately 0.18 acre was excavated from each site in generally circular areas. Soil was excavated to a depth of 2 to 3 feet at both locations. Also, approximately 0.28 acre of support area was cleared of munitions to a depth of 2 to 3 feet.

6.1.4 CS-19

The CS-19 Disposal Area in the western portion of the Central Impact Area was used historically for ordnance disposal. Of the 5,806 items found at the Disposal Area, the vast majority of items (over 95%) found were associated with small arms ammunition, including 0.5, 0.30, and 30.06 caliber ball ammunition. Other items encountered included: 20mm, 37mm, 40mm, 75mm, 90mm, 105mm and 155mm projectiles; 2.36-inch and 2.75-inch rockets; 60mm, 81mm and 4.2-inch mortars; rifle grenades; a small bomb; bulk explosives; and fuzes.

Removal action activities were conducted at the site by AFCEE under the Installation Restoration Program in 2004 – 2006 and in 2007 – 2009. Phase I activities included the on-site treatment of approximately 3,000 tons of RDX contaminated soil using low-temperature thermal desorption. During Phase II and III activities in 2005-2006, approximately 1,310 tons of soil was removed. Approximately one acre within the original CS-19 Disposal Area (as bounded by the perimeter road) was excavated to a depth of 3 feet. In addition, approximately 0.6 acre outside of the perimeter road (the Expansion Area) was also excavated to depths of up to 3 feet. Also, a 2-acre support area was cleared of munitions to a depth of 2 to 3 feet.

The CS-19 Bunker Area is located immediately north of the CS-19 Disposal Area (Figure 6-1). Remedial investigations of this area conducted by AFCEE under the Installation Restoration Program in 2007-2008 indicated the presence of explosives in several 50 feet by 50 feet multi-point composite sampling grids. Items found within the CS-19 Bunker Area were similar to the rest of the Central Impact Area. Of the 60 UXO items found, the most frequently detected items were 37mm projectiles (40%), 105mm projectiles (25%), and 81mm mortars (20%). Other items encountered included: 155mm projectiles; 4.5-inch rockets; 60mm mortars; and bulk explosives. The vertical distribution of munitions indicated that the majority of all of the items were found in the top 2 feet and only two of the 60 items were found from 3 to 4 feet.

In 2009, a soil removal action was conducted by AFCEE. A total of approximately 1,300 tons of soil was removed from five grid locations. In addition, approximately 43 tons of explosives contaminated soil was removed from a burn pit area where munitions disposal had occurred. Approximately 0.3 acre was excavated to depths of up to 3 feet. Munitions removal was conducted at a burn pit to a depth of 4 feet. The support area cleared for the CS-19 Disposal Area was also used for the CS-19 Bunker Area.

6.2 Geophysical Surveys

Munitions have been removed during several geophysical investigations conducted in the Central Impact Area. Major geophysical investigations conducted include an AIRMAG survey, HUTA Phase I, HUTA Phase II, the SCAR site, the Eastern Test site, and nine unexploded ordnance density estimation test plots. Geophysical investigations were also conducted at the robotics technology demonstrations (discussed in Section 6.3.2). Munitions clearance has also been conducted at drill pad sites, roads, buffer areas around removal actions, and the CS-19 support area.

6.2.1 AIRMAG

An airborne magnetometer survey was conducted over the entire 330-acre Central Impact Area in 2000. The survey identified many large ferrous anomalies, particularly along Tank Alley and Turpentine Road. Field verification was conducted on 134 anomalies and 23 were excavated. One potential HE 105mm projectile was discovered and blown-in-place. Based on the field verification and aerial photography, the vast majority of the anomalies were categorized as cultural, geologic, target-related, and signal noise. AIRMAG was useful at identifying areas with significant surface or near surface metal but not useful at identifying individual munitions. Although 23 anomalies were excavated, the areas impacted were small and thus they are not shown on Figure 6-1 nor listed in Table 6-1, and no acreage was included in calculations of cleared areas.

6.2.2 High Use Target Area I

HUTA I was a square, 4-acre area within the Central Impact Area selected for investigation in 2000 based primarily on AIRMAG results. The objectives of the HUTA I investigation were to characterize the physical distribution of munitions items and characterize soil contamination. The area was cleared of vegetation and surface cleared for munitions. Successive 1-meter lifts of soil were removed from each of the test plots while munitions, munitions debris, and range-related debris were catalogued.

As discussed in Section 3, nearly all unexploded ordnance items were reported within 3 feet of the ground surface. The most common munitions items found were 81mm mortar and 155mm projectiles. As a result of the extensive excavation involved, 1.32 acres were cleared to depth and another 2.68 acres of support area were cleared of munitions to a depth of approximately 2 feet.

6.2.3 High Use Target Area II

HUTA II consisted of five 7 by 200-meter (0.35 acre) transects positioned across suspected target areas based on AIRMAG survey anomalies. Three of these transects (Transects 2, 3, and 4) were located in the Central Impact Area. The objectives of the HUTA II investigation were to determine the density of munitions items near targets and attenuation away from targets; catalogue munitions items and munitions debris by type and condition; and characterize soil contamination. Sampling and survey methods were similar to those used for the HUTA I investigation, except that test plots were not excavated. Predominant munitions types varied between transects; for example, 81mm mortars were most common in Transects 1 and 5, while 155mm and 105mm projectiles were most common in Transects 2 and 3. Munitions conditions varied from “good” to “heavily corroded.” All were intact (not cracked or breached). With the exception of inert SCARs around the southern SCAR target, no pattern of munitions items was apparent throughout the five transects.

As a result of the extensive anomaly removal, 1.05 acres were cleared of munitions to depth with another 0.12 acre of access roads were cleared of munitions to a depth of 2 to 3 feet.

6.2.4 Sub-caliber Aircraft Rocket Site

The SCAR site is located in the northern part of the Central Impact Area. This is one of two sites located in the Central Impact Area where inert 2.25-inch rockets (SCARs) were fired from airplanes at targets located on the ground. SCARs are unfused metal tubes that contain 1.75 pounds of ballistite propellant, which is consumed during firing. Ballistite is composed of nitrocellulose (51%) and nitroglycerine (43%) blended with small amounts of plasticizers, stabilizers, wax, and blackening agents.

The entire site was cleared of vegetation and surface-cleared for unexploded ordnance in 2002. SCARs were the most common item discovered during the surface clearance. In addition, 105mm and 155mm projectiles were also discovered on or near the ground surface. An EM-61 survey was then conducted and 15 anomalies were investigated. In addition, one test trench was excavated through a large centrally located anomaly. Finds during the intrusive investigation consisted mostly of inert SCARs; however, several HE 155mm projectiles were also discovered.

Overall, the SCAR site is approximately 10 acres in size. Approximately 0.5 acre was cleared of munitions to a depth of 2 to 3 feet for vehicle access. In addition, another 9.5 acres were surface cleared and the largest anomalies removed.

6.2.5 Eastern Test Site

The Eastern Test site is located in the northeastern portion of the Central Impact Area. The site was identified based on historic aerial photographs but its exact use is not known. The site was cleared of vegetation and surface cleared for munitions in 2002. The majority of items discovered during surface clearance were 155mm LITR projectiles; however, one HE 155mm projectile was also discovered. An EM-61 survey was conducted over the entire site and nine anomalies were investigated. Most of the items discovered during the intrusive investigation were 155mm LITR projectiles. A number of live fuses were also discovered.

Overall, the Eastern Test site area of investigation is approximately 4.5 acres in size, which was surface cleared and major anomalies removed. Vehicle accessed this site via the road built for monitoring wells MW-26 and MW-59, which was previously cleared to a depth of 2 to 3 feet.

6.2.6 2006 Post Screening Investigation Unexploded Ordnance Test Plots

Nine 0.22-acre test plots were investigated to further characterize munitions density in the Central Impact Area (Figure 6-1). The test plots were located in areas believed to have high (H-1 to H-3), medium (M-1 to M-3), and low (L-1 to L-3) munitions densities, respectively. At each location, anomalies were investigated in 1-foot lifts down to approximately 4 feet.

The most frequently detected munitions in the test plots were 81mm mortars and 105mm projectiles. Other items encountered included 60mm and 4.2-inch mortars and 155mm projectiles. The vertical distribution of munitions (discussed in Section 3) indicated that almost all of the items were found in the top 3 feet and most in the top 2 feet. The initial characterization of low munitions density was validated by the investigation. The remaining medium and high density test plots had similar numbers of finds, which suggest that initial characterization overestimated the number of munitions in the high density test plots. As a result of the extensive excavation, 2 acres were cleared to depth with another 0.4 acre of support area cleared of munitions to a depth of 2 to 3 feet.

6.2.7 Other Geophysical Activities

To facilitate investigation in the Central Impact Area, munitions clearance to a depth of 2 to 3 feet was conducted over approximately 16 acres of roads, well pads, soil investigation areas and other sites.

6.3 Recent Response Actions

This section summarizes recent response actions at the Central Impact Area, including consideration of geophysical approaches.

6.3.1 Geophysical Evaluation

Fragmentation in near surface soils within the Central Impact Area has presented significant challenges to identifying unexploded ordnance using geophysics, as first noted in the AIRMAG survey of 2000, which was useful at identifying areas with significant surface or near surface metal but not useful at identifying individual munitions.

In order to potentially establish a geophysical survey method for evaluating individual munitions items and discriminating them from fragmentation within the Central Impact Area, a test program comparing a Geonics EM-63 and a modified Geonics EM-61 MK2 was performed in February 2009. This comparison was performed in two one-quarter-acre grids (CIA001, 42_46 and CIA002, 48_55). Based on the initial EM-63 results, time gates were reconfigured on an EM-61 (Modified EM-61 MK2).

In the EM-63, the time decay of the current is measured over a wide dynamic range of time. The output of the main sensor is measured and recorded by the main console at 26 geometrically-spaced time gates, covering a time range from 177µs to 25 ms. The measurement time provides diagnostic information to characterize the shape, size, and composition of fragmentation and UXO items. In this study, the EM-63 was used to establish transient response curves for fragmentation as well as for full size control items “seeded” in the geophysical prove out area and to optimize future EM-61-MK2 data collection.

In February 2009, EM-63 geophysical surveys were performed on the MMR (¼ acre of the CIA1 soil rapid response area, and ¼ acre of CIA2 test grid). Transient response curve analysis was conducted for the EM-63 and typical EM-61-MK2 response for comparison and to determine the appropriate time gate ratio selection to distinguish larger ordnance items from smaller fragmentation. Based on the transient response analysis performed with the EM63, it was recommended that an EM61-MK2 be modified to collect data to at least the equivalent of EM-63 time gate 15 to establish an optimal time collection for larger items.

Modified EM-61-MK2 Survey

A modified EM-61-MK2 geophysical survey was conducted in May 2010 on a ¼-acre grid identified as CIA Grid 002. A ranked dig list was generated with the first 10 targets selected from the previous EM-63 survey and the next 143 targets identified using the auto pick tool within Geosoft Oasis Montaj mapping software. Additional manual target picks were made by a project geophysicist via visual inspection of the reconfigured EM-61-MK2 response data.

The geophysical data was processed to determine the ratio of responses of the late to early time-channels, a method shown to be effective at discriminating larger ordnance from small fragmentation. The data was analyzed using the ratio of the 15th time channel (t15) to the 1st time channel (t1) and used to create a ranked dig list from 1 to 153. All 153 targets in the list were dug during the period from May to November 2010.

In the top 51 items, 16 of the 21 UXO items were identified. Five of these UXO items contained HE (two 60mm mortars, one 81mm mortar, one 4.2-inch mortar, and one low-order 155mm round). The three seed items also have a t15/t1 ratio ≥ 0.028 and are included in the top third percent of the items on the list. The remaining five UXO items fall below this ratio and are spread out in the remaining 102 targets. Two of these contained HE and both are 81mm mortar. They are ranked 118 and 150.

A false positive check was conducted by randomly selecting an additional 13 targets that were not included on the list. Targets were selected by a project geophysicist and 10 percent were excavated. No UXO items were identified. Thus by using a t15/t1 ratio of 0.028 as a discriminator, approximately 76 percent of all UXO items would be removed by excavating only 33 percent of all anomalies. While this technique appears promising, it will be further evaluated throughout the project.

6.3.2 Robotics Technology Demonstration

In 2008, the Air Force Research Laboratory (AFRL) conducted a technology demonstration at the Central Impact Area. The demonstration was conducted to evaluate methods to clear potential unexploded ordnance from the range using remotely controlled equipment. During initial activities, AFRL demonstrated the use of a C325 excavator equipped with a Brontosaurus attachment to clear vegetation in an area of approximately 19 acres (Figure 6-3). An electromagnetic attachment was then used to clear unexploded ordnance from approximately seven of the 19 acres. The remaining 12 acres were surface cleared by unexploded ordnance technicians. The results of the demonstration indicate that the electromagnet was effective at removing ferromagnetic metallic objects, including unexploded ordnance, that were located at or slightly below the ground surface. The evaluation of this demonstration project based on visual examination by unexploded ordnance technicians indicated that greater than 60 percent of the MEC items had been removed.

A total of 30 items were identified as potential HE (i.e., 81mm mortars (24 items), 105mm projectiles (5 items), and one 60mm mortar) during the AFRL magnetic sweep and subsequent surface clearance of the 19 acres. A total of 631 inert munitions-related items were also discovered. Approximately 83 percent of these items were inert pieces of 155mm projectiles (381 items) and/or 81mm mortars (140 items). Many of these items were expended illumination projectiles and canisters and unspecified munitions frag. A large number of pieces of metallic target and range-related debris also were recovered.

6.3.3 Robotic Source Removal Action

In 2010, a second technology demonstration was conducted by AFRL within the Central Impact Area to remove sources of groundwater contamination. Remotely operated equipment was used to address the two areas determined by water table detections of RDX to be the most significant potential source areas of groundwater contamination in the Central Impact Area. Both of these areas are located along Turpentine Road and were designated as the northern and southern excavation areas (Figure 6-3). This demonstration employed an All-Purpose Remote Transport System with robotic arm and bucket attachments, an excavator, front end loader, a bulldozer, and a mobile track-mounted screener. Soil was excavated in 1-foot lifts from both the northern and southern excavation areas.

This source removal was conducted over an area of more than 3 acres. The entire northern excavation area soil was excavated from an area of 1.4 acres to a depth of 2 feet. One third (0.5 acre) of the northern area with a large number of magnetic anomalies was excavated to 3 feet after conducting an EM-61 survey. Approximately 8,250 tons of soil was removed. In the southern excavation area, soil was excavated from a 1.65-acre area to a depth of one foot. In this area, 4,050 tons of soil was removed.

After the soil was excavated, it was run through a screener that separated out material greater than one inch (overs). From both areas, the screened soil was then stockpiled.

Additional soil may be removed based on multi-point composite soil sample results and EM-61 survey evaluations of deeper depths. If the soil is clean and there are not too many anomalies remaining, significant anomalies will be removed by hand. A ranked dig list will be generated and anomalies having an amplitude greater than is typical of 60mm mortar will be recommended for excavation.

Based on sampling results, the screened (<1-inch) soil will be treated and replaced on-site or identified for off-site disposal. As a result of the extensive excavation and follow on anomaly removal, 3.05 acres were cleared to depth. At this time, soil samples of the soil stockpiles less than 1-inch have been taken and the material greater than 1 inch are being examined by unexploded ordnance technicians. As of June 2011, approximately 30 percent of the overs piles have been examined for MEC from the second lift and eight potential HE items have been identified including five 81mm mortars, one 105mm projectile, and two 155mm practice projectile rounds.

6.4 Summary of Response Actions

Soil removal actions have been conducted at Target 9 (0.12 acre), Target 25 (0.12 acre), Target 23 (0.18 acre), Target 42 (0.18 acre), CS-19 (1.6 acres), the CS-19 Bunker Area (0.3 acre), and on Tank Alley and Turpentine Road (3.05 acres). Thus, a total of over 5.5 acres have been completely cleared of munitions and approximately 15,200 tons of soil have been excavated and treated on-site, disposed of off-site, or is awaiting its final disposition. It is assumed the removal actions have completely removed all sources of RDX at these locations (see Figure 6-2).

During the investigation of HUTA I (1.3 acres), HUTA II (1 acre), and the nine munitions density test plots (2 acres), munitions were cleared to depth. Thus, complete (100%) removal of all detected munitions has been performed from an area of approximately 10 acres (5.5 acres from the soil removals and 4.3 acres by investigation) in the Central Impact Area (see Figure 6-2).

The SCAR site (10 acres), the Eastern Test site (4.5 acres), and the CS-19 Bunker Area outside the excavation (1 acre) have been surface cleared and major (recent investigations at MMR identify “major” items as having a magnetic signature typical of a 60mm mortar at a depth of 1 foot) magnetic anomalies have been removed. The area along Tank Alley and Turpentine Road, where low-level RDX water table detections were observed, has been surface-cleared for munitions. A modified EM-61 survey will be completed over this 8-acre area and significant anomalies (having a signature greater than a 60mm mortar) will be excavated. Once this has been completed, the majority of munitions will have been removed from a total of 22 acres. It is estimated that this type of clearance will result in the removal of 75 percent of munitions items in these areas (see Figure 6-2).

Drill pads, roads, and support areas have been cleared to 2 to 3 feet to allow vehicle traffic. A total of 6.4 acres have been cleared for drilling, 4.7 acres for roads, 2.7 acres between HUTA test plots and 2 acres at the CS-19 site. Thus, a total of approximately 16 acres have been cleared to a minimum of 2 feet. Based on the professional judgment of unexploded ordnance technicians and the findings of the depth studies, it is estimated that this clearance will remove approximately 85 percent of all unexploded ordnance in these areas (see Figure 6-2).

Surface clearance only has been performed on approximately 8 acres, including the area along Tank Alley and Turpentine Road not included in the soil removal action or unexploded ordnance clearance. Based on the professional judgment of unexploded ordnance technicians and the findings of the depth studies, it is believed that surface clearance will remove approximately 25 percent of all unexploded ordnance in these areas (see Figure 6-2).

7.0 INVESTIGATION FINDINGS

The Central Impact Area has been used as an impact area for artillery and mortar firing from the late 1930s until 1997 (Ogden 1997). During the late 1940s, the Central Impact Area also contained Navy air-to-ground rocket ranges that utilized inert 2.25-inch rockets. Various types of munitions, including 37mm, 40mm, 75mm, 90mm, 105mm, and 155mm artillery projectiles and 50mm, 60mm, 70mm, 81mm, and 4.2-inch mortars, have been fired into the Central Impact Area (USACE 2001). These munitions include HE charges designed to explode upon impact, and practice rounds, which do not contain an HE charge but may contain a spotting charge designed to emit smoke upon impact.

The primary groundwater contaminants in the Central Impact Area, RDX and perchlorate, are present in co-located plumes. Other explosives compounds, including HMX, TNT, 2A-DNT and 4A-DNT, have also been detected, but in a relatively few isolated monitoring wells. The RDX plume is comprised of multiple parallel and overlapping plumelets and is oriented in a southeast to northwest direction consistent with the regional groundwater flow direction.

The apparent irregular shape of the plume edges reflects its complex internal structure and origin from individual contaminant sources distributed over the Central Impact Area. The contamination within this region is not continuous and many of the component plumelets appear to be detached from historic source areas, while others correlate to continuing shallow detections. The furthest downgradient extent of the plume is located about two miles from its presumed origin. The highest RDX concentrations and center of mass appear at deeper intervals within the aquifer in downgradient portions of the plume supporting the interpretation that the active source is progressively depleting and the plume is migrating advectively with groundwater flow.

As part of the source investigation in the Central Impact Area, approximately 3,800 soil samples were analyzed for explosives and 671 for perchlorate. The total number of samples analyzed for each analyte includes discrete, composite, and multi-point composite samples. The highest frequencies of detection were observed for perchlorate (19.2%), RDX (5.0%), 2A-DNT (4.6%), TNT (4.0%), 4A-DNT (3.9%), and HMX (2.5%). Detections of explosives are scattered throughout most of the areas sampled. Most of the detections for explosives are located adjacent to non-detects, i.e., contaminant particles are scattered and heterogeneously distributed in soil. The types and frequencies of explosives compounds observed in soil reflect the munitions fired into the Central Impact Area.

The results of multi-point composite samples collected upgradient of drive points with water table RDX detections indicated only low levels of explosives detected in a few samples. Thus no clear connection was established between explosives detections in soil and shallow groundwater contamination. The results suggest that the current source of the Central Impact Area plume is likely contamination still flushing through the unsaturated zone or low-order/breach munitions items and not a broad area of soil contamination.

Several major geophysical investigations have been conducted in the Central Impact Area to evaluate the distribution of unexploded ordnance including an airborne magnetometer survey (AIRMAG), the SCAR site, the Eastern Test site, the High Use Target Area (HUTA) Phase I, HUTA Phase II, unexploded ordnance density estimation test plots, and the robotics technology demonstrations. Several soil response actions have also been undertaken to reduce levels of contamination from certain areas identified during the investigation of the Central Impact Area. These include soil removals at the APC (Target 25), Mortar Target 9, and Targets 23 and 42. Information on the distribution of unexploded ordnance was also collected during these actions.

The distribution of unexploded ordnance within the Central Impact Area has been documented through the results of the numerous geophysical investigations and removal actions. Approximately 68 percent of the high-explosives filled unexploded ordnance items found in the Central Impact Area consist of 81mm mortars and 105mm and 155mm shells. The three next most common items include 60mm mortars, 4.2-inch mortars and 37mm projectiles. However, within the CS-19 disposal area, small arms ammunition was the dominant item found. Results indicate that unexploded ordnance items are predominantly located near targets and other high use areas. Investigation results indicate that the large majority (90%) of unexploded ordnance are located within three feet of the ground surface. The majority of the unexploded ordnance items found in the Central Impact Area were intact. The intact category includes items that were fully intact or dented and/or bent but not cracked or breached. Relatively few items (39 out of 356) were identified as being cracked or breached.

Because of the inconsistency of soil detections, potential groundwater plume source areas were identified through water table detections. Source areas were inferred from the extent of water table detections as of April 2007. For each source area, starting with the observed water table concentration, a range of RDX concentrations in aquifer recharge was iteratively simulated using the groundwater fate and transport model until a satisfactory match to interpreted plume extent and maximum RDX concentration at the water table was achieved. The source areas inferred from water table detections are consistent with other potential source area indicators such as target locations, unexploded ordnance density, cratering on aerial photographs and particle backtracks from wells with explosives detections. More recent (post-2007) RDX water table data shows declining concentrations indicating significant depletion of the source from 2007 to 2010.

To address the areas that are believed to represent the potential current sources, removal actions have been conducted or are ongoing at several locations and approximately 15,200 tons of soil has been excavated and treated on-site, disposed of off-site, or is awaiting final disposition. Munitions have also been removed to depth under various investigations (HUTA I, HUTA II, unexploded ordnance test plots) from an area of approximately 4.3 acres. Thus complete (100%) munitions removal of all detected munitions has been completed over an area of approximately 10 acres (5.5 acres from the soil removals and 4.3 acres from the above investigations).

Surface clearance and major EM anomalies investigations have been conducted over an area of approximately 14 acres. A modified EM-61 survey will be completed over an additional 8-acre area and significant anomalies will be excavated. When completed, the majority of munitions (estimated 75%) will have been removed from an area of approximately 22 acres. Munitions have been cleared to a minimum depth of two feet from an area of approximately 16 acres to allow vehicle access on drill pads, roads, and the CS-19 support area. These actions have removed an estimated 85 percent of munitions from these areas. Surface clearance has been performed on approximately 8 acres, which has resulted in an estimated 25 percent munitions removal.

Based on recent trends indicating decreasing groundwater RDX concentrations, coupled with the source removal actions completed to date, the groundwater plume is expected to continue to contract.

A potential long-term source of groundwater contamination exists as a result of remaining unexploded ordnance. The magnitude and impact of this long-term source on groundwater cannot be accurately predicted or modeled due to the number of uncertainties. However, given the length of time for metal casings to corrode and the explosives filler to dissolve, release rates are likely to be slow. Land use controls will be in place to ensure there is no exposure and no health risk. In addition, continuation of current extensive long-term groundwater monitoring and an active treatment system could be used to address this future contamination if it occurs.

8.0 REFERENCES

AFCEE (Air Force Center for Engineering and the Environment). 2003. Final Chemical Spill-19 Remedial Investigation Report (CS-19). AFCEE/MMR Installation Restoration Program, Otis ANGB, Massachusetts Military Reservation, Cape Cod, Massachusetts. October 1, 2003. Jacobs Engineering Group, Inc.

AFCEE. 2008. CS-19 Source Area Interim Report. AFCEE/MMR Installation Restoration Program, Otis ANGB, Massachusetts Military Reservation, Cape Cod, Massachusetts. June 2008. ECC.

AFCEE. 2009. Final CS-19 Soil Removal Action Report. AFCEE/MMR installation Restoration Program, Otis ANGB, Massachusetts Military Reservation, Cape Cod, Massachusetts. September 30, 2009. ECC.

AMEC. 2003a. Final IAGWSP Technical Team Memorandum 02-3 Aquifer Test Summary Report Central Impact Area Post-Screening Investigation, Massachusetts Military Reservation, Cape Cod, Massachusetts. April 7, 2003. AMEC Earth and Environmental, Inc., Westford, Massachusetts.

AMEC. 2003b. Draft Saturated Zone Flow & Transport Modeling Summary Report TM 03-1, Massachusetts Military Reservation, Cape Cod, Massachusetts. June 13, 2003. AMEC Earth and Environmental Inc., Westford, Massachusetts.

AMEC 2004a. Draft Final High Use Target Area Report Phase I (HUTA I). AMEC Earth and Environmental Inc., Westford, Massachusetts. February 2004.

AMEC. 2004b. Central Impact Area Focused Investigation Report. Agency Draft. AMEC Earth and Environmental Inc., Westford, Massachusetts. November 16.

AMEC. 2006. Post Screening Investigation – Central Impact Area Source Area Characterization Work Plan. Final. AMEC Earth and Environmental, Inc. Westford, Massachusetts. June 28, 2006.

AMEC. 2007a. Final Report Package, Addendum to Final IAGWSP Technical Team Memorandum TM 01-6, Central Impact Area Groundwater Report. AMEC Earth and Environmental, Inc. Westford, Massachusetts. March 21.

AMEC. 2007b. Central Impact Area Feasibility Study Screening Report. Draft. AMEC Earth and Environmental, Inc. Westford, Massachusetts. April.

AMEC. 2008. IAGWSP UXO/Source Investigation Report for the Central Impact Area. Draft. Camp Edwards Impact Area Groundwater Quality Study, Massachusetts Military Reservation, Cape Cod, Massachusetts. January 4. AMEC Earth and Environmental, Inc. Westford, Massachusetts.

ANG (Air National Guard). 2001. Final Environmental Baseline Survey. 102d Fighter Wing Massachusetts Air National Guard, Otis Air National Guard Base, Massachusetts Military Reservation. September.

Barber, L.B., E.M. Thurman, M. P. Schroeder, and D. R. LeBlanc. 1988. "Long-term Fate of Organic Micropollutants in Sewage-contaminated Groundwater." Environmental Science and Technology. 22:205-211.

Cape Cod Commission, 1998. Massachusetts Military Reservation Master Plan Final Report: Prepared in conjunction with the Community Working Group By the Cape Cod Commission.

Hewitt, A. D. and M. E. Walsh. 2003. On-site Processing and Subsampling of Surface Soil Samples for the Analysis of Explosives. ERDC/CRREL TR-03-14. United States Army Engineer Research and Development Center, Cold Regions Research and Engineering Laboratory. Hanover, NH.

Jenkins, T.F., T.A. Ranney, M.E. Walsh, P.H. Miyares, A.D. Hewitt, and N.H. Collins. 2000a. Evaluating the Use of Snow-Covered Ranges to Estimate the Explosives Residues that Results from Detonation of Army Munitions. CRREL Technical Report ERDC/CRREL TR-00-15. U.S. Army Cold Regions Research and Engineering Laboratory. Hanover, New Hampshire.

Jenkins, T.F., T.A. Ranney, P.H. Miyares, N.H. Collins, and A.D. Hewitt. 2000b. Use of Surface Snow Sampling to Estimate the Quantity of Explosive Residues resulting from Land Mine Detonations. CRREL Technical Report ERDC/CRREL TR-00-12. U.S. Army Cold Regions Research and Engineering Laboratory. Hanover, New Hampshire.

LeBlanc, D.R., S.P. Garabedian, K.M. Hess, L.W. Gelhar, R.D. Quadri, K.G. Stollenwerk, and W.W. Wood. 1991. "Large-scale Natural Gradient Tracer Test in Sand and Gravel. Cape Cod, Massachusetts 1. Experimental Design and Observed Tracer Movement." Water Resources Research 27:895-910.

MAARNG (Massachusetts Army National Guard). 2001. Integrated Natural Resources Management Plan. Camp Edwards, Massachusetts.

Masterson, J.P., D.A. Walter, and J. Savoie. 1996. Use of Particle Tracking to Improve Numerical Model Calibration and to Analyze Groundwater Flow and Contaminant Migration, Massachusetts Military Reservation, Western Cape Cod, Massachusetts. U. S. Geological Survey. Open File Report 96-214. Marlborough, Massachusetts.

Morrison, D. A. and A. J. Johnson, 1967. Summary of hydrologic and physical properties of rock and soil materials as analyzed by the Hydrologic Laboratory of the United States Geological Survey, 1948-60. United States Geological Survey Water Supply Paper 1839-0.

NGB. 1990. Final Environmental Impact Statement (FEIS)/Final Environmental Impact Report (FEIR), 102 Fighter Interceptor Wing, Massachusetts Air National Guard. June 1990.

Ogden (Ogden Environmental and Energy Services). 1997. Draft Range Use History Report for the Camp Edwards Impact Area Groundwater Quality Study, Massachusetts Military Reservation, Cape Cod, Massachusetts. July.

Pennington, J.C., and J.M. Brannon. 2002. Environmental Fate of Explosives. Thermochimica Acta. 384: 163-172.

Tetra Tech EC, Inc. 2011. Central Impact Area Feasibility Study. Impact Area Groundwater Study Program, Massachusetts Military Reservation, Cape Cod, Massachusetts. December 2010.

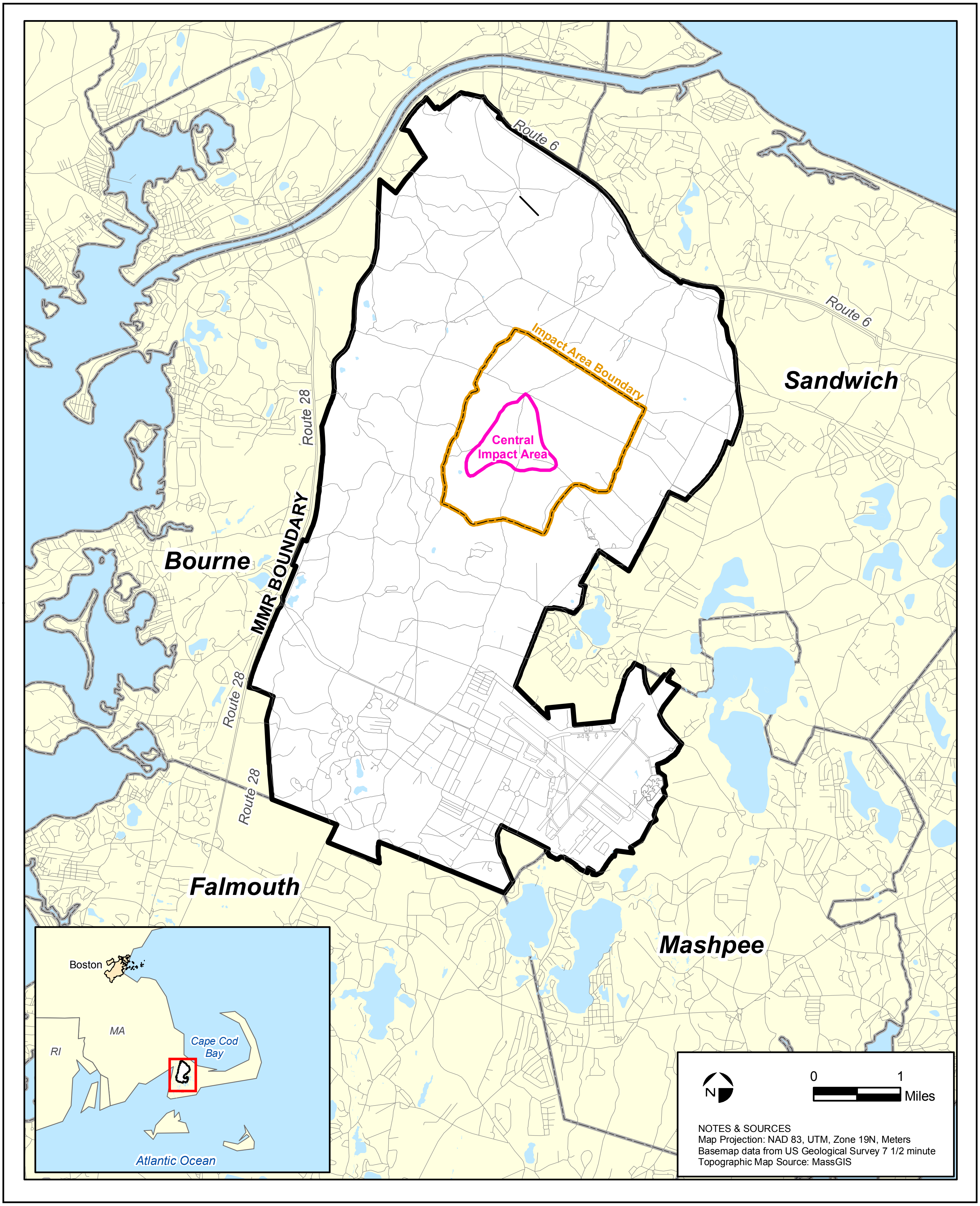
Thielsch Engineering, Inc. 2007. Soil Testing, On-Site Corrosion Examinations and Laboratory Testing of Corroded Inert Items Removed From Six Test Plots Within the Central Impact Area, Massachusetts Military Reservation, Cape Cod, Massachusetts, Report No. 12080.

USACE (U.S. Army Corps of Engineers). 2001. Revised Ordnance and Explosives Archives Search Report for MMR. October 2001. USACE Rock Island District and Defense Ammunition Center, McAlester AAP, Oklahoma.

USACE. 2002. Natural and Cultural Resources Environmental Compliance Assessment. Impact Area Groundwater Study, Massachusetts Military Reservation, Cape Cod, Massachusetts. United Army Corps of Engineers, New England District, and ENSR International, Westford, Massachusetts.

USGS (U.S. Geologic Survey). 1996. Use of Particle Tracking to Improve Numerical Model Calibration and to Analyze Groundwater Flow and Contaminant Migration. Massachusetts Military Reservation, Western Cape Cod, Massachusetts. USGS Open File Report 96-214 (p. 13.)

FIGURES



MMR Location
and General Site Use

FIGURE
2-1

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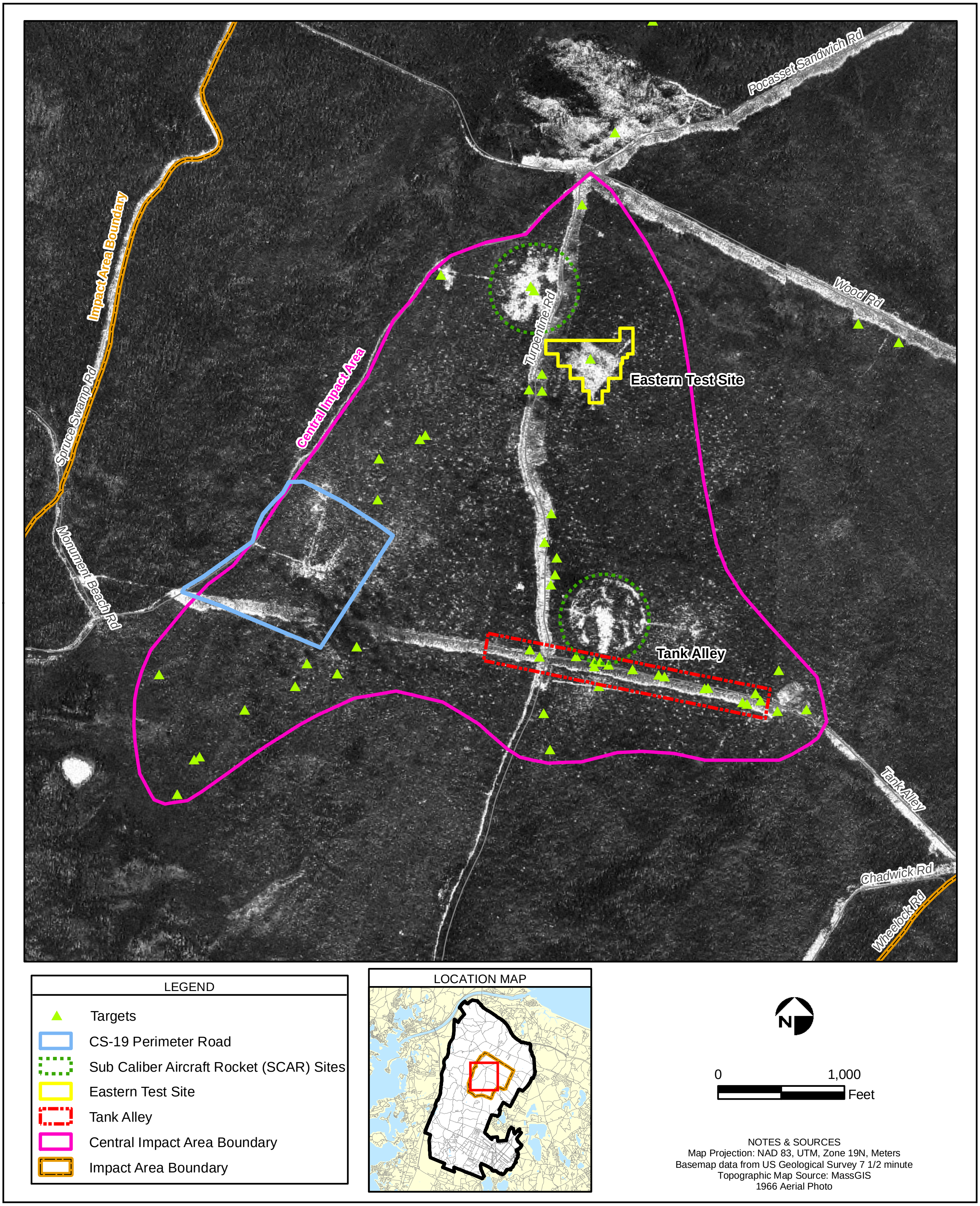
Prepared By: william.scales
Coordinate System: NAD 1983 UTM Zone 19N

Impact Area
Groundwater Study Program



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Westford, Massachusetts

Central Impact Area Location & Site History

FIGURE
2-2

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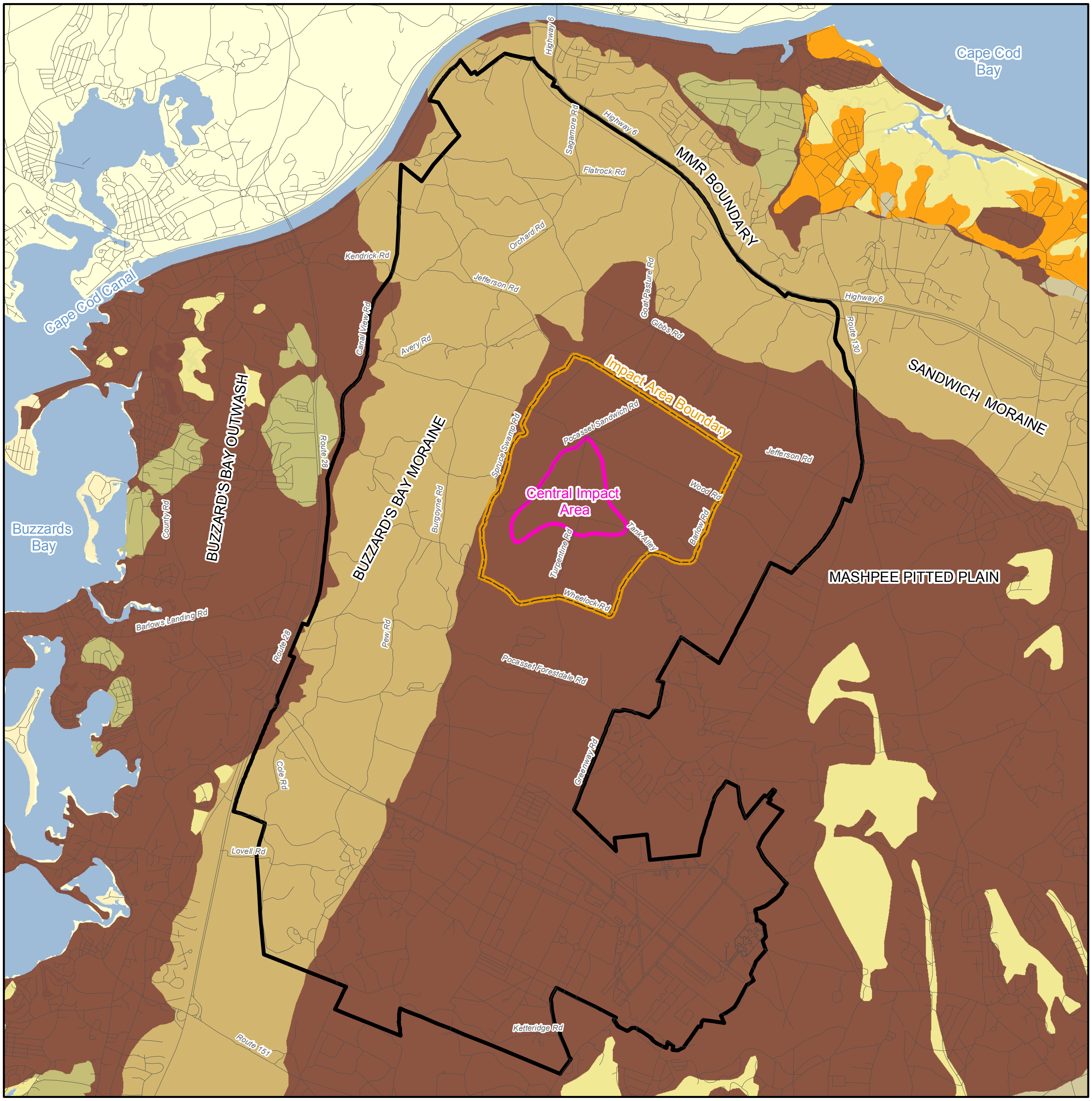
Prepared By: william.scales
Coordinate System: NAD 1983 UTM Zone 19N

Impact Area
Groundwater Study Program



LEGEND

- Sand and Gravel Deposits
- Till or Bedrock
- Sandy Till Over Sand
- End Moraines
- Large Sand Deposits
- Fine-Grained Deposits
- Floodplain Alluvium

LOCATION MAP

N

0 7,000 Feet

NOTES & SOURCES
Map Projection: NAD 83, UTM, Zone 19N, Meters
Basemap data from US Geological Survey 7 1/2 minute
Topographic and Geologic Map Source: MassGIS

AMEC Earth & Environmental, Inc.
Westford, Massachusetts

Surficial Geology of Western Cape Cod

FIGURE 2-3

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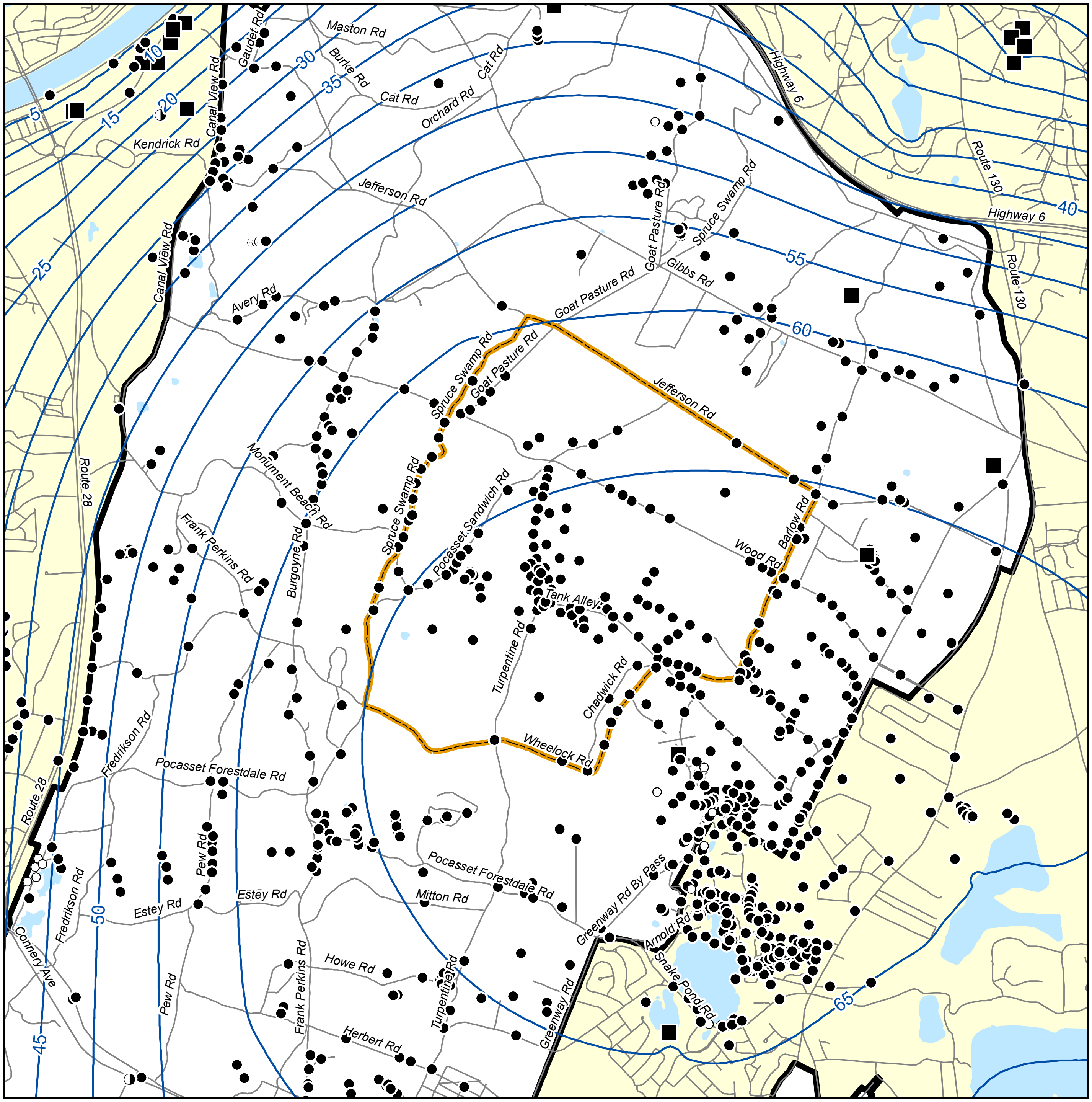
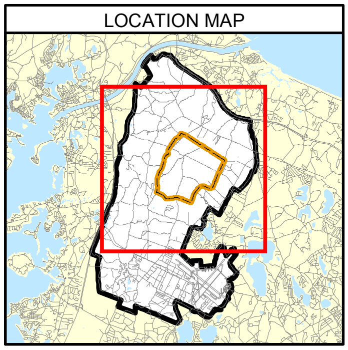
February 22, 2007 DWN: JBB KMP CHKD: AP

Impact Area Groundwater Study Program



LEGEND	
○	Proposed Monitoring Wells
●	Existing Monitoring Wells
■	Existing Water Supply Well
◑	Existing Irrigation Well
—	Groundwater Elevation Contours AMEC Model 10NW (5 ft)
▭	Impact Area Boundary

LOCATION MAP



N

0 4,000 Feet

NOTES & SOURCES
Map Projection: NAD 83, UTM, Zone 19N, Meters
Basemap data from US Geological Survey 7 1/2 minute
Topographic Map Source: MassGIS

Water Table Elevations

FIGURE
2-4

P:\Terc-JV\TO4\Restricted Files\GIS\Spatial\MXD\RI\MXD_Verification_073109\CIA\MXDs\Figure_2-6.mxd
February 5, 2007 DWN: JBB CHKD: AP

Impact Area
Groundwater Study Program

Impact Area Groundwater Study Program

LEGEND

Central Impact Area Boundary

Impact Area Boundary

MMR Boundary

RDX in Groundwater

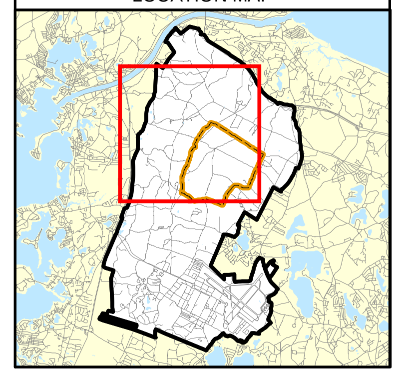
0.6 - 2 ppb

2 - 6 ppb

6 - 21 ppb

impact_area polygon

LOCATION MAP



NOTES & SOURCES

Map Projection: NAD 83, UTM, Zone 19N, Meters
Basemap data from US Geological Survey 7 1/2 minute
Aerial Imagery Source: ESRI Streaming Imagery

TITLE

Extent of RDX in Groundwater (2010)

0 1,800 3,600 Feet

N

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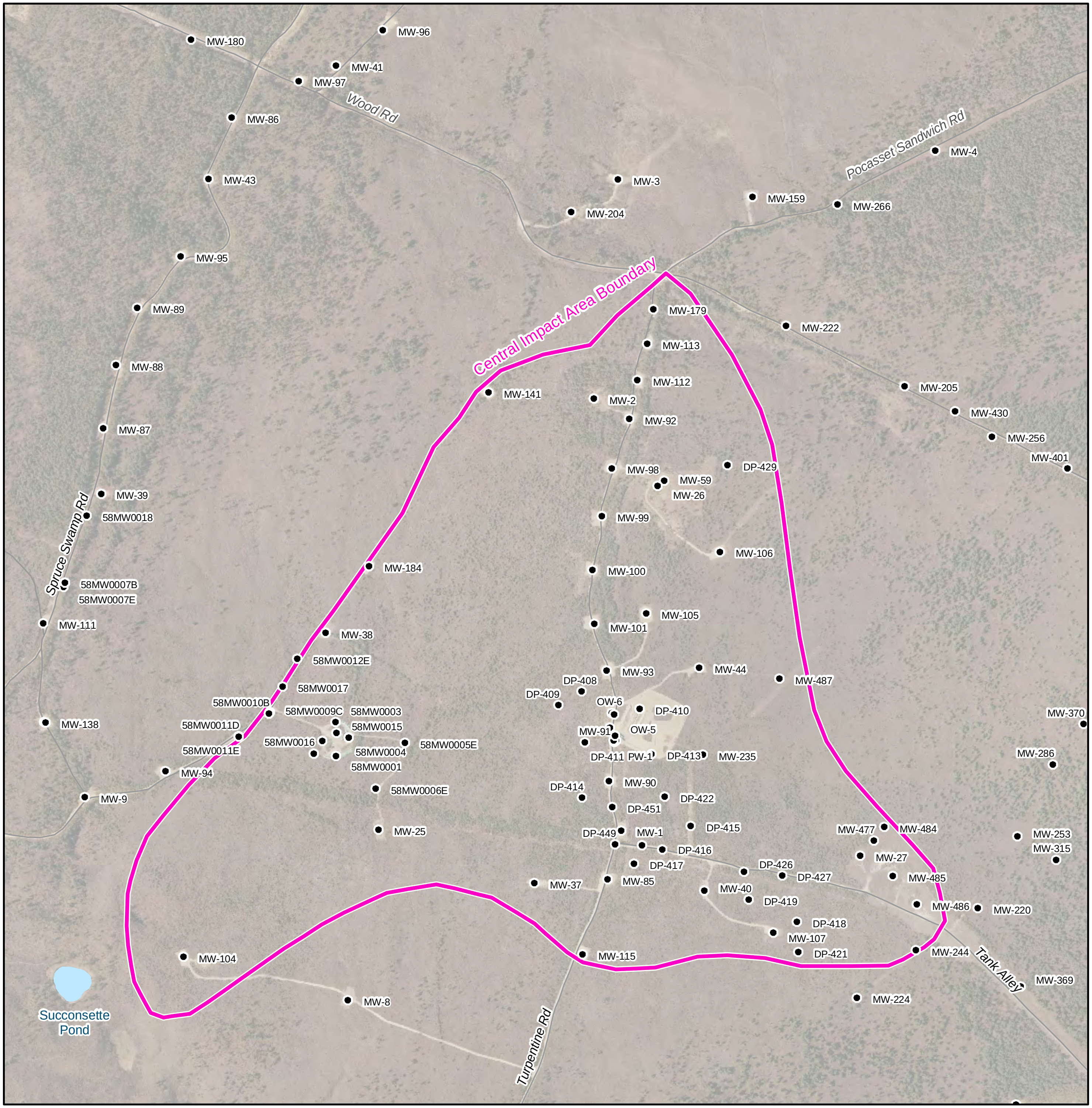
20110601_SourceReport\
20110601_Fig3-1_ExtentRDX.mxd
Prepared By: william.scales
Coordinate System: NAD 1983 UTM Zone 19N

FIGURE

3-1

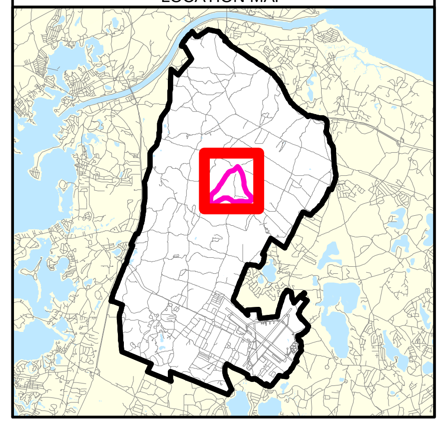


Impact Area Groundwater Study Program

LEGEND

● Monitoring Wells

LOCATION MAP



NOTES & SOURCES

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Topographic Map Source: MassGIS
Aerial photos Color Digital Orthophotos
Date Flown: 2002 Source: EarthData International

TITLE

Monitoring Well Locations

0 950 Feet

N

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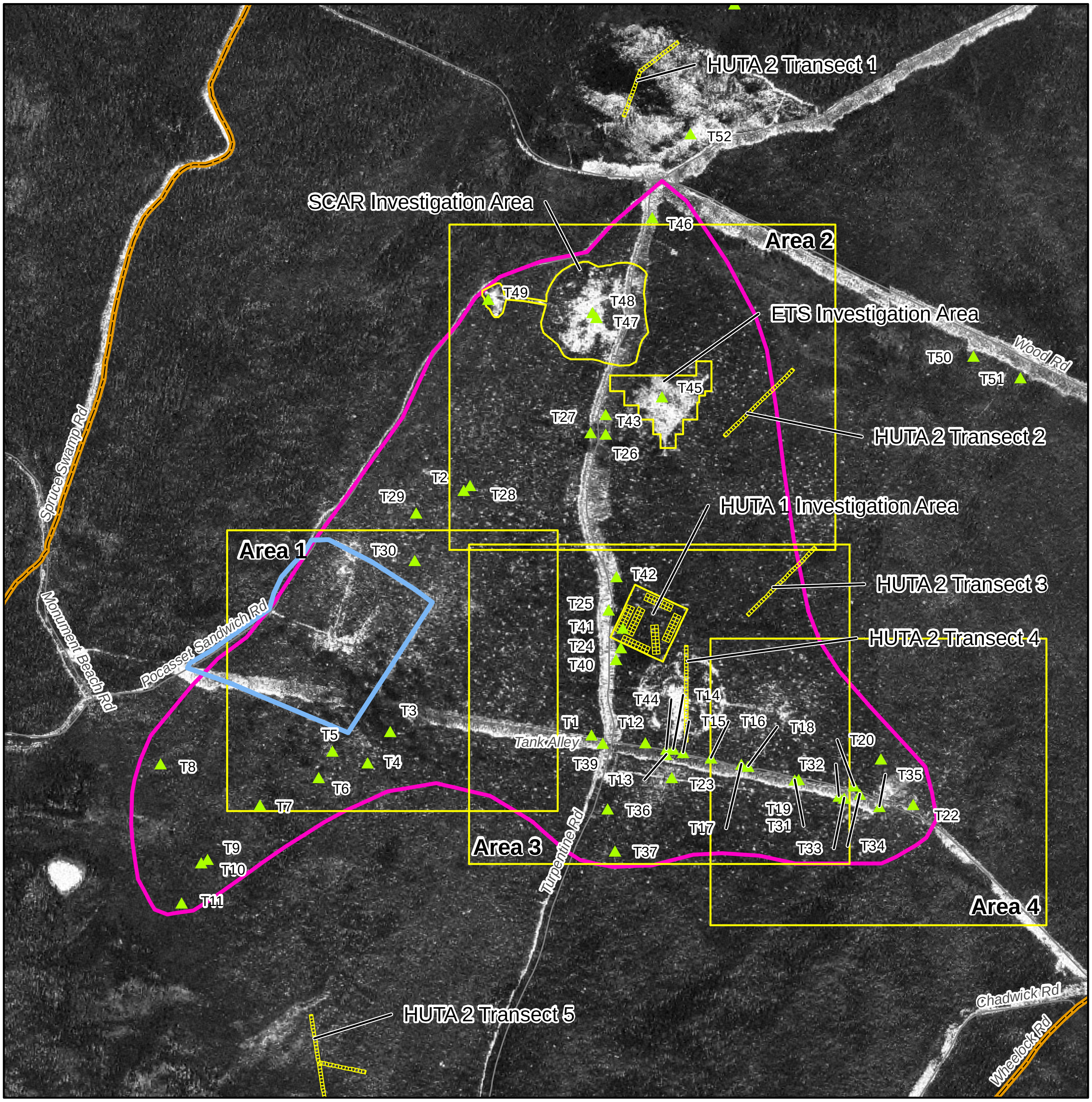
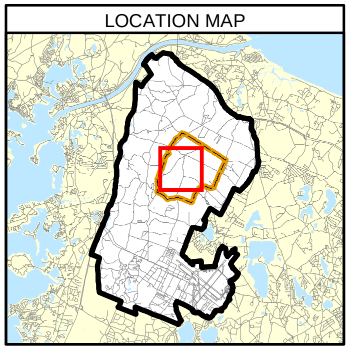
Prepared By: william.scales
Coordinate System: NAD 1983 UTM Zone 19N

FIGURE

3-2



LEGEND	
▲	Targets
	CS-19 Perimeter Road
	Locations of Investigations
	Central Impact Area Boundary
	Impact Area Boundary



0 1,000 Feet

NOTES & SOURCES
Map Projection: NAD 83, UTM, Zone 19N, Meters
Basemap data from US Geological Survey 7 1/2 minute
Topographic Map Source: MassGIS
1966 Aerial Photo

Locations of Investigations

FIGURE 3-3

File: P:\GIS\MMR\CIA\GIS\Spatial\MXD\20110601_SourceReport\
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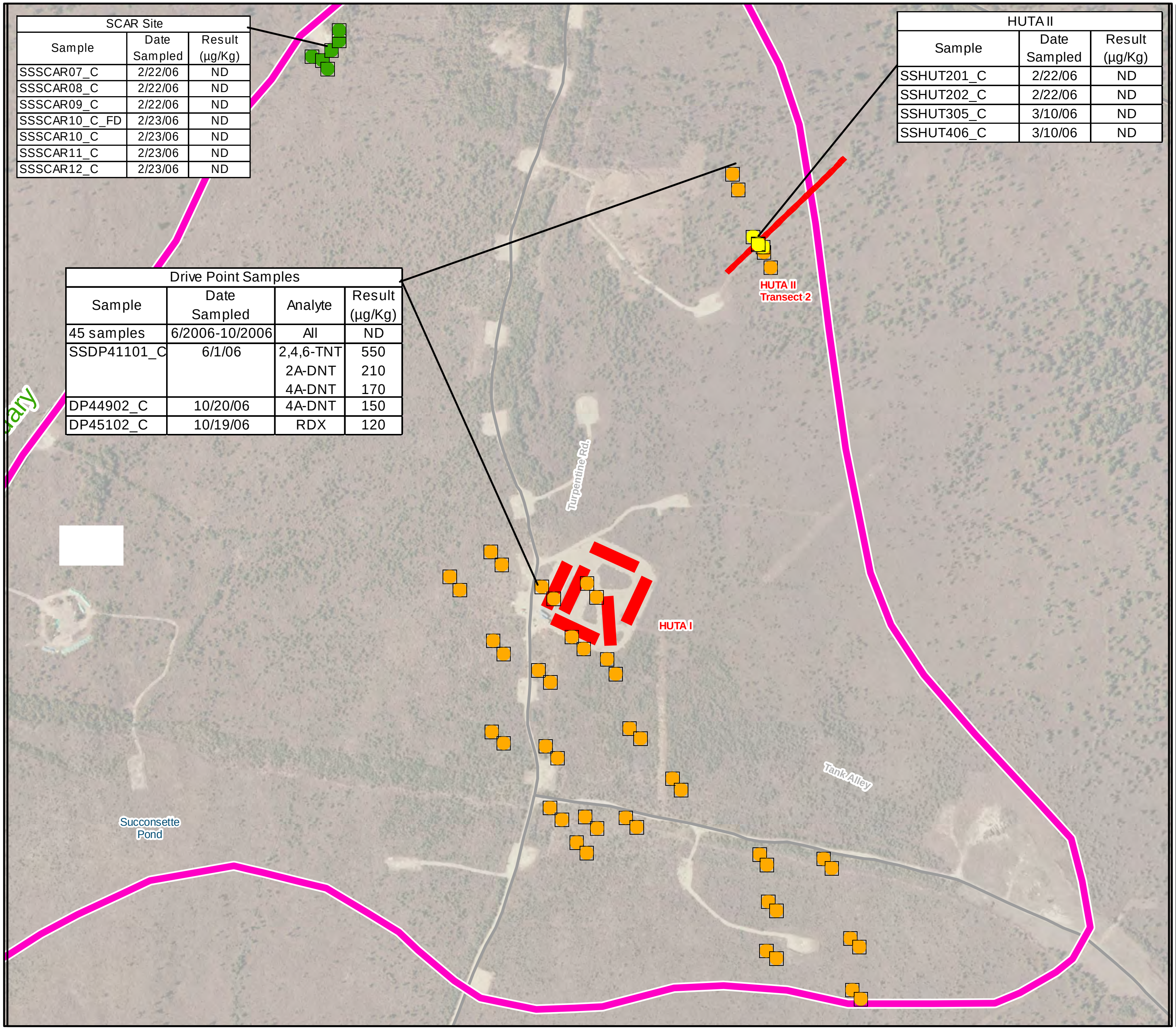
Prepared By: william.scales
Coordinate System: NAD 1983 UTM Zone 19N

Impact Area Groundwater Study Program



SCAR Site		
Sample	Date Sampled	Result (µg/Kg)
SSSCAR07_C	2/22/06	ND
SSSCAR08_C	2/22/06	ND
SSSCAR09_C	2/22/06	ND
SSSCAR10_C_FD	2/23/06	ND
SSSCAR10_C	2/23/06	ND
SSSCAR11_C	2/23/06	ND
SSSCAR12_C	2/23/06	ND

HUTA II		
Sample	Date Sampled	Result (µg/Kg)
SSHUT201_C	2/22/06	ND
SSHUT202_C	2/22/06	ND
SSHUT305_C	3/10/06	ND
SSHUT406_C	3/10/06	ND

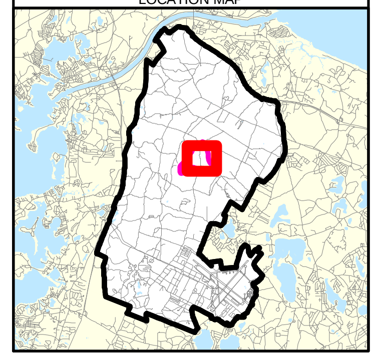
Drive Point Samples			
Sample	Date Sampled	Analyte	Result (µg/Kg)
45 samples	6/2006-10/2006	All	ND
SSDP41101_C	6/1/06	2,4,6-TNT	550
		2A-DNT	210
		4A-DNT	170
DP44902_C	10/20/06	4A-DNT	150
DP45102_C	10/19/06	RDX	120

Impact Area Groundwater Study Program

LEGEND

- Drive Point Multi-point Composite
- HUTA II Multi-point Composite
- SCAR Multi-point Composite
- HUTA Investigation Area
- Central Impact Area Boundary

LOCATION MAP



NOTES & SOURCES

Map Projection: NAD 83, UTM, Zone 19N, Meters
Basemap data from US Geological Survey 7 1/2 minute
Topographic Map Source: MassGIS
Aerial photos Color Digital Orthophotos
Date Flown: 2002 Source: EarthData International

TITLE

Central Impact Area
Multi-point Composite Soil Samples
Explosives

0 950 Feet

DRAFT

FIGURE 3-4

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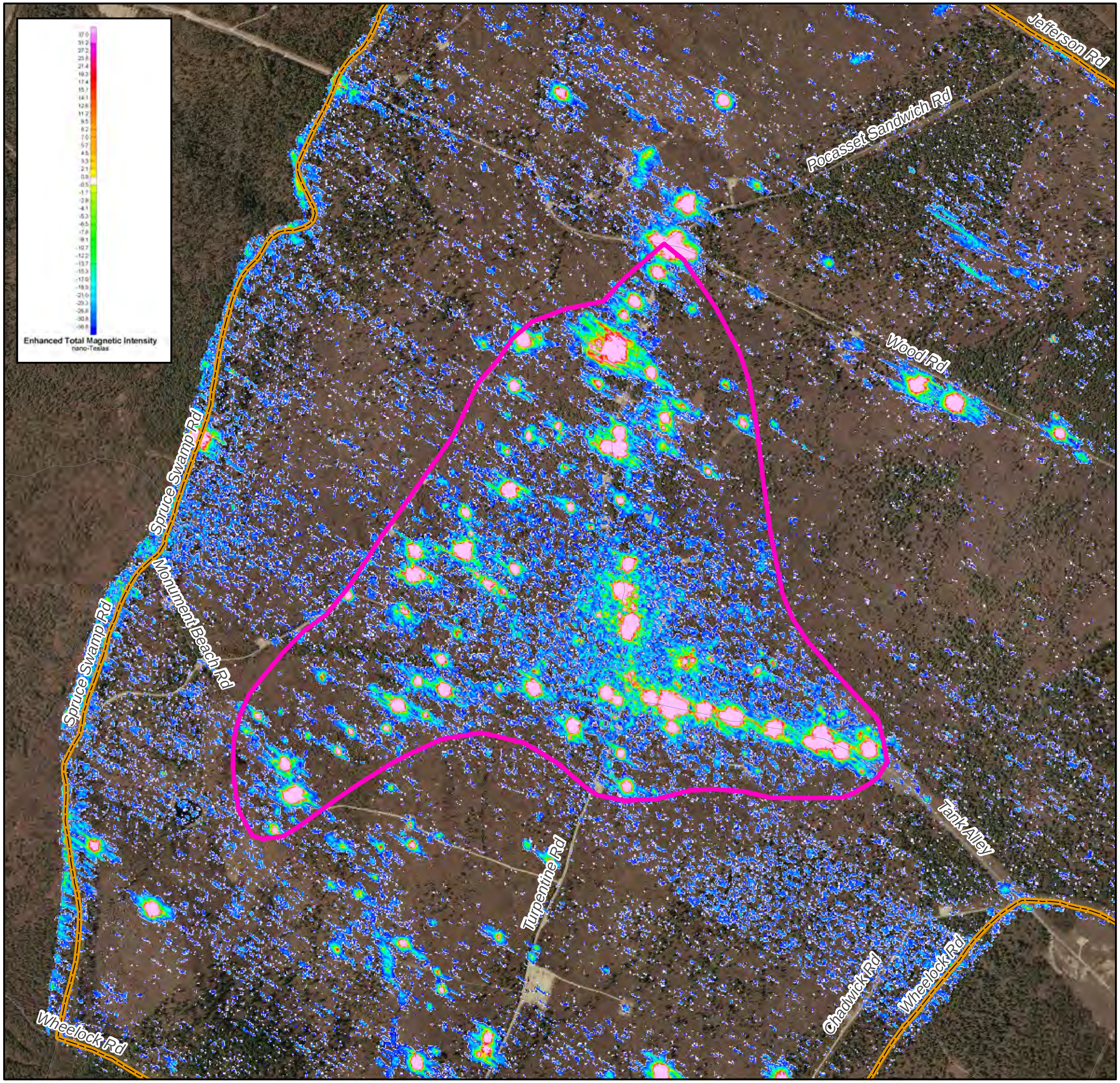
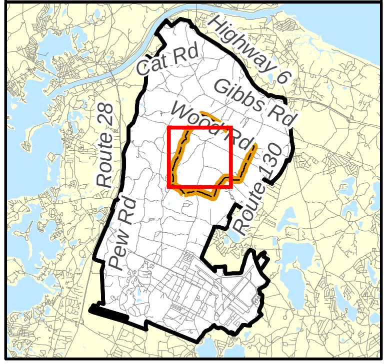


Impact Area
Groundwater Study Program

LEGEND

- Enhanced AIRMAG Signal Intensity
- Central Impact Area
- Impact Area

LOCATION MAP



NOTES & SOURCES

Map Projection: NAD 83, UTM, Zone 19N, Meters
Basemap data from US Geological Survey 7 1/2 minute
Topographic Map Source: MassGIS

TITLE

Enhanced AIRMAG
Signal Intensity

0 750
Feet

N

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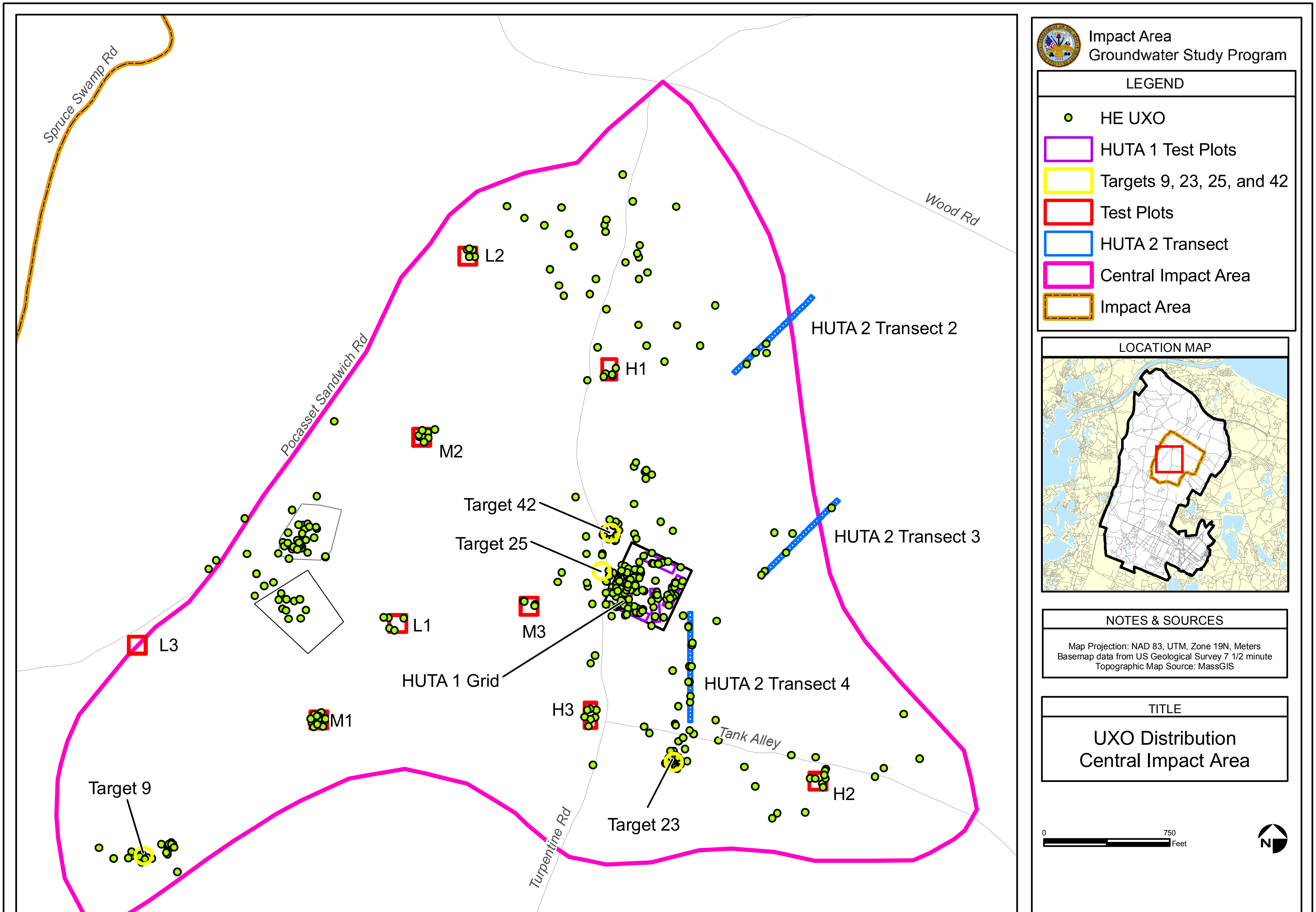
Prepared By: william.scales
Coordinate System: NAD 1983 UTM Zone 19N

FIGURE
3-5



Spruce Swamp Rd
Wood Rd
Pocasset Sandwich Rd
Turpentine Rd
Tank Alley
L1
L2
L3
M1
M2
M3
H1
H2
H3
HUTA 2 Transect 2
HUTA 2 Transect 3
HUTA 2 Transect 4
Target 42
Target 25
Target 23
Target 9
HUTA 1 Grid
Impact Area
Groundwater Study Program
LEGEND
HE UXO
HUTA 1 Test Plots
Targets 9, 23, 25, and 42
Test Plots
HUTA 2 Transect
Central Impact Area
Impact Area
LOCATION MAP
NOTES & SOURCES
Map Projection: NAD 83, UTM, Zone 19N, Meters
Basemap data from US Geological Survey 7 1/2 minute
Topographic Map Source: MassGIS
TITLE
UXO Distribution
Central Impact Area
0
750
Feet
N
File: P:\GIS\MMR\CIA\GIS\Spatial\MXD\
20110623_SourceReportUpdates\
20110623_Fig3-6_UXODistribution.mxd
Prepared By: william.scales
Coordinate System: NAD 1983 UTM Zone 19N

FIGURE

3-6

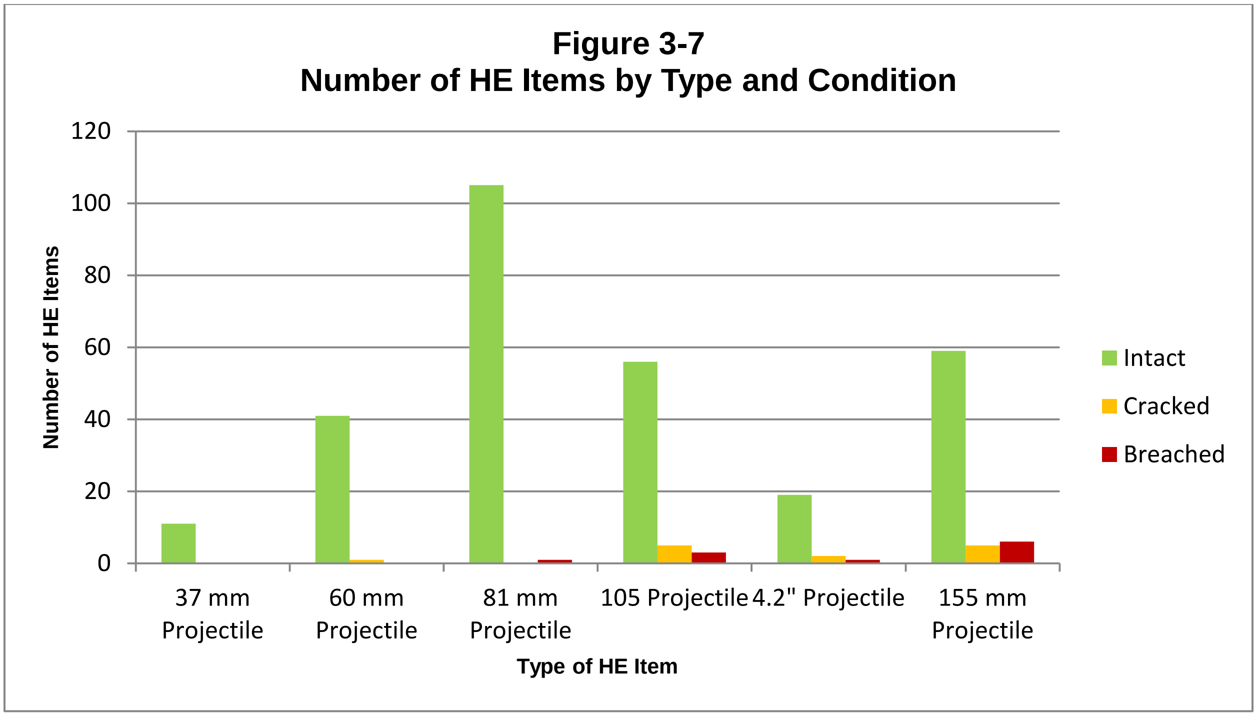
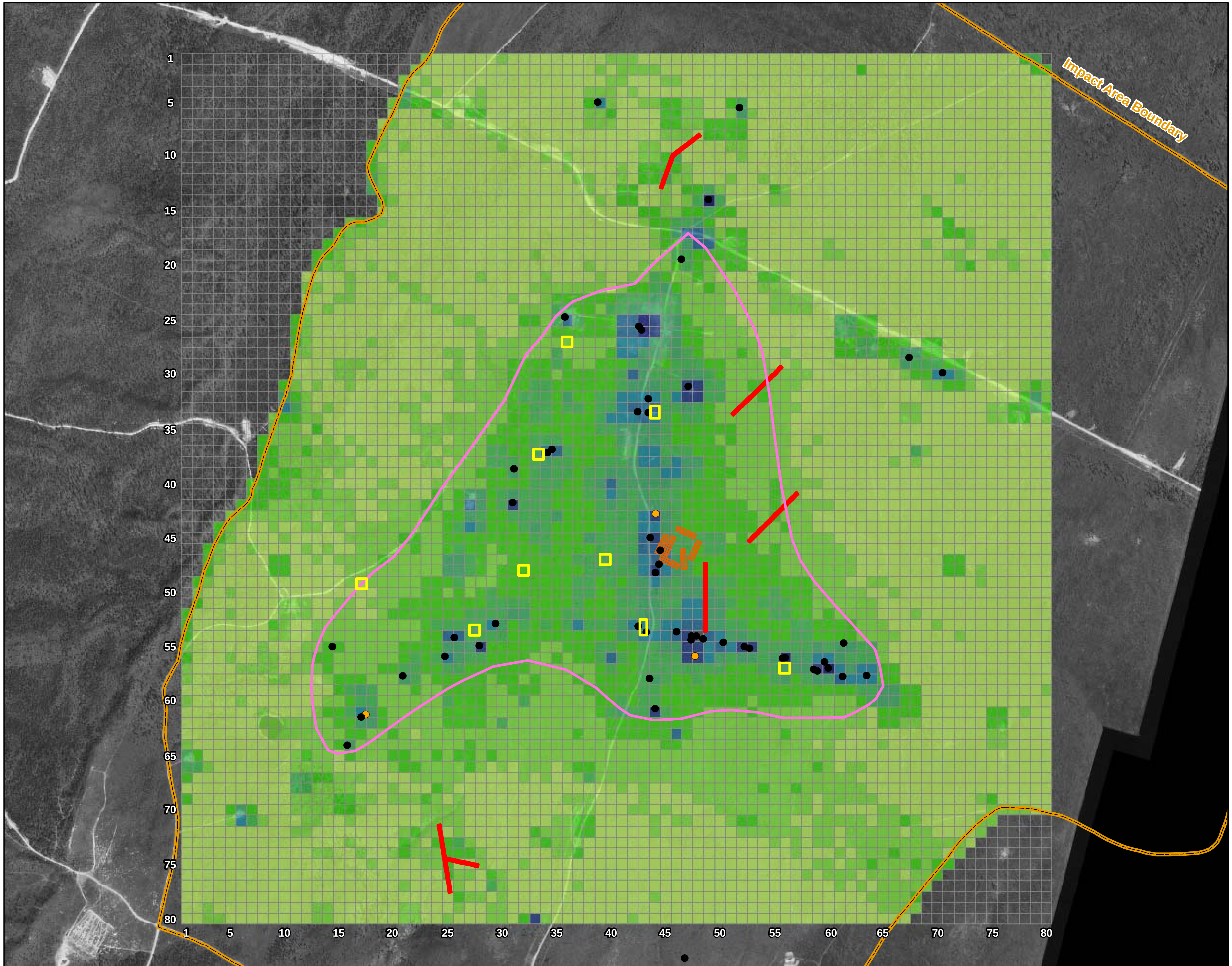


Figure 3-7
Number of HE Items by Type and Condition
120
100
80
60
40
20
0
Number of HE Items
37 mm Projectile
60 mm Projectile
81 mm Projectile
105 Projectile
4.2" Projectile
155 mm Projectile
Type of HE Item
Intact
Cracked
Breached

Impact Area Groundwater Study Program



LEGEND

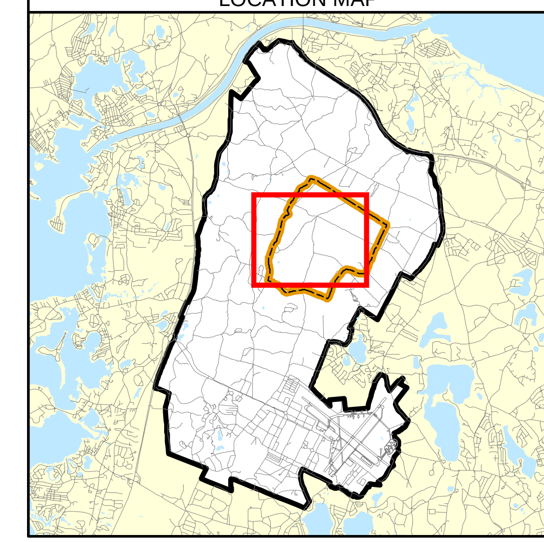
DENSITY CLASSIFICATION

Number of UXO items per acre

- 1 - 5
- 6 - 10
- 11 - 20
- 21 - 30
- 31 - 40
- 41 - 50
- 51 - 60
- 61 - 80
- > 80

- Targets
- Targets with known densities
- HUTA I
- HUTA II
- Central Impact Area
- Quarter-Acre Grid Cell
- PSI Plots

LOCATION MAP



NOTES & SOURCES

Map Projection: NAD 83, UTM, Zone 19N, Meters
Basemap data from US Geological Survey 7 1/2 minute
Topographic Map Source: MassGIS
Orthophoto: 1947

THE MAPPED VALUE CORRELATES GENERALLY TO EXPECTED UXO DENSITY. THIS MAP DOES NOT DEPICT THE STRENGTH OF CONTAMINANT SOURCES TO GROUNDWATER, WHICH DEPEND ON ADDITIONAL FACTORS.

TITLE

Estimated HE UXO Density

in the Impact Area

0 200 400 Meters

0 500 1,000 Feet

N

AMEC Earth and Environmental, Inc.
Westford, Massachusetts

G:\MMR_COE\Work2011\C10091\C10091_Fig_1.mxd
June 1, 2011 DWN: JDP AP DJK KMP CHKD: CA

FIGURE

3-8

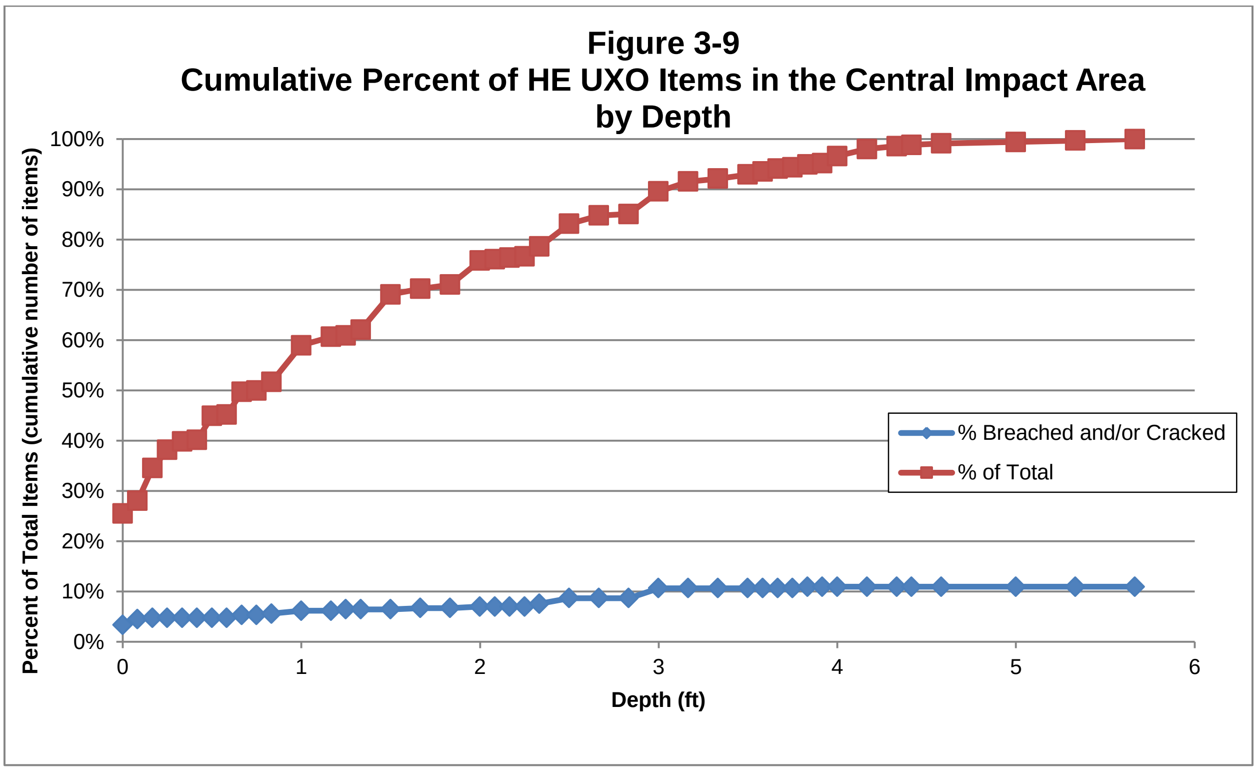


Figure 3-9
Cumulative Percent of HE UXO Items in the Central Impact Area
by Depth
Percent of Total Items (cumulative number of items)
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0
1
2
3
4
5
6
Depth (ft)
% Breached and/or Cracked
% of Total

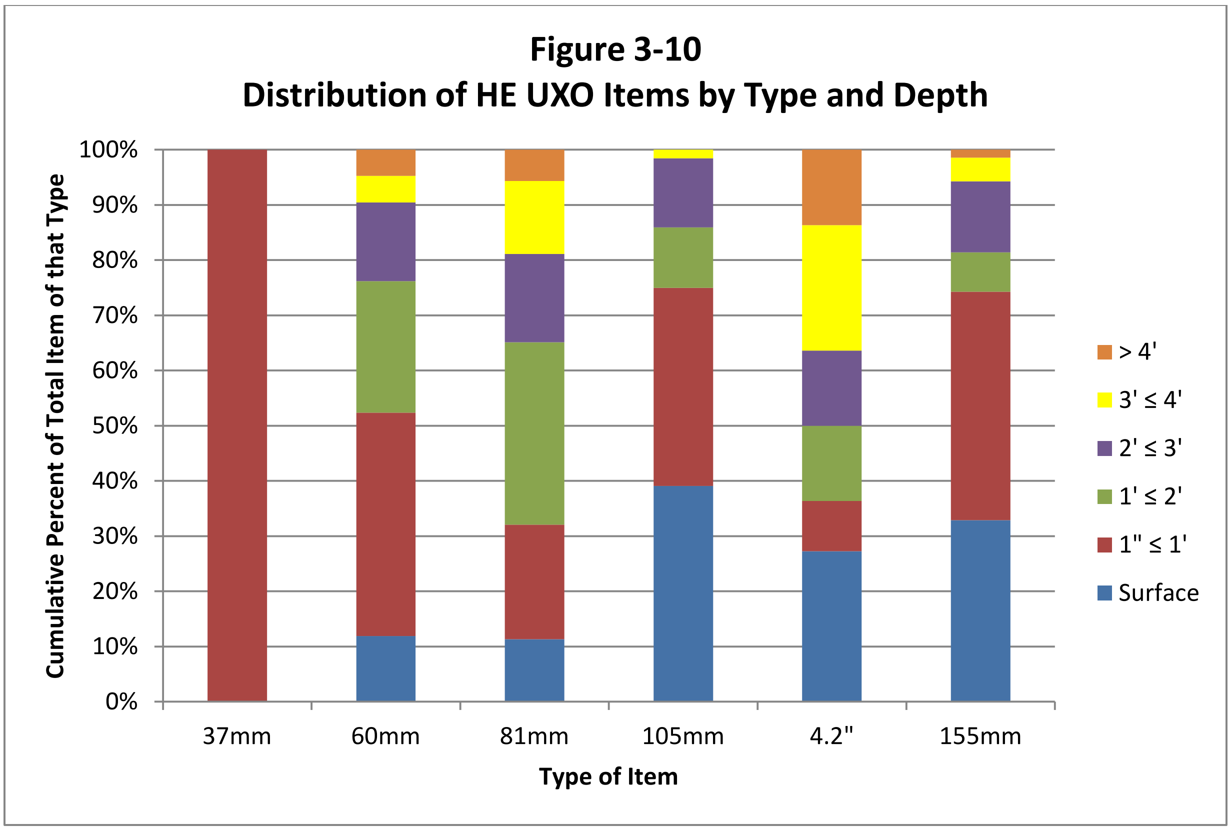


Figure 3-10
Distribution of HE UXO Items by Type and Depth
Cumulative Percent of Total Item of that Type
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
37mm
60mm
81mm
105mm
4.2"
155mm
Type of Item
> 4'
3' ≤ 4'
2' ≤ 3'
1' ≤ 2'
1" ≤ 1'
Surface

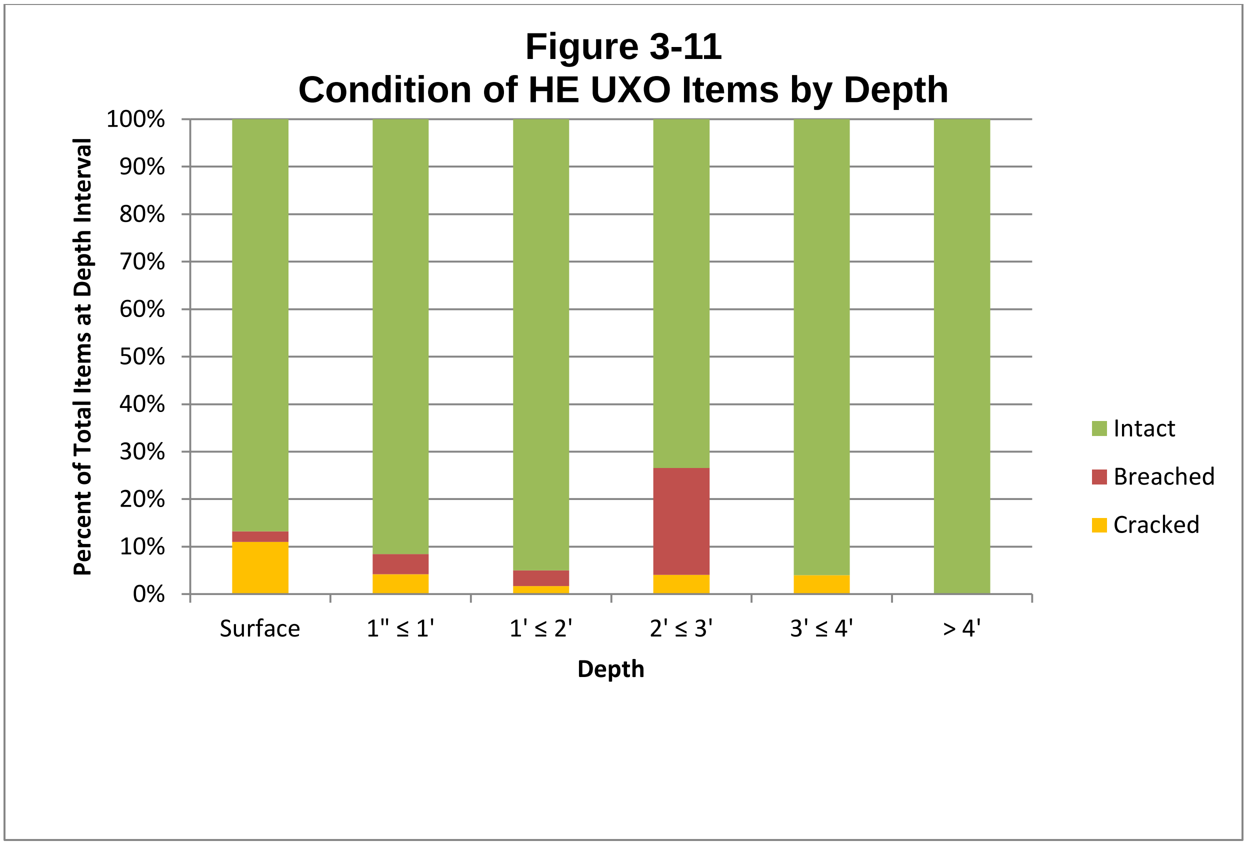
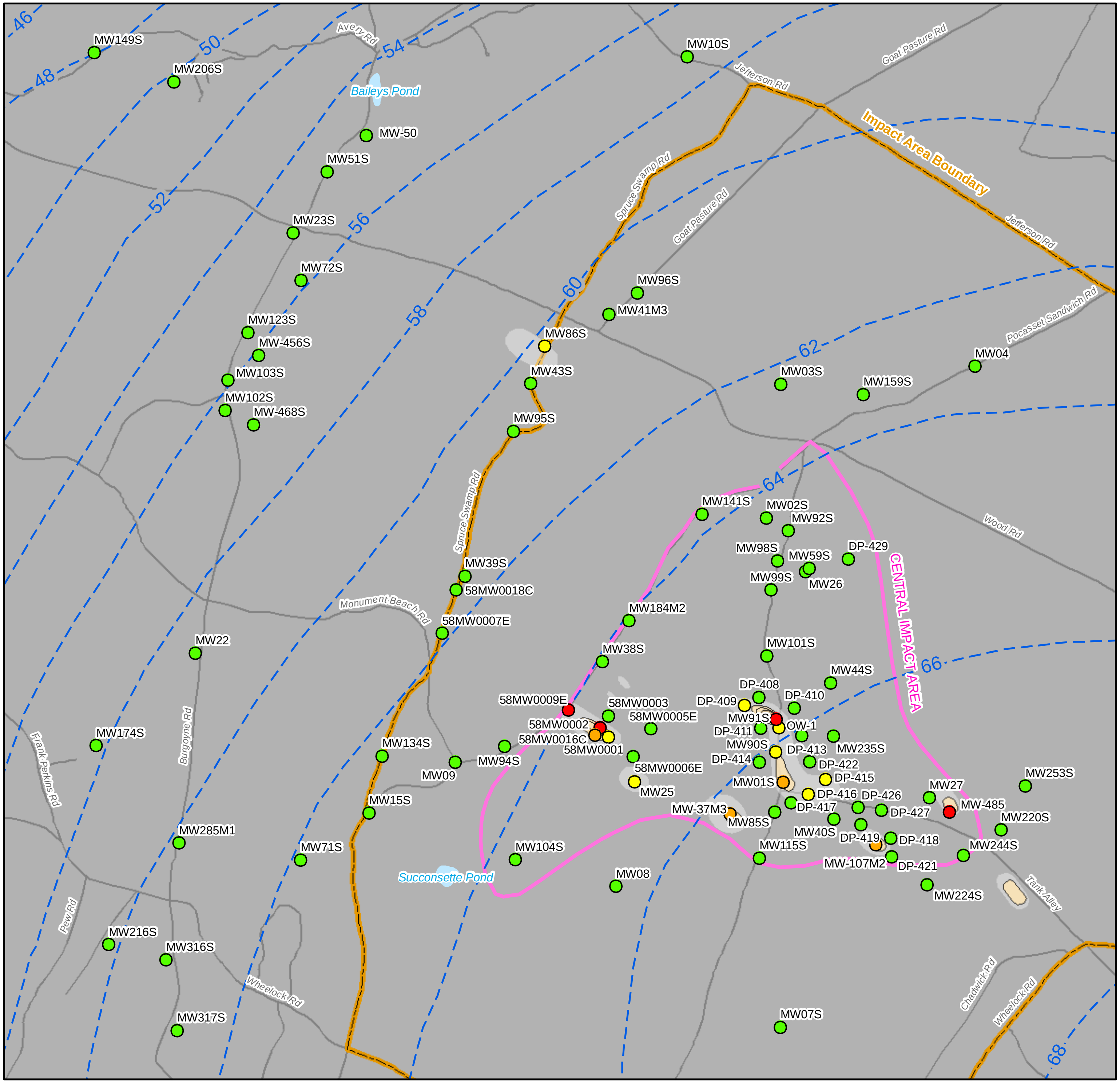


Figure 3-11
Condition of HE UXO Items by Depth
Percent of Total Items at Depth Interval
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Surface
1" ≤ 1'
1' ≤ 2'
2' ≤ 3'
3' ≤ 4'
> 4'
Depth
Intact
Breached
Cracked



Impact Area Groundwater Study Program

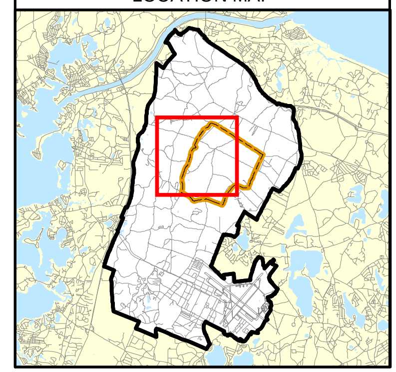
LEGEND

2007 RDX Water Table and Drivepoint Results*

- Non-detect to less than 0.6 ppb
- 0.6 ppb to less than 2 ppb
- 2 ppb to less than 6 ppb
- 6 ppb to less than 40 ppb
- 0.6 ppb to less than 2 ppb
- 2 ppb to less than 6 ppb
- 6 ppb to less than 25 ppb
- Water Table Contour (Feet NVGD) AMEC, August 2004

*RDX results as of 03/07

LOCATION MAP



NOTES & SOURCES

Map Projection: NAD 83, UTM, Zone 19N, Meters
Basemap data from US Geological Survey 7 1/2 minute
Topographic Map Source: MassGIS

TITLE

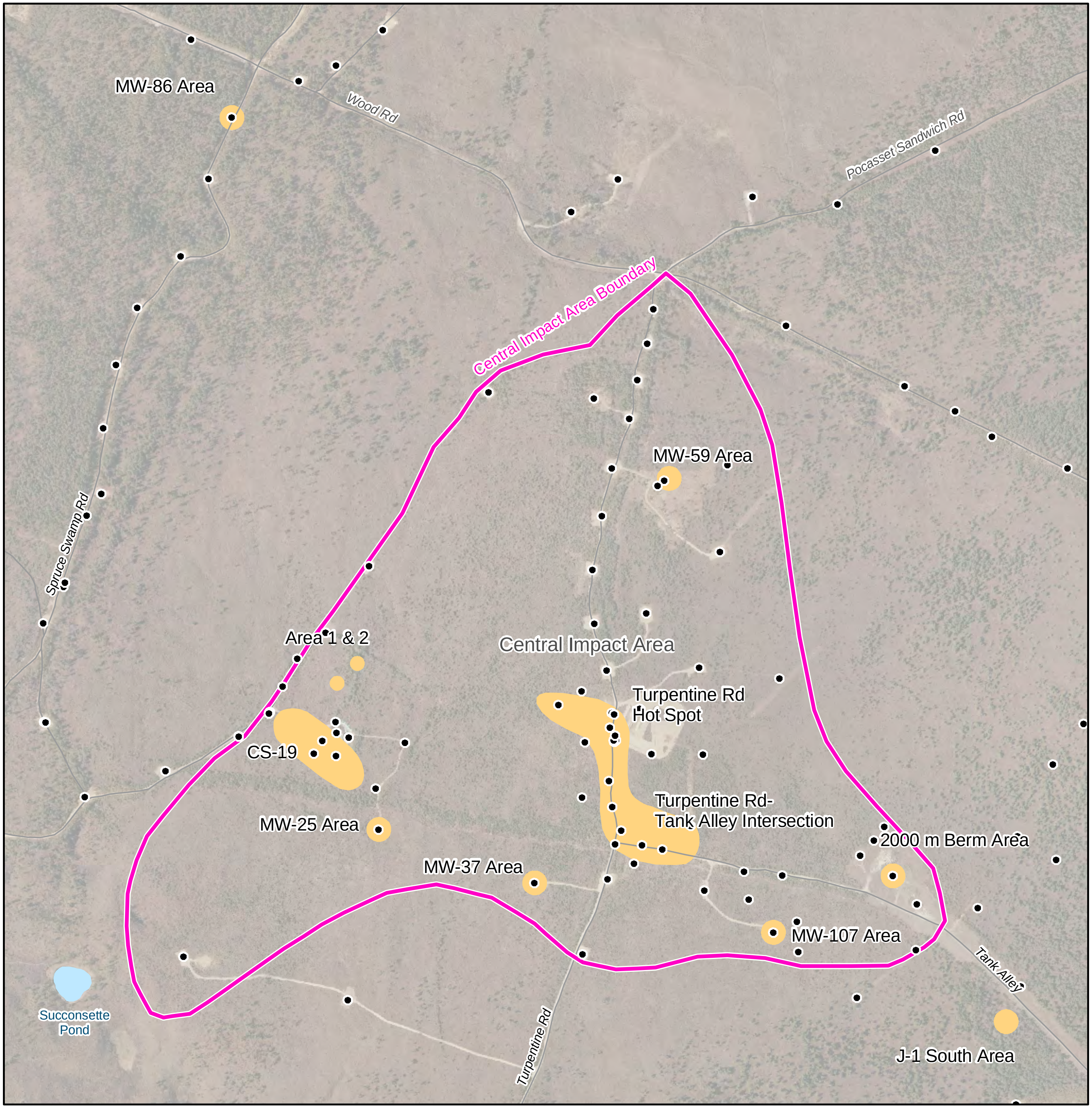
2007 Impact Area RDX Water Table Results

0 1,800 Feet

N

File: P:\GIS\MMR\CIA\GIS\Spatial\MXD\20110601_SourceReport\20110601_Fig_4-1_2007RDXResults.mxd
Prepared By: william.scales
Coordinate System: NAD 1983 UTM Zone 19N

FIGURE 4-1



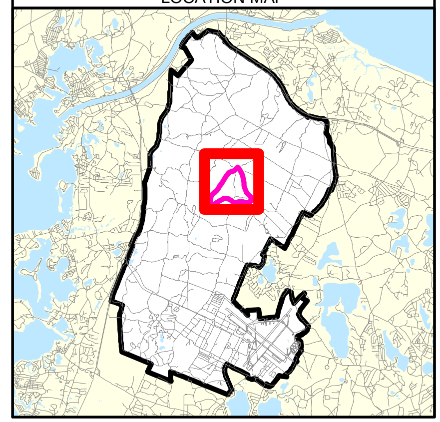
Impact Area
Groundwater Study Program

LEGEND

Monitoring Wells

Preliminary RDX Source Area

LOCATION MAP



NOTES & SOURCES

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Basemap data from US Geological Survey 7 1/2 minute
Topographic Map Source: MassGIS
Aerial photos Color Digital Orthophotos
Date Flown: 2002 Source: EarthData International

TITLE

2007 Estimated RDX
Source Areas

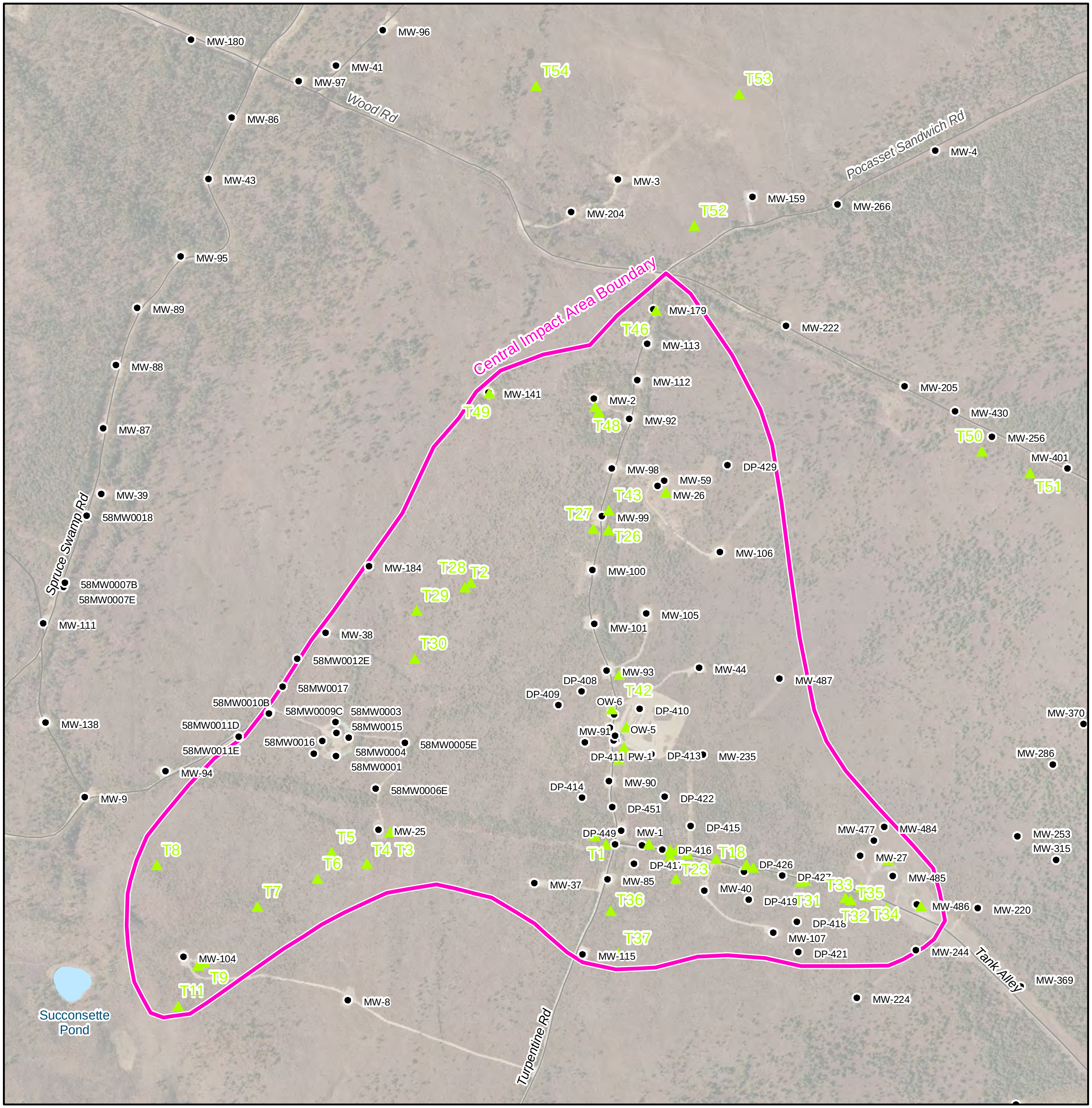
0 950
Feet

N

File: P:\Terc-JV\TO4\Restricted Files\GIS\Spatial\MXD\RI\
MXD_Verification_073109\CIA\MXDs\020711 Updates\
Figure_4-2.mxd
Prepared By: william.scales
Coordinate System: NAD 1983 UTM Zone 19N

FIGURE

4-2

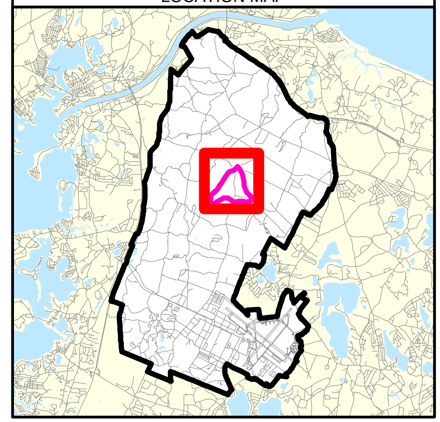


Impact Area Groundwater Study Program

LEGEND

- Monitoring Wells
- Targets

LOCATION MAP



NOTES & SOURCES

Map Projection: NAD 83, UTM, Zone 19N, Meters
Basemap data from US Geological Survey 7 1/2 minute
Topographic Map Source: MassGIS
Aerial photos Color Digital Orthophotos
Date Flown: 2002 Source: EarthData International

TITLE

Monitoring Well and Target Locations

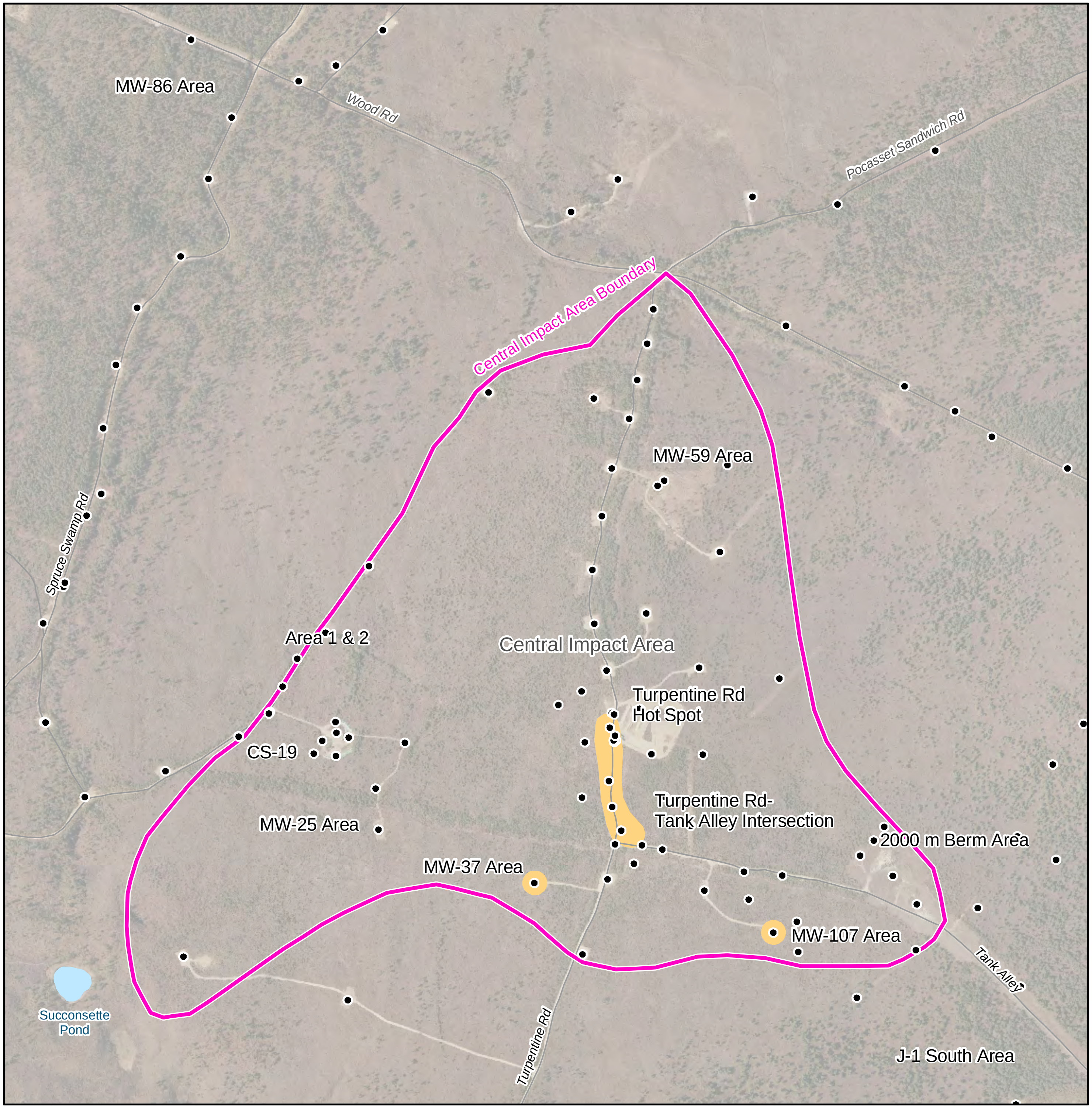
0 1,000 Feet

N

File: P:\GIS\MMR\CIA\GIS\Spatial\MXD\20110601_SourceReport\20110607_Fig4-3_TargetsWells.mxd
Prepared By: william.scales
Coordinate System: NAD 1983 UTM Zone 19N

FIGURE

4-3

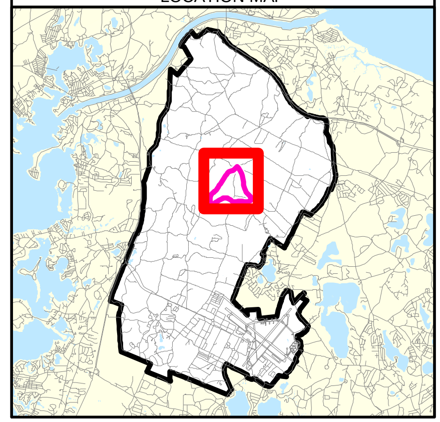


Impact Area
Groundwater Study Program

LEGEND

- Monitoring Wells
- 2010 Estimated RDX Source Area

LOCATION MAP



NOTES & SOURCES

Map Projection: NAD 83, UTM, Zone 19N, Meters
Basemap data from US Geological Survey 7 1/2 minute
Topographic Map Source: MassGIS
Aerial photos Color Digital Orthophotos
Date Flown: 2002 Source: EarthData International

TITLE

2010 Estimated RDX Source Areas

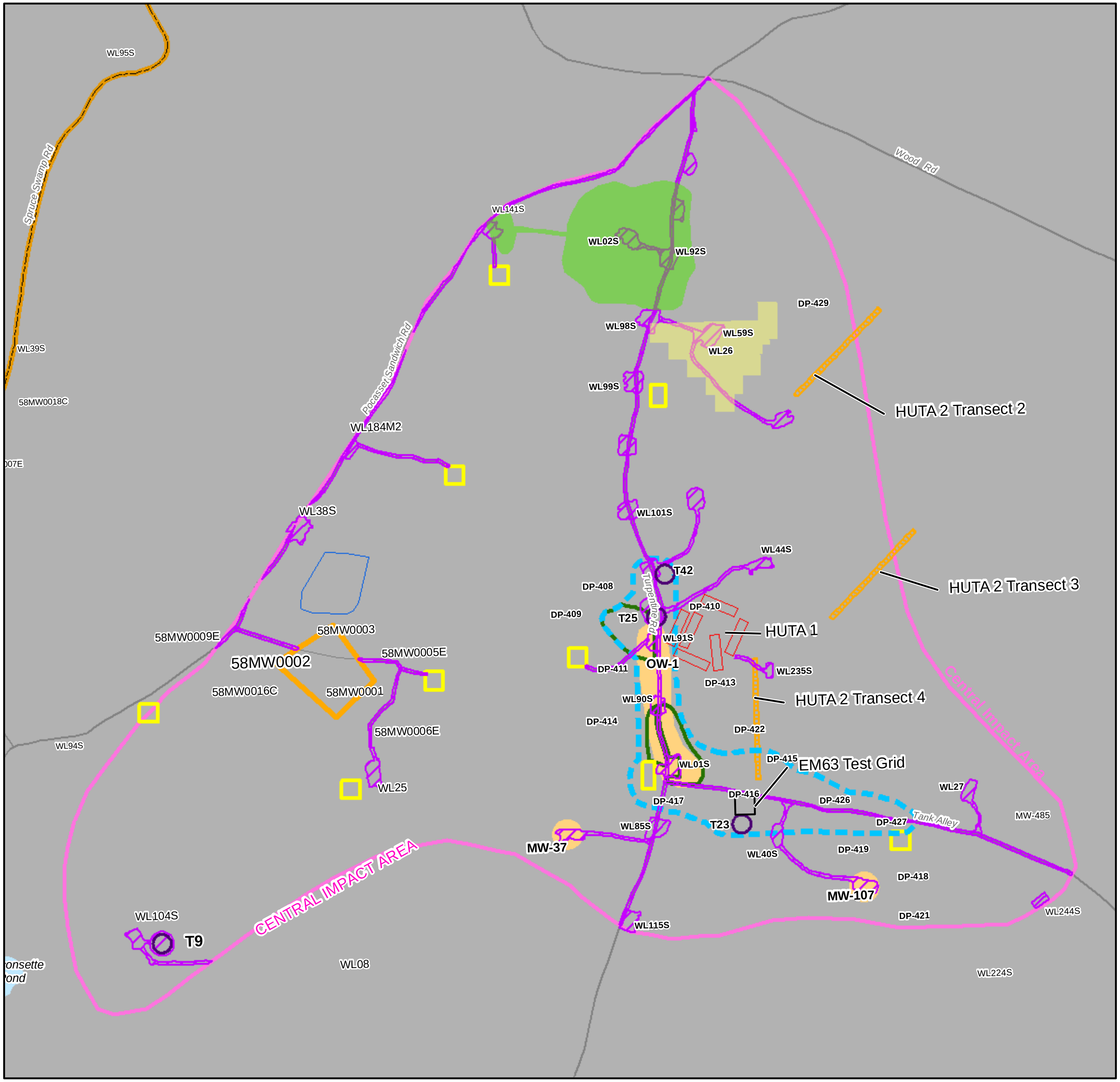
0 950 Feet

N

File: P:\GIS\MMR\CIA\GIS\Spatial\MXD\
20110623_SourceReportUpdates\
20110623_Fig4-4_2010EstimatedRDXArea.mxd
Prepared By: william.scales
Coordinate System: NAD 1983 UTM Zone 19N

FIGURE
4-4

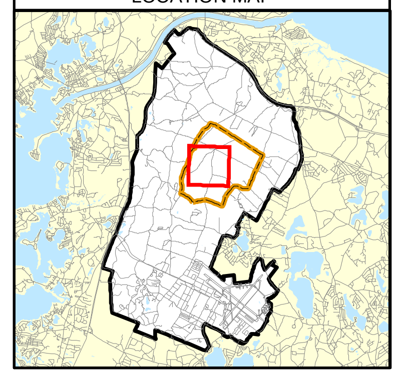
Impact Area
Groundwater Study Program



LEGEND

- 2010 Estimated RDX Source Area
- Robotic Excavation
- Robotics Clearance Area
- PSI UXO Test Plots
- HUTA 1
- HUTA 2
- UXO Clearance Area (Well pads, Access Roads, etc.)
- CS-19 Disposal Area
- CS-19 Bunker Area
- SCAR Site
- Eastern Test Site

LOCATION MAP



NOTES & SOURCES

Map Projection: NAD 83, UTM, Zone 19N, Meters
Basemap data from US Geological Survey 7 1/2 minute
Topographic Map Source: MassGIS

TITLE

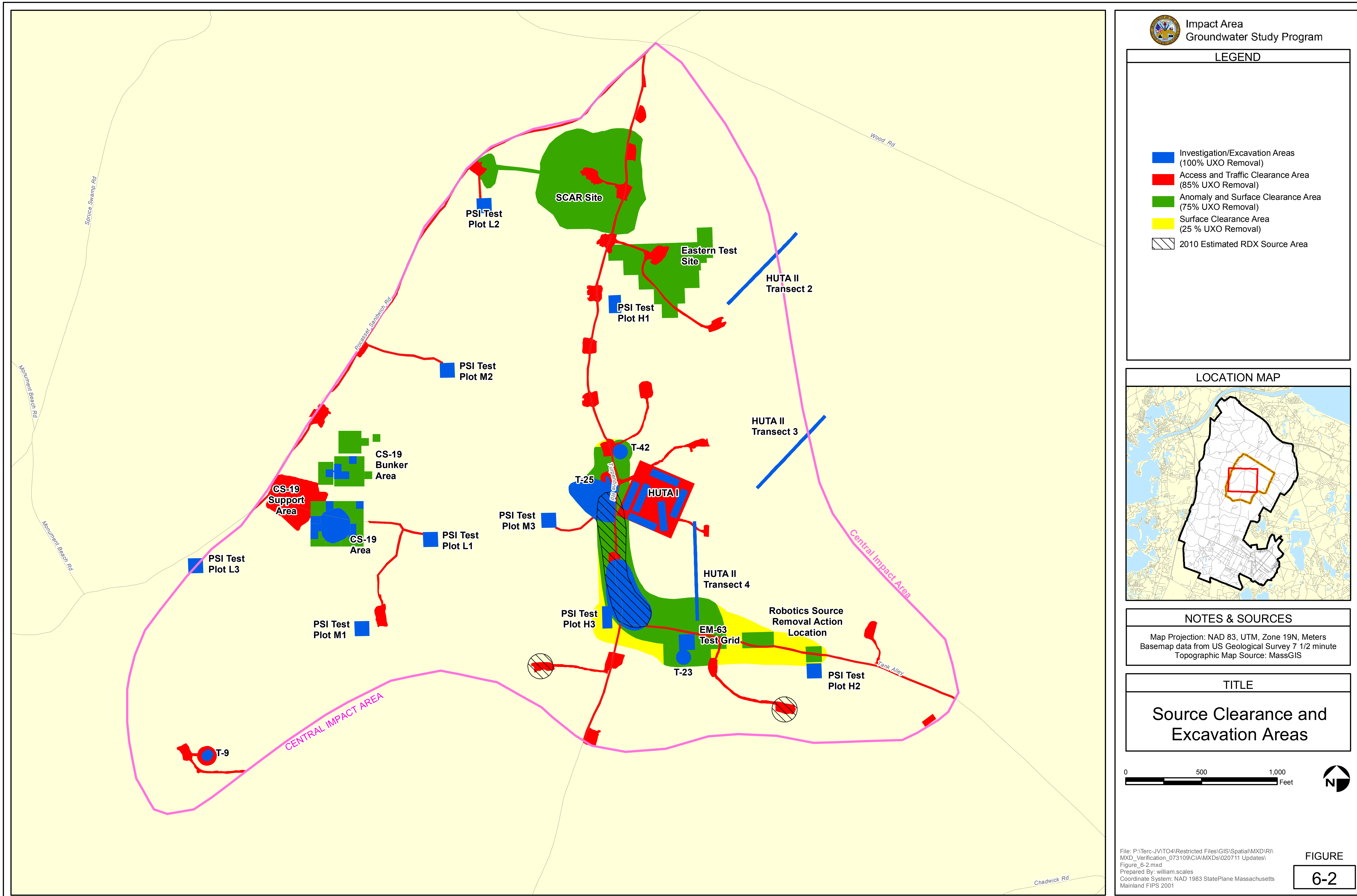
Source Investigation and Excavation Areas

0 550 Feet

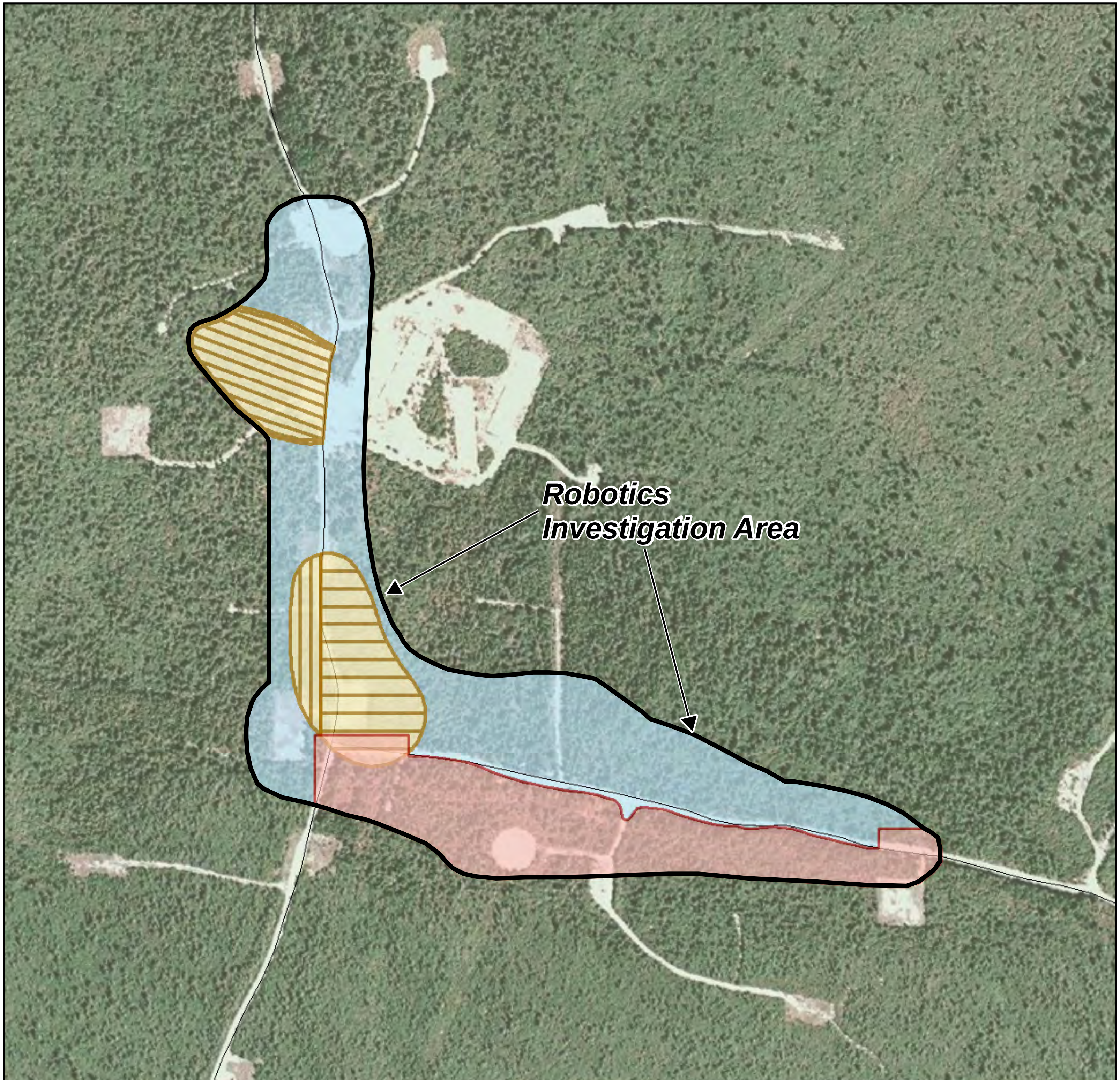
N

File: P:\Terc-JV\TO4\Restricted Files\GIS\Spatial\MXD\RI\MXD_Verification_073109\CIA\MXDs\020711 Updates\Figure_6-1.mxd
Prepared By: william.scales
Coordinate System: NAD 1983 StatePlane Massachusetts Mainland FIPS 2001

FIGURE
6-1



SCAR Site
PSI Test Plot L2
Eastern Test Site
PSI Test Plot H1
HUTA II Transect 2
PSI Test Plot M2
HUTA II Transect 3
T-42
CS-19 Bunker Area
CS-19 Support Area
T-25
HUTA I
PSI Test Plot M3
CS-19 Area
PSI Test Plot L1
PSI Test Plot L3
HUTA II Transect 4
Robotics Source Removal Action Location
PSI Test Plot H3
PSI Test Plot M1
EM-63 Test Grid
T-23
PSI Test Plot H2
T-9
CENTRAL IMPACT AREA
Central Impact Area
Wood Rd
Spruce Swamp Rd
Pocasset Sandwich Rd
Monument Beach Rd
Tank Alley
Chadwick Rd
Impact Area Groundwater Study Program
LEGEND
Investigation/Excavation Areas (100% UXO Removal)
Access and Traffic Clearance Area (85% UXO Removal)
Anomaly and Surface Clearance Area (75% UXO Removal)
Surface Clearance Area (25 % UXO Removal)
2010 Estimated RDX Source Area
LOCATION MAP
NOTES & SOURCES
Map Projection: NAD 83, UTM, Zone 19N, Meters
Basemap data from US Geological Survey 7 1/2 minute
Topographic Map Source: MassGIS
TITLE
Source Clearance and Excavation Areas
0
500
1,000
Feet
N
File: P:\Terc-JV\TO4\Restricted Files\GIS\Spatial\MXD\RI\MXD_Verification_073109\CIA\MXDs\020711 Updates\Figure_6-2.mxd
Prepared By: william.scales
Coordinate System: NAD 1983 StatePlane Massachusetts Mainland FIPS 2001
FIGURE
6-2

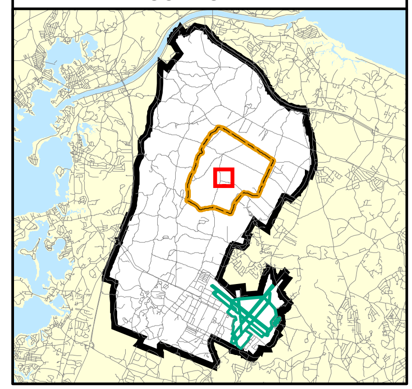


Impact Area
Groundwater Study Program

LEGEND

- Robotics Clearance Area
- Robotics Magnet Demonstration Area
- Surface Cleared
- Robotics Excavation Area
- Roads

LOCATION MAP



NOTES & SOURCES

Map Coordinates: NAD 83, UTM, Zone 19N, Meters
Basemap data from MA ARNG

TITLE

2009 Robotics Technology Demonstration

0 50 100 200
Feet

N

File: P:\Terc-JV\TO4\Restricted Files\GIS\Spatial\MXD\RI\
MXD_Verification_073109\CIA\MXDs\020711 Updates\Figure_6-3.mxd
Prepared By: william.scales
Coordinate System: NAD 1983 UTM Zone 19N

FIGURE

6-3

TABLES

Table 3-1
Ordnance Abundance by Type Within the Central Impact Area

ITEM TYPE	TOTAL NUMBER OF UXO ITEMS	% OF TOTAL ITEMS	NUMBER OF HE ITEMS	% OF TOTAL HE ITEMS
14.5 mm Projectile	2	0.4%	0	0.0%
20 mm Projectile	1	0.2%	1	0.3%
30 mm Projectile	2	0.4%	2	0.6%
37 mm Projectile	21	4.0%	11	3.1%
57 mm Projectile	1	0.2%	1	0.3%
2.36" Rocket	4	0.8%	4	1.1%
60 mm Mortar	43	8.1%	42	11.8%
2.75" Rocket	6	1.1%	6	1.7%
75 mm Projectile	3	0.6%	0	0.0%
81 mm Mortar	142	26.8%	106	29.8%
3.5" Projectile	1	0.2%	1	0.3%
90 mm Projectile	3	0.6%	3	0.8%
105 Projectile	81	15.3%	64	18.0%
4.2" Mortar	27	5.1%	22	6.2%
5" Projectile	1	0.2%	0	0.0%
155 mm Projectile	126	23.8%	70	19.7%
175 mm Projectile	1	0.2%	1	0.3%
7" Projectile	7	1.3%	6	1.7%
8" Projectile	4	0.8%	4	1.1%
Explosive Compound	5	0.9%	5	1.4%
Burster Tubes, Fuzes, Illumination Cannisters, etc.	37	7.0%	0	0.0%
Not Available	11	2.1%	7	2.0%
Total Number of Items	**529**	**100%**	**356**	**100%**

Table 3-2
High Explosive Unexploded Ordnance Distribution and Depth Profile

	Targets					HUTA 1								HUTA 2				TEST PLOTS													
ITEM TYPE	**T-9**	**T-23**	**T-25**	**T-42**	**Targets Total**	**Non-Test Plot Area**	**Test Plot 1**	**Test Plot 2**	**Test Plot 3**	**Test Plot 4**	**Test Plot 5**	**Test Plot 6**	**HUTA1 Total**	**Transect 2**	**Transect 3**	**Transect 4**	**HUTA2 Total**	**L-1**	**L-2**	**L-3**	**M-1**	**M-2**	**M-3**	**H-1**	**H-2**	**H-3**	**Test Plots Total**	**OTHER AREAS**	**OVERALL TOTAL**	**% OF TOTAL HE ITEMS**	**ITEM TYPE**
20 mm Projectile																												1	1	0.3%	20 mm Projectile
30 mm Projectile																												2	2	0.6%	30 mm Projectile
37 mm Projectile																		1			5	1	1				8	3	11	3.1%	37 mm Projectile
57 mm Projectile															1		1												1	0.3%	57 mm Projectile
2.36" Rocket																												4	4	1.1%	2.36" Rocket
60 mm Mortar	4				4	2			3	3	2	2	12					1			2	1		1			5	21	42	11.8%	60 mm Mortar
2.75" Rocket																												6	6	1.7%	2.75" Rocket
81 mm Mortar	2	10		5	17	5	3	9	1	7	10	10	45		1	2	3	1	2		7	2	2	2	3	3	22	19	106	29.8%	81 mm Mortar
3.5" Rocket			1																										1	0.3%	3.5" Rocket
90 mm Projectile																												3	3	0.8%	90 mm Projectile
105 Projectile		3		1	4	6	1	1		1	3	1	13	1	1	2	4		2		1	3	1		1	1	9	34	64	18.0%	105 Projectile
4.2" Mortar				2	2	1	1		1		4		7	1			1				1		1	1	1		4	8	22	6.2%	4.2" Mortar
155 mm Projectile		3		1	4	6	1	4	2	1	1	4	19		1	5	6		1					1	1	2	5	36	70	19.7%	155 mm Projectile
175 mm Projectile																												1	1	0.3%	175 mm Projectile
7" Projectile				2	2																							4	6	1.7%	7" Projectile
8" Projectile																												4	4	1.1%	8" Projectile
Bulk Explosives		1			1							1	1								1						1	2	5	1.4%	Bulk Explosives
Not Available	1				1	3		2					5															1	7	2.0%	Not Available
TOTAL	7	17	1	11	36	23	6	16	7	12	20	18	102	2	4	9	15	3	5	0	17	7	5	5	6	6	54	149	356	100%	TOTAL
% OF TOTAL HE ITEMS	2.0%	4.8%	0.3%	3.1%	10.1%	6.5%	1.7%	4.5%	2.0%	3.4%	5.6%	5.1%	28.7%	0.6%	1.1%	2.5%	4.2%	0.8%	1.4%	0.0%	4.8%	2.0%	1.4%	1.4%	1.7%	1.7%	15.2%	41.9%	100%		% OF TOTAL HE ITEMS

	Targets					HUTA 1								HUTA 2				TEST PLOTS													
DEPTH	**T-9**	**T-23**	**T-25**	**T-42**	**Targets Total**	**Non-Test Plot Area**	**Test Plot 1**	**Test Plot 2**	**Test Plot 3**	**Test Plot 4**	**Test Plot 5**	**Test Plot 6**	**HUTA1 Total**	**Transect 2**	**Transect 3**	**Transect 4**	**HUTA2 Total**	**L-1**	**L-2**	**L-3**	**M-1**	**M-2**	**M-3**	**H-1**	**H-2**	**H-3**	**Test Plots Total**	**OTHER AREAS**	**OVERALL TOTAL**	**% OF TOTAL HE ITEMS**	**DEPTH**
Surface	1	5	1	3	10	7		1			1	1	10			1	1					2			2		4	66	91	25.6%	Surface
1" ≤ 1'	5	4		1	10	10	4	8			3	2	27	1	3	4	8	2	1		7	1	2	1	1	2	17	57	119	33.4%	1" ≤ 1'
1' ≤ 2'	1	2		2	5		1	5	1	3	3	4	17	1	1	2	4	1	1		8	4	2	2	3	2	23	11	60	16.9%	1' ≤ 2'
2' ≤ 3'		5		3	8	1		2	4	5	3	3	18			1	1		3		2		1	1		2	9	13	49	13.8%	2' ≤ 3'
3' ≤ 4'				2	2	3	1			2	6	7	19			1	1							1			1	2	25	7.0%	3' ≤ 4'
> 4'		1			1	2			2	2	4	1	11																12	3.4%	> 4'
Total	7	17	1	11	36	23	6	16	7	12	20	18	102	2	4	9	15	3	5	0	17	7	5	5	6	6	54	149	356	100%	Total

Table 6-1
Summary of Principal Central Impact Area Response Actions

Area	Excavation Size (acres)	Excavation Depth (feet bgs)	Soil Removed (tons)	Date
APC (Target 25)	0.12	1-3	330	2000
Mortar Target 9	0.12	2	572	2001
Target 23	0.18	2-3	885	2004 – 2005
Target 42	0.18	2-3	1,100	2004 – 2005
CS-19 Disposal Area	1.0	3	3,000	2004 – 2006
Additional	0.6	3	1,310	2007 – 2009
CS-19 Bunker Area	0.3	3	1,300	2009
Burn Pit	0.1	4	43	
Tank Alley-Turpentine Road	3	1-3	12,300	2010

Table 6-2
Summary of Clearance Activities

Category 1 – Excavation Areas (100% UXO Removal)	
Area	**Acres**
1A Soil Removal Actions	
Target 25	0.12
Target 23	0.18
Target 42	0.18
Target 9	0.12
CS-19	1.6
CS-19 Bunker	0.3
Tank Alley and Turpentine Road	3.05
Subtotal	**~5.5 acres**
1B Investigations	
HUTA I Test Plots	1.3
HUTA II Transects	1
PSI Nine Test Plots	2
Subtotal	**~4.3 acres**
Category 2 – Anomaly and Surface Clearance (75% UXO Removal)	
Area	**Acres**
SCAR Site	10
Eastern Test Site	4.5
CS-19 Bunker Area (Outside Excavation)	1
Tank Alley and Turpentine Road	8
Subtotal	**23.5 acres**
Category 3 – Access and Traffic Clearance (85% UXO Removal)	
Area	**Acres**
Drill Pads	6.4
Roads	4.7
Area between HUTA I Test Plots	2.7
CS-19 And Other Support Areas	2.25
Subtotal	**16 acres**
Category 4 – Surface Clearance (25% UXO Removal)	
Area	**Acres**
Tank Alley-Turpentine Road	8
Subtotal	**8 acres**

Appendix A
Central Impact Area Unexploded Ordnance Data Compilation

Appendix A
Central Impact Area Unexploded Ordnance Data Compilation

Information on unexploded ordnance discoveries considered in this report was derived from the MMR-EDMS data system, USACE field observations, and previous data reviews, as well as AFCEE-related data for CS-19.

Methodology

The following describes the process that was used to compile the database used to evaluate various aspects of the set of munitions items discovered in the Central Impact Area. This database was compiled using the MMR-EDMS and the recorded descriptive fields with subsequent filtering criteria applied to ensure the inclusion of only HE items. The initial database development process matched that used in the analysis of these items performed for the 2008 UXO/Source Area Report.

EDMS was queried to locate only those items that were categorized as unexploded ordnance (UXO), munitions constituents (MC) or munitions and explosives of concern (MEC) from within the Central Impact Area. It should be noted that there are a few items identified as being from the J1 Range that are included in the current database because they are also coded in EDMS as being found within the Central Impact Area. Additionally, some items categorized as UXO in the 2008 database have since been updated to either MEC (with a BIP Result Code of Inert) or MD in the EDMS data base. These items were not retained. It should also be noted that the Central Impact Area database that was analyzed for depth, item type and item condition distributions does not include the data from CS-19 since these items were from a different type of activity (munitions test and disposal).

Eight items were removed from the database because they were emplaced test items for a test exercise that was designed to determine if explosives-sniffing dogs could find unexploded ordnance items located below the surface.

Incident reports that referenced more than one item were represented in the database as multiple rows such that each row represented one item of that type.

The remaining items were then checked to ensure that they fell within the boundary of the Central Impact Area. A group of 128 Items had coordinates that fell outside of the Central Impact Area boundary so these items were removed from the database.

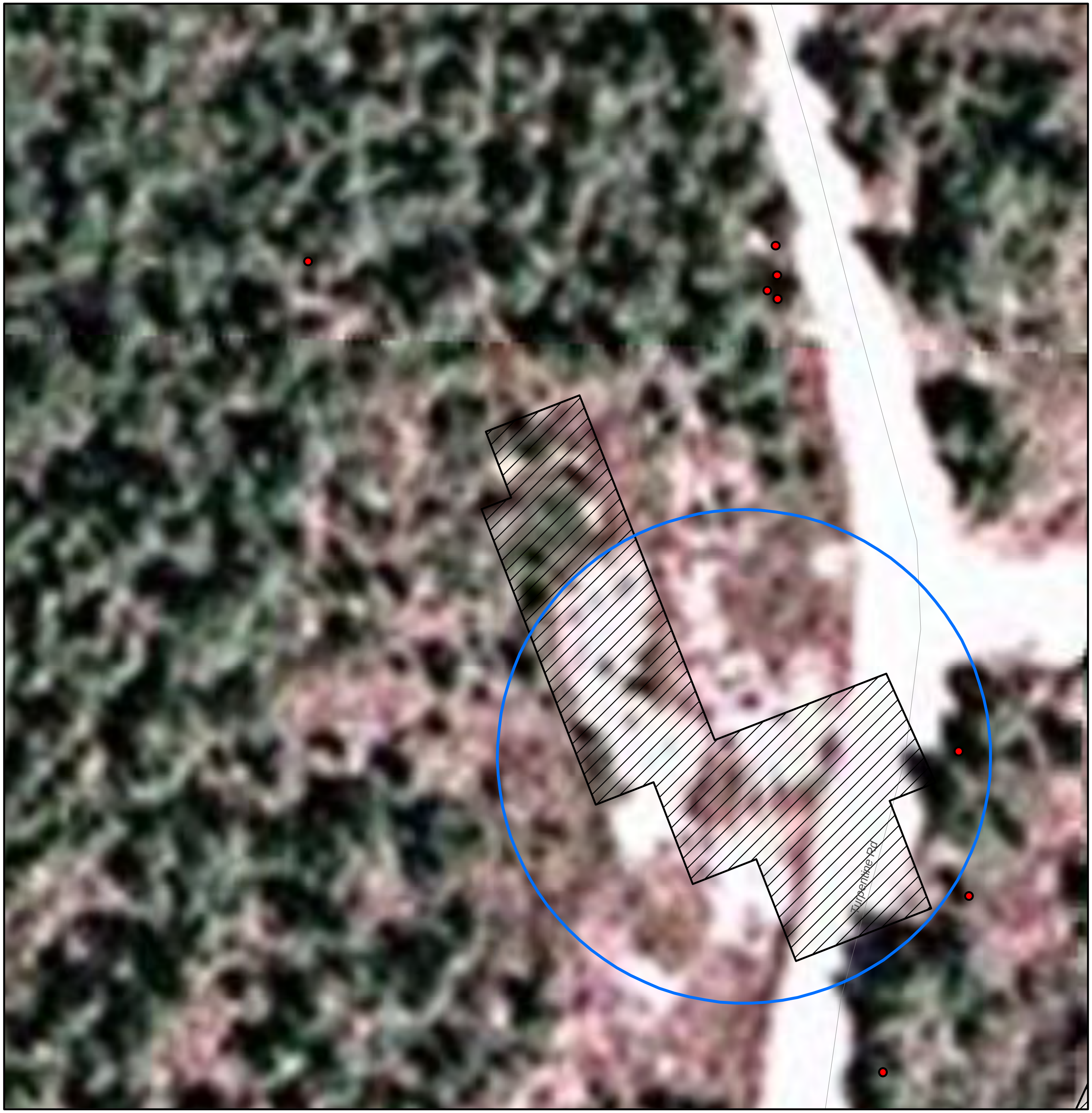
A set of 98 of the remaining items with a final Disposition Code of “determined to be scrap” were removed from the database.

The remaining items were then reviewed by a senior UXO Specialist with experience at MMR to identify which items were HE. The fields included in this review were: the entered Item Description text; the BIP Result Code (e.g., HE, IN for inert, NA for Not Available); the Filler Code (e.g., HE, IN, LE for Low Explosive, Unknown) and the Remarks field. One item was removed from the database because the item was already in the database under a different location ID and, therefore, was a duplicate entry. Three items that were originally classified as HE based on the BIP Result Code were reclassified to “Not HE” because they were actually fuses or practice mortars. Conversely, 254 items that were originally classified as something other than HE based on the BIP Result Code were reclassified for this analysis as HE because the filler was listed as HE or unknown and the item description was not sufficient to determine the items was “Not HE.”

The 2011 database was compared to the 2008 database utilized in the *UXO/Source Investigation Report* (AMEC 2008). The 2011 database included 356 items, which is lower than the 486 items that were retained in the 2008 database. The difference results primarily from the fact that the 2008 database included items outside the Central Impact Area, primarily on the J-1 and J-3 Ranges, and previously not classifiable items that were subsequently evaluated by an unexploded ordnance specialist and determined to be “Not HE.”

Note that four of the unexploded ordnance items did not have coordinates but were retained in the database as a conservative measure.

Appendix B
Excavation and Investigation Areas



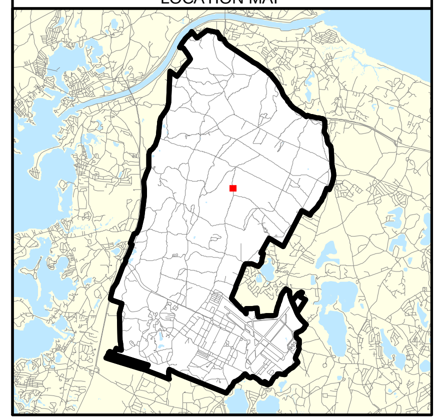
Impact Area
Groundwater Study Program

CIA UXO Data LEGEND

DEPTH

- 0 - 1 ft
- 1 - 2 ft
- 2 - 3 ft
- 3 - 4 ft
- > 4 ft
- Target 25 - 50ftBuffer
- Limits of Soil Excavation Areas

LOCATION MAP



NOTES & SOURCES

Map Projection: NAD 83, UTM, Zone 19N, Meters
Basemap data from US Geological Survey 7 1/2 minute
Topographic Map Source: MassGIS

TITLE

Target 25
Excavation Area
and UXO Discoveries

0 7.5 15 Meters
0 20 40 Feet
N

P:\Terc-JV\TO4\Restricted Files\GIS\Spatial\MXD\RI\
MXD_Verification_073109\
CIA\MXDs\060111 Updates\FigB-1.mxd
Prepared By: Tanya Ambrose

FIGURE
B-1

Impact Area
Groundwater Study Program

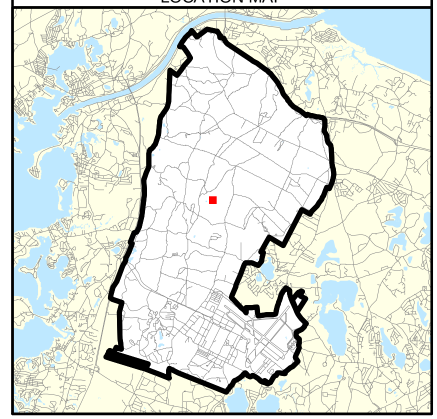
LEGEND

CIA UXO Data

DEPTH

- 0 - 1 ft
- 1 - 2 ft
- 2 - 3 ft
- 3 - 4 ft
- > 4 ft
- Limits of Soil Excavation Areas

LOCATION MAP



NOTES & SOURCES

Map Projection: NAD 83, UTM, Zone 19N, Meters
Basemap data from US Geological Survey 7 1/2 minute
Topographic Map Source: MassGIS

TITLE

Mortar Target 9 Excavation Area and UXO Discoveries

0 7.5 15 Meters
0 20 40 Feet

N

P:\Terc-JV\TO4\Restricted Files\GIS\Spatial\MXD\RI\MXD_Verification_073109\CIA\MXDs\060111 Updates\FigB-2.mxd
Prepared By: Tanya Ambrose

FIGURE
B-2

Impact Area
Groundwater Study Program

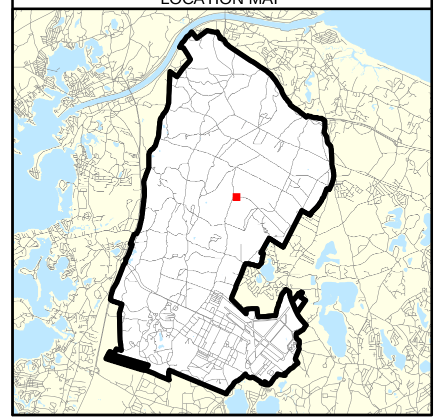
LEGEND

CIA UXO Data

DEPTH

- 0 - 1 ft
- 1 - 2 ft
- 2 - 3 ft
- 3 - 4 ft
- > 4 ft
- Limits of Soil Excavation Areas

LOCATION MAP



NOTES & SOURCES

Map Projection: NAD 83, UTM, Zone 19N, Meters
Basemap data from US Geological Survey 7 1/2 minute
Topographic Map Source: MassGIS

TITLE

Target 23 Excavation Area and UXO Discoveries

0 7.5 15 Meters
0 20 40 Feet

N

P:\Terc-JV\TO4\Restricted Files\GIS\Spatial\MXD\RI\MXD_Verification_073109\CIA\MXDs\060111 Updates\FigB-3.mxd
Prepared By: Tanya Ambrose

FIGURE

B-3

Impact Area Groundwater Study Program

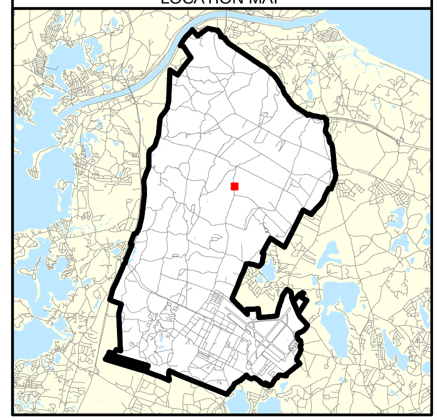
LEGEND

CIA UXO Data

DEPTH

- 0 - 1 ft
- 1 - 2 ft
- 2 - 3 ft
- 3 - 4 ft
- > 4 ft
- Limits of Soil Excavation Areas

LOCATION MAP



NOTES & SOURCES

Map Projection: NAD 83, UTM, Zone 19N, Meters
Basemap data from US Geological Survey 7 1/2 minute
Topographic Map Source: MassGIS

TITLE

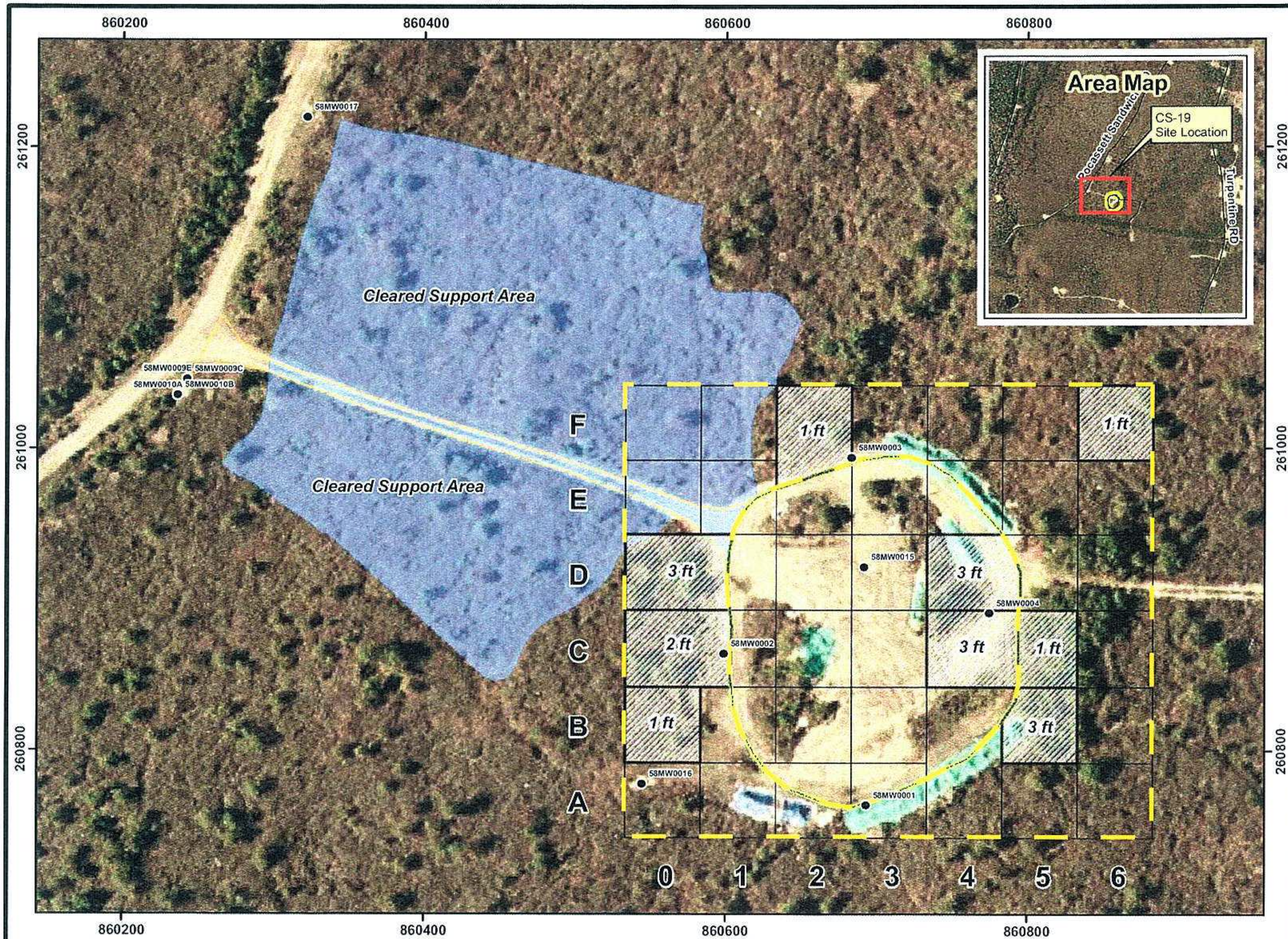
Target 42
Excavation Area
and UXO Discoveries

0 7.5 15 Meters
0 20 40 Feet

N

P:\Terc-JV\TO4\Restricted Files\GIS\Spatial\MXD\RI\
MXD_Verification_073109\
CIA\MXDs\060111 Update\FigB-4.mxd
Prepared By: Tanya Ambrose

FIGURE
B-4



Contract No.	FA8903-04-D-8672-005
Description	Progress Map at CS-19.
Coordinate System	NAD 1927, State Plane, Massachusetts Mainland in feet
Sources	MMR boundary, 2002 aerial digital orthophotos, MA ARNG.

Date	30-SEP-2009	Rev.	Date	Approved
Drawn	C. Guido			
CB	J. Fein			
App.				

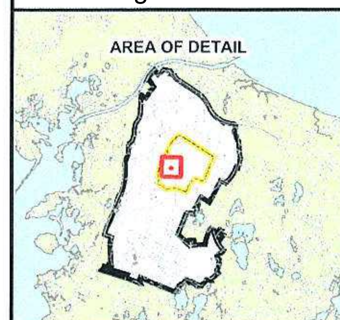
Legend

- Existing Monitoring Wells
- CS-19 Expansion Area
- Excavated Area
- CS-19 Perimeter Boundary
- Cleared Support Area
- CS-19 Access Road

Note: Final excavation depth indicated in feet below ground surface for excavated areas (i.e. 3 ft).

0 30 60 120 Feet

Figure B-5

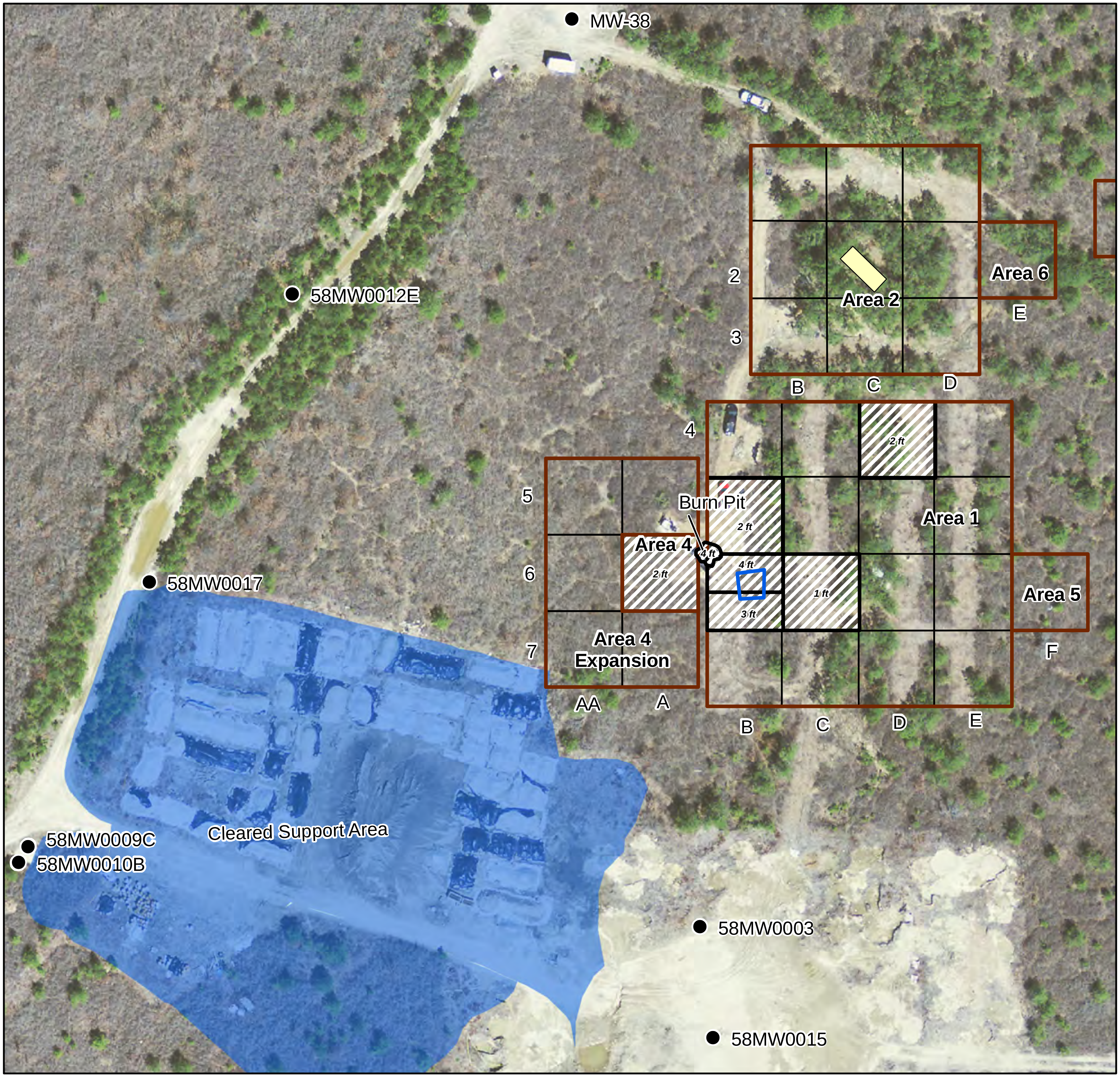


Environmental Chemical Corporation

CS-19 Perimeter Road and Expansion Areas Excavation Map

Air Force Center for Engineering and the Environment
Massachusetts Military Reservation
Cape Cod, Massachusetts

ECC GIS: C:\AFCEE_GIS\CS19\CS19_CERCLA\MapDocuments\CS19_Fig3-7_ExcavDepths.mxd

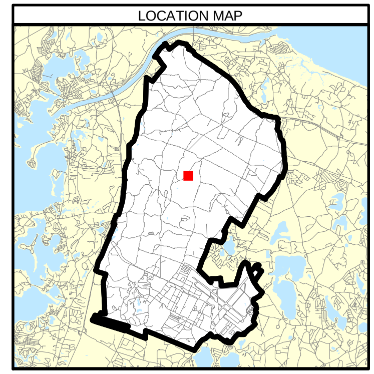


Impact Area
Groundwater Study Program

LEGEND

- Investigation Area
- CS-19 Bunker
- Excavated Area (with Final Excavation Depths)
- Cleared Support Area

LOCATION MAP



NOTES & SOURCES

Map Projection: NAD 83, UTM, Zone 19N, Meters; Basemap data from US Geological Survey 7 1/2 minute; Topographic Map Source: MassGIS; Aerial Photos: Color Digital Orthophotos; Resolution: 6 inch; Date Flown: 2007; Source: MA ARNG; Site geographic data from ECC.

TITLE

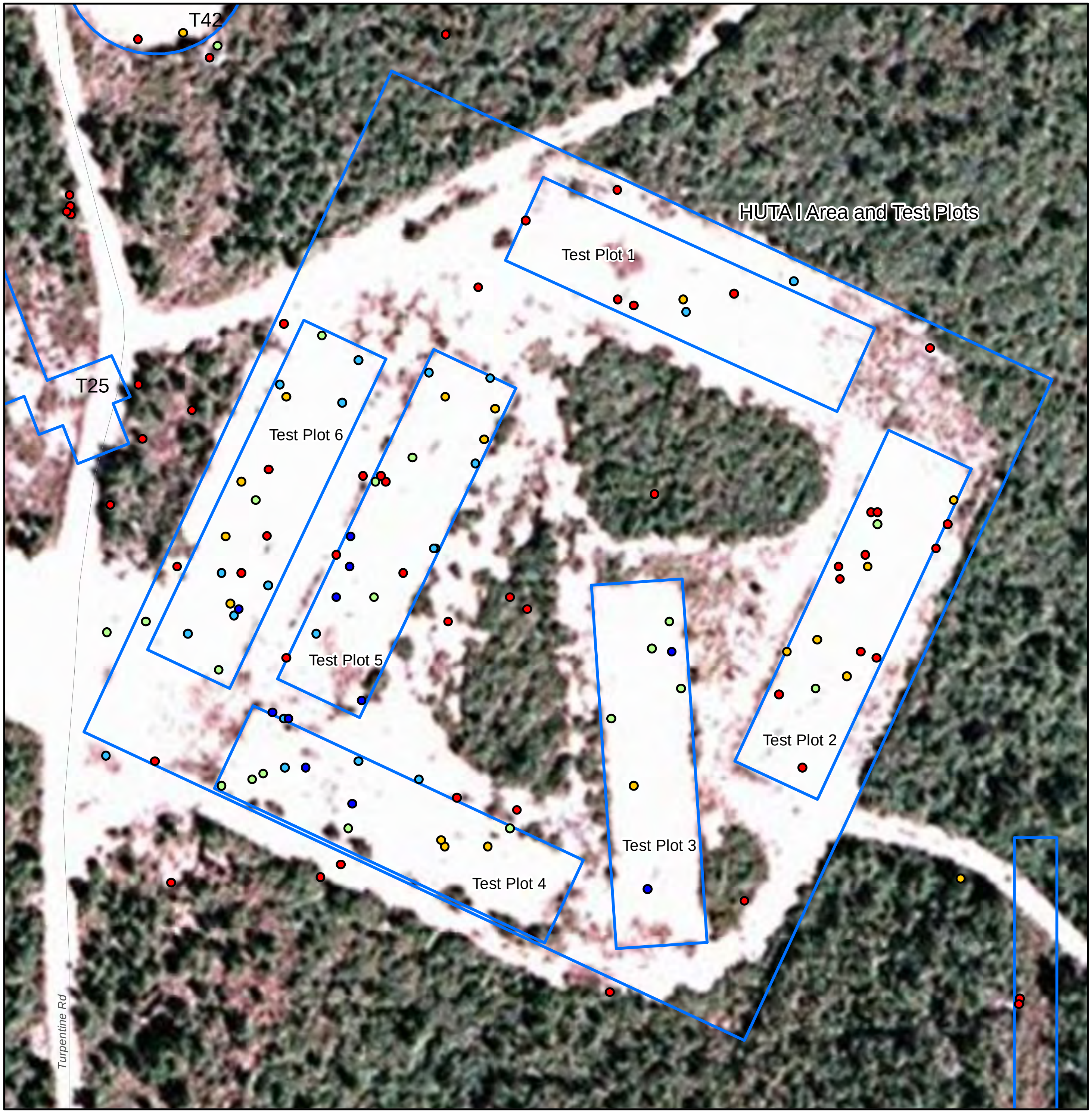
CS-19 Bunker Area
Excavation Map

0 25 50 75 100
Feet

N

File: P:\Terc-JV\TO4\Restricted Files\GIS\Spatial\MXD\RI\MXD_Verification_073109\CIA\MXDs\060111 Updates\FigB-6.mxd
Prepared By: william.scales
Coordinate System: NAD 1927 StatePlane Massachusetts Mainland FIPS 2001

FIGURE
B-6



Impact Area
Groundwater Study Program

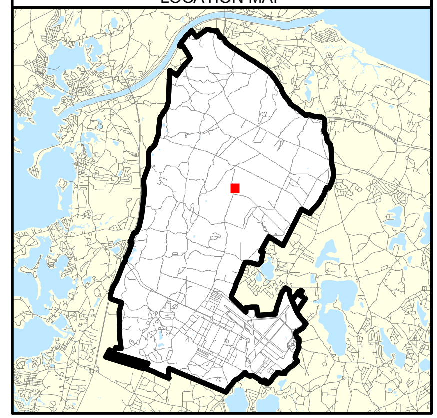
LEGEND

HUTA I UXO Item Locations

DEPTH

- 0 - 1 ft
- 1 - 2 ft
- 2 - 3 ft
- 3 - 4 ft
- > 4 ft
- Limits of Soil Excavation Areas

LOCATION MAP



NOTES & SOURCES

Map Projection: NAD 83, UTM, Zone 19N, Meters
Basemap data from US Geological Survey 7 1/2 minute
Topographic Map Source: MassGIS

TITLE

HUTA I
Excavation Area
and UXO Discoveries

0 7.5 15 Meters
0 20 40 Feet

N

P:\Terc-JV\TO4\Restricted Files\GIS\Spatial\MXD\RI\
MXD_Verification_073109\
CIA\MXDs\060111 Updates\FigB-7.mxd
Prepared By: Tanya Ambrose

FIGURE

B-7

Impact Area
Groundwater Study Program

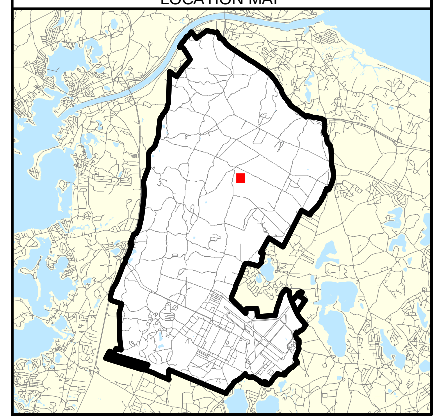
LEGEND

HUTA II Transect 2 UXO Item Locations

DEPTH

- 0 - 1 ft
- 1 - 2 ft
- 2 - 3 ft
- 3 - 4 ft
- > 4 ft
- Limits of Soil Investigation Area

LOCATION MAP



NOTES & SOURCES

Map Projection: NAD 83, UTM, Zone 19N, Meters
Basemap data from US Geological Survey 7 1/2 minute
Topographic Map Source: MassGIS

TITLE

HUTA II Transect 2
Investigation Area
and UXO Discoveries

0 7.5 15 Meters
0 20 40 Feet

N

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MXD_Verification_073109\
CIA\MXDs\060111 Updates\FigB-8.mxd
Prepared By: Tanya Ambrose

FIGURE
B-8

Impact Area Groundwater Study Program

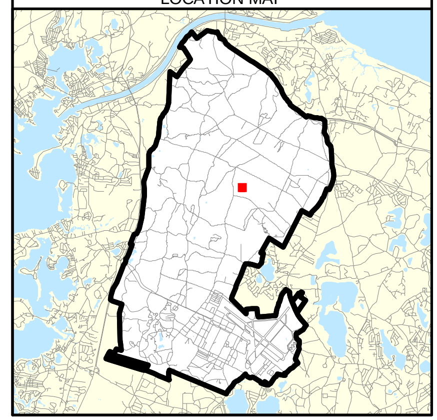
LEGEND

HUTA II Transect 3 UXO Item Locations

DEPTH

- 0 - 1 ft
- 1 - 2 ft
- 2 - 3 ft
- 3 - 4 ft
- > 4 ft
- Limits of Soil Investigation Areas

LOCATION MAP



NOTES & SOURCES

Map Projection: NAD 83, UTM, Zone 19N, Meters
Basemap data from US Geological Survey 7 1/2 minute
Topographic Map Source: MassGIS

TITLE

HUTA II Transect 3 Investigation Area and UXO Discoveries

0 7.5 15 Meters
0 20 40 Feet

N

P:\Terc-JV\TO4\Restricted Files\GIS\Spatial\MXD\RI\
MXD_Verification_073109\
CIA\MXDs\060111 Updates\FigB-9.mxd
Prepared By: Tanya Ambrose

FIGURE

B-9

Impact Area Groundwater Study Program

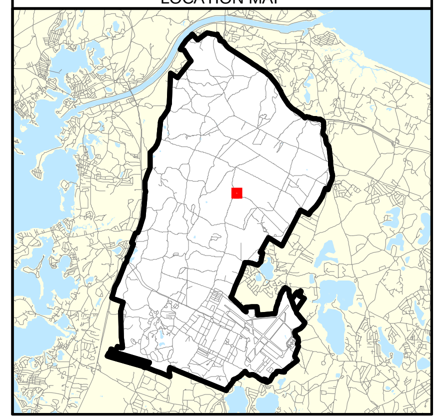
LEGEND

HUTA II Transect 4 UXO Item Locations

DEPTH

- 0 - 1 ft
- 1 - 2 ft
- 2 - 3 ft
- 3 - 4 ft
- > 4 ft
- Limits of Soil Investigation Areas

LOCATION MAP



NOTES & SOURCES

Map Projection: NAD 83, UTM, Zone 19N, Meters
Basemap data from US Geological Survey 7 1/2 minute
Topographic Map Source: MassGIS

TITLE

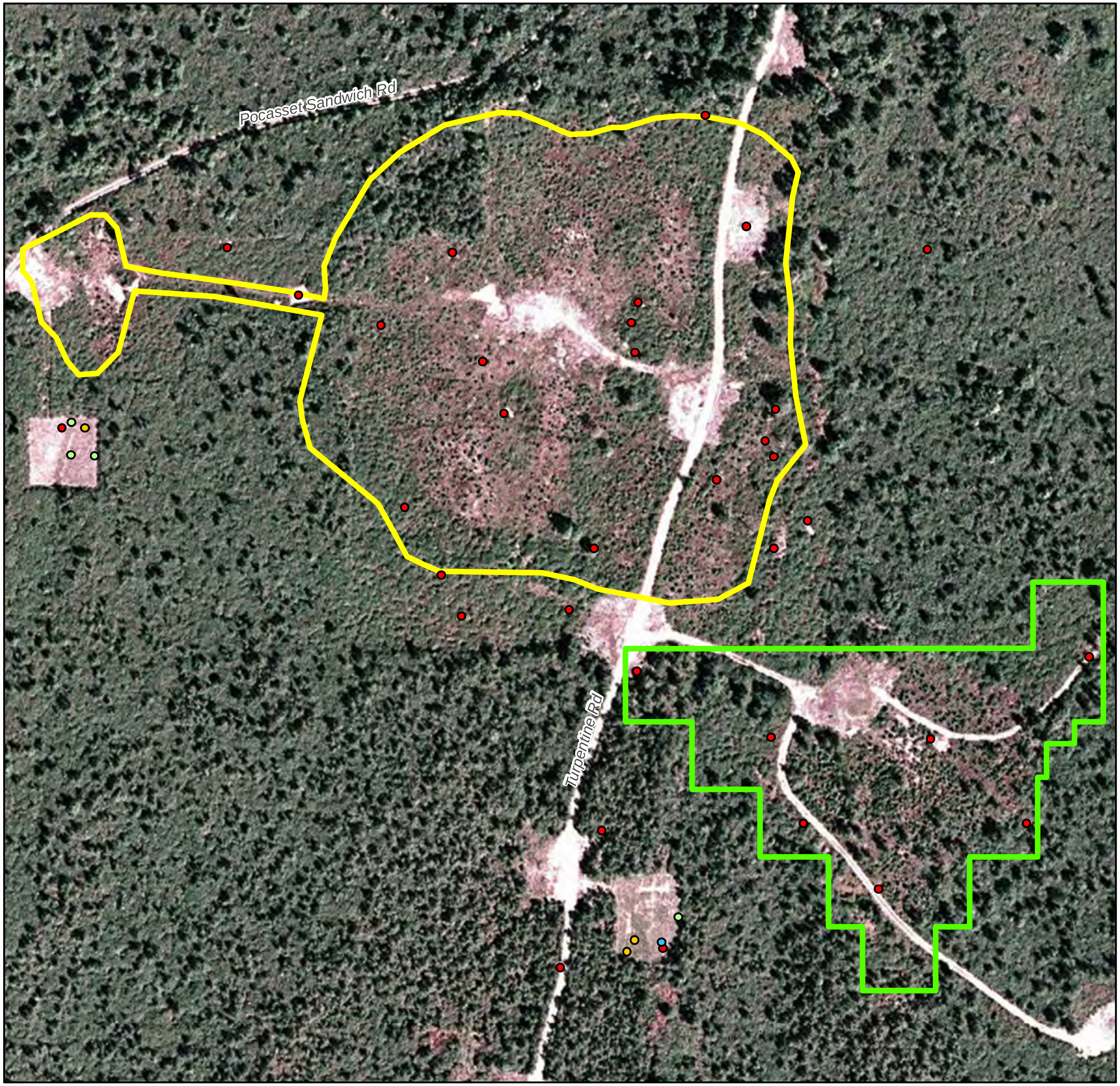
HUTA II Transect 4
Investigation Area
and UXO Discoveries

0 7.5 15 Meters
0 20 40 Feet

N

P:\Terc-JV\TO4\Restricted Files\GIS\Spatial\MXD\RI\
MXD_Verification_073109\
CIA\MXDs\060111 Updates\FigB-10.mxd
Prepared By: Tanya Ambrose

FIGURE
B-10



Impact Area
Groundwater Study Program

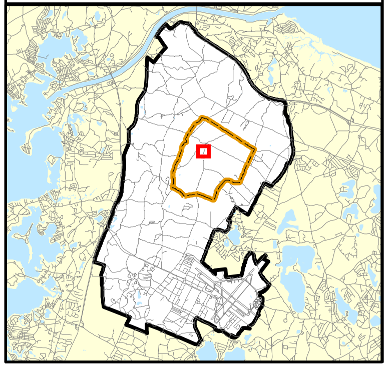
LEGEND

SCAR & ETS UXO Item Locations

DEPTH

- 0 - 1 ft
- 1 - 2 ft
- 2 - 3 ft
- 3 - 4 ft
- > 4 ft
- ETS Site
- SCAR Site

LOCATION MAP



NOTES & SOURCES

Map Projection: NAD 83, UTM, Zone 19N, Meters
Basemap data from US Geological Survey 7 1/2 minute
Topographic Map Source: MassGIS

TITLE

UXO Discoveries SCAR and Eastern Test Sites

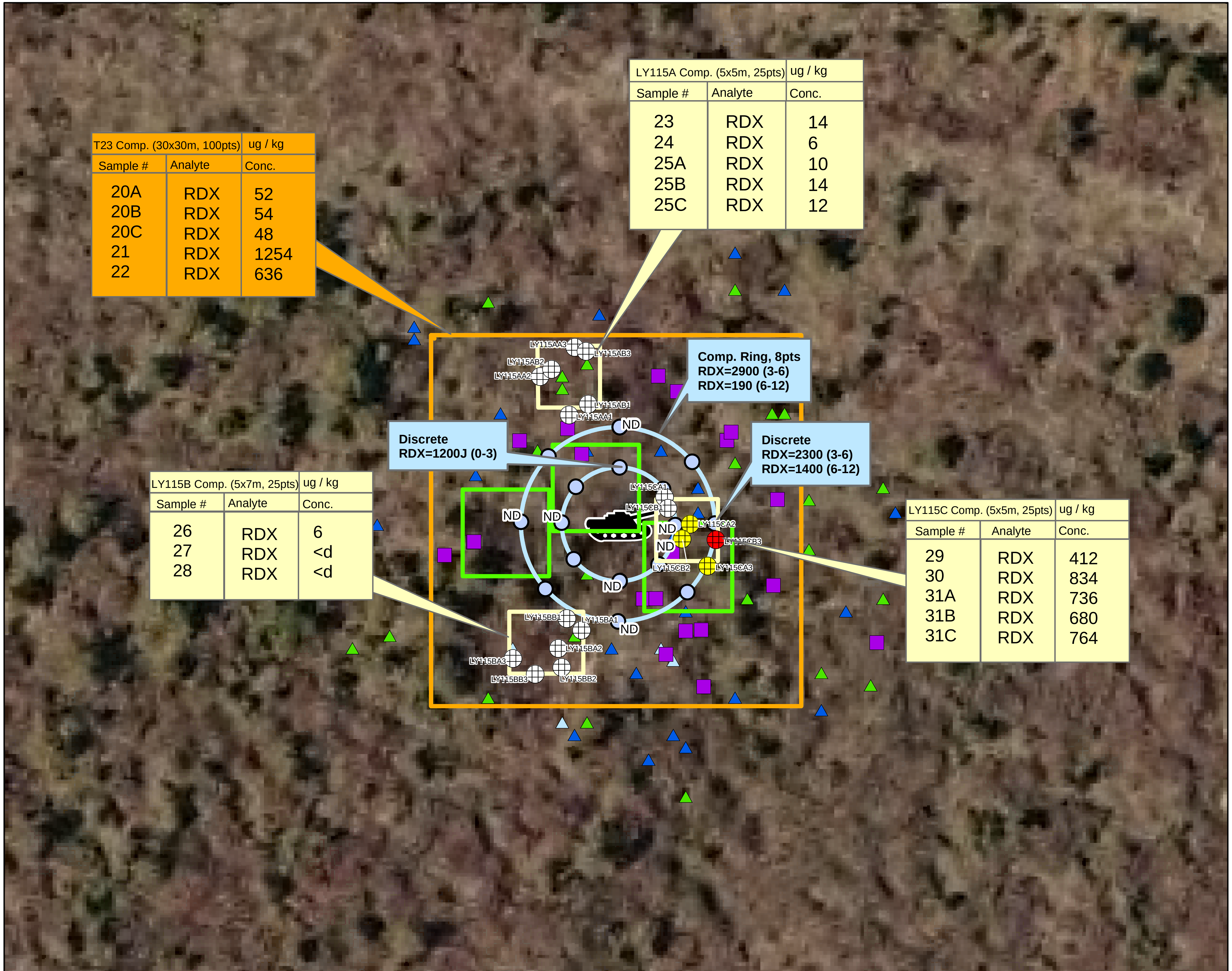
0 35 70 140 210 280 Feet

N

P:\Terc-JV\TO4\Restricted Files\GIS\Spatial\MXD\RI\
MXD_Verification_073109\
CIA\MXDs\060111 Updates\FigB-11.mxd
Prepared By: Tanya Ambrose

FIGURE

B-11



Impact Area Groundwater Study Program

LEGEND

- Target
- UXO

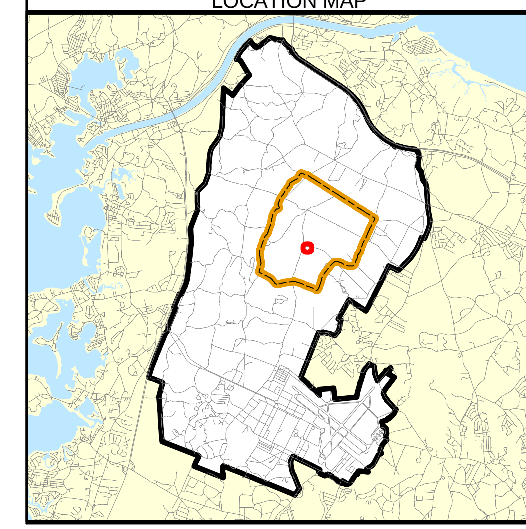
Munitions Debris

- Fuse
- 155MM LITR
- 81mm Illum
- Comp. Grid (30 x 30m, 100pts)
- Comp. Grid (3 to 5 x 5m, 25pts)
- Non-Detect Comp. Grid (7 x 7m, 5pts)
- Ring Grids (8pt composites)
- Discrete Sample Points

Maximum RDX Detections in Lysimeters

- Non-detect
- 0.1 ppb to less than 10 ppb
- 10 ppb to less than 100 ppb
- Greater than 100 ppb

LOCATION MAP



NOTES & SOURCES

Map Coordinates: NAD 83, UTM, Zone 19N, Meters
Basemap data from US Geological Survey 7 1/2 minute
Topographic Maps. Source: MassGIS
Aerial Photos: Color Digital Orthophotos; Date Flown: 2002
Source: EarthData International

TITLE

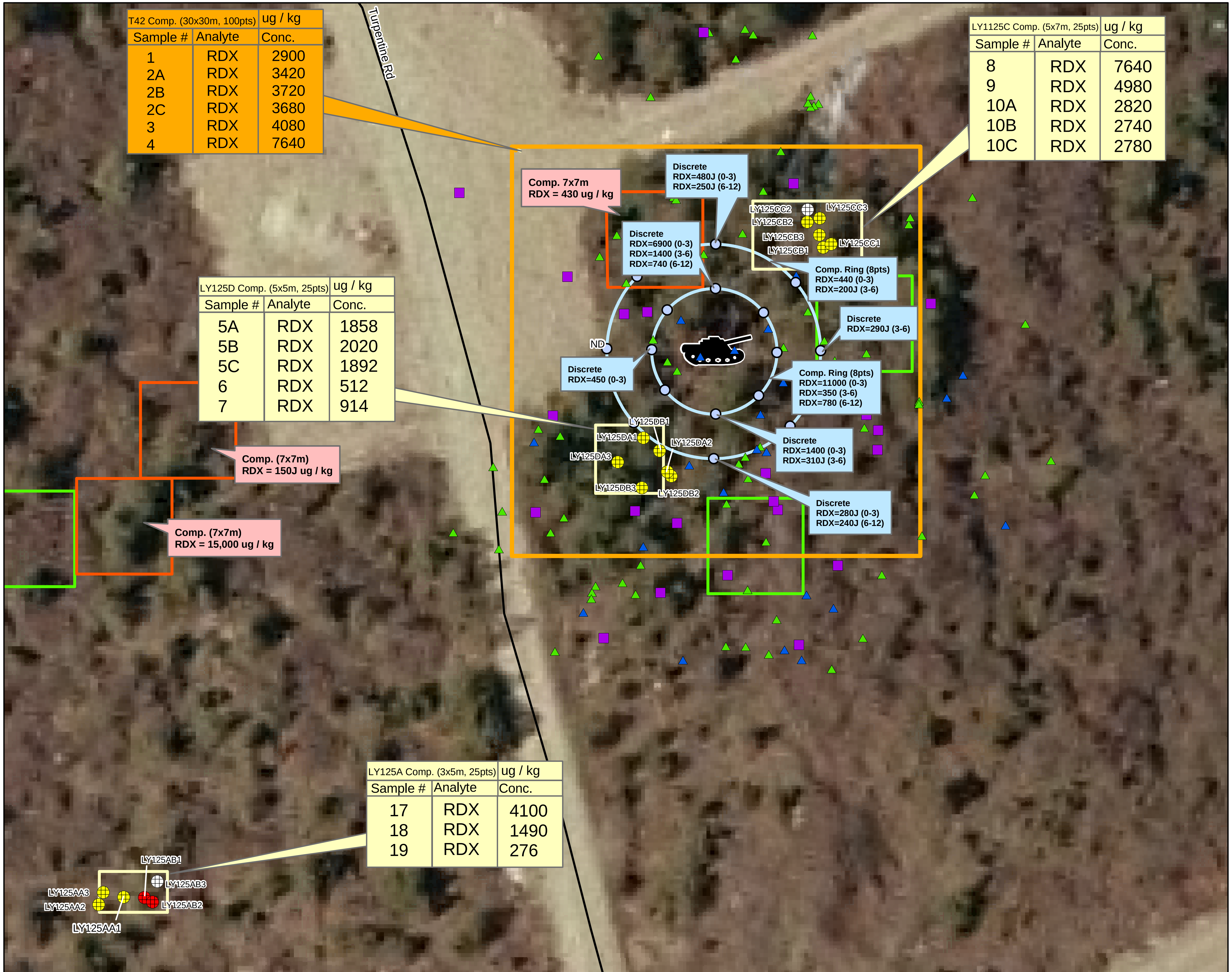
Lysimeter Results
and Munition Items
at Target 23

0 25 Feet

AMEC Earth and Environmental, Inc.
Westford, Massachusetts

J:/mmr/ReportFigs2004/C351/C351_T23.pdf
G:/MMR_COE/Work2004/C351/C351_T23.mxd
February 2, 2005 DWN BY: AP JBB ABF CHKD BY: CAH

FIGURE B-12



T42 Comp. (30x30m, 100pts)		ug / kg
Sample #	Analyte	Conc.
1	RDX	2900
2A	RDX	3420
2B	RDX	3720
2C	RDX	3680
3	RDX	4080
4	RDX	7640

LY1125C Comp. (5x7m, 25pts)		ug / kg
Sample #	Analyte	Conc.
8	RDX	7640
9	RDX	4980
10A	RDX	2820
10B	RDX	2740
10C	RDX	2780

LY125D Comp. (5x5m, 25pts)		ug / kg
Sample #	Analyte	Conc.
5A	RDX	1858
5B	RDX	2020
5C	RDX	1892
6	RDX	512
7	RDX	914

LY125A Comp. (3x5m, 25pts)		ug / kg
Sample #	Analyte	Conc.
17	RDX	4100
18	RDX	1490
19	RDX	276

Impact Area Groundwater Study Program

LEGEND

- Target
- UXO

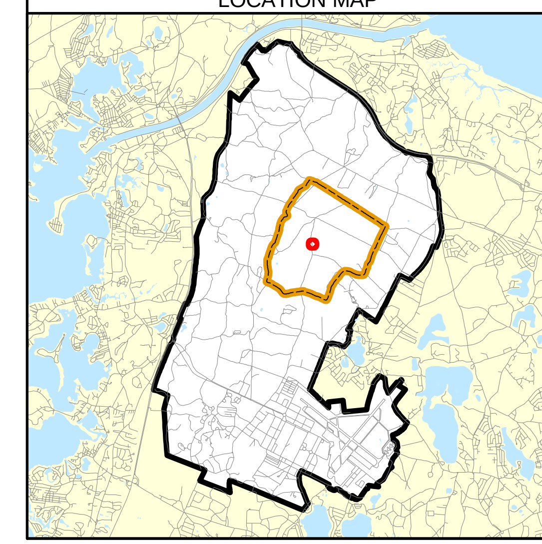
Munitions Debris

- Fuse
- 155MM LITR
- 81mm Illum
- Comp. Grid (30 x 30m, 100pts)
- Comp. Grid (3 to 8 x 5m, 25pts)
- Detect Comp. Grid (7 x 7m, 5pts)
- Non-Detect Comp. Grid (7 x 7m, 5pts)
- Ring Grids (8pt composites)
- Discrete Sample Points

Maximum RDX Detections in Lysimeters

- Non-detect
- 0.1 ppb to less than 10 ppb
- 10 ppb to less than 100 ppb
- Greater than 100 ppb

LOCATION MAP



NOTES & SOURCES

Map Coordinates: NAD 83, UTM, Zone 19N, Meters
Basemap data from US Geological Survey 7 1/2 minute
Topographic Maps. Source: MassGIS
Aerial Photos: Color Digital Orthophotos; Date Flown: 2002
Source: EarthData International

TITLE

Lysimeter Results and Munition Items at Target 42

0 25 Feet

N

AMEC Earth and Environmental, Inc.
Westford, Massachusetts

J:/mmr/ReportFigs2004/C351/C351_T42.pdf
G:/MMR_COE/Work2004/C351/C351_T42.mxd
November 8, 2004 DWN BY: AP JBB CHKD BY: CAH ABF

FIGURE B-13