COST AND PERFORMANCE REPORT

MAECTITE® Technology at the
Massachusetts Military Reservation,
Training Range and Impact Area
Cape Cod, Massachusetts

November 2000

U.S. Environmental Protection Agency
Office of Solid Waste and Emergency Response
Technology Innovation Office

SITE INFORMATION

IDENTIFYING INFORMATION

Site Name: Massachusetts Military Reservation, Training Range and Impact Area

Location: Cape Cod, MA

Regulatory Context: Administrative Order under Safe Drinking Water Act, Section 1431 (a)

TECHNOLOGY APPLICATION

Period of Operation: February 1998 through June 1998

Quantity of Material Treated during Application: 23,168 cubic yards of soil; consisting of 17,788 cubic yards treated *ex situ* (27,952 tons), and 5,380 cubic yards treated *in situ* [5]

BACKGROUND [5, 8, 9]

Waste Management Practice That Contributed to Contamination: Use of lead bullets at firing ranges

Site History: The Massachusetts Military Reservation (MMR), founded by the Commonwealth of Massachusetts in 1935 as a National Guard training camp and federalized in 1940 to prepare for World War II, currently houses Otis Air National Guard Base, U.S. Coast Guard Air Station Cape Cod, and Army National Guard Camp Edwards. MMR covers 34 square miles of upper Cape Cod (approximately 22,000 acres), and borders the towns of Bourne, Falmouth, Mashpee and Sandwich, Massachusetts.

From the 1940's to the 1970's, the time of MMR's heaviest military activity, large amounts of hazardous waste were generated. The common disposal practice for many years was to dispose of such wastes by landfilling, dumping in storm drains, dumping and burning wastes in fire training areas, or dumping them on the ground. In the U.S. Environmental Protection Agency's Administrative Order (Findings of Fact), concentrations of lead in soil in the Training Range and Impact Area and groundwater (in a well near the Impact Area) were reported as high as 1,830 mg/kg and 17 ug/L, respectively.

MMR was placed on EPA's Superfund National Priority List in 1989, and has 78 pollution source areas currently identified and 10 major groundwater pollution plumes moving at approximately 1.5 to 2 feet per day. The reservation sits atop the recharge area for the sole source groundwater aquifer from which all of upper Cape Cod draws its drinking water.

The Training Range and Impact Area includes 16 small arms firing ranges (training ranges). Bullets used at the ranges contain a lead core in a metal alloy jacket, usually composed of lead, copper, iron, antimony, and nickel. Berms constructed behind targets at the ranges to capture bullets and fragments of bullets behind targets became contaminated with lead. In addition, unexploded ordnance (UXO) has been found in the Training Range and Impact Area, including RDX and TNT.

Investigations of the area determined that the lead contamination was concentrated in the berms, with lead levels as high as 12,200 mg/kg. Remediation focused on berms that had bullet fragments and lead found in leachate at levels higher than the Toxicity Characteristic Leaching Procedure (TCLP) limit of 5 mg/L. Remediation consisted of *ex situ* and *in situ* processing of lead in the berms, including tearing down portions of the berms when necessary and stabilization (chemical fixation) of the lead-contaminated soil in the berms. This report addresses the chemical fixation using MAECTITE® of the berms at the 16 small arms ranges within the Training Range and Impact Area of MMR.

SITE LOGISTICS/CONTACTS

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MATRIX DESCRIPTION

MATRIX IDENTIFICATION

Type of Media Treated With Technology System: Soil (from small arms firing range berms)

CONTAMINANT CHARACTERIZATION

Primary Contaminant Groups and Concentrations Measured During Site Investigation [5, 9]:
Lead is the primary contaminant in the small arms firing range berms at the Training Range and Impact Area. It was estimated that approximately 12,000 pounds of lead would accumulate during each year of operation in the berm of a single small arms range.

Table 1 provides a summary of the maximum concentrations of lead in the 16 small arms berms at MMR before treatment with MAECTITE®. Samples contained total lead as high as 12,200 mg/kg, and TCLP leachable lead as high as 734.1 ug/L. The maximum concentrations of other metals found in berm soil samples were total copper - 191 mg/kg; total iron - 15,000 mg/kg; total nickel - 78 mg/kg; and total antimony - 59.8 mg/kg.

Table 1. Maximum Concentrations for Lead in Soil at Selected Ranges - Before Treatment* [5]

Range	Total Lead (mg/kg)	TCLP Leachable Lead (mg/L)
A	2,119	84.29
B	11,546	734.1
C	1,339.7	67.1
D	5,003	250.3
E	290.8	6.2
G	12,200	525
H	4,063	474.6
I	9,569	325.3
J	5,090	251
K	4,450	315
KD	130	3.1
N	2,763	43.8
O	2,392	126
P	1,189.9	32.8
SE	147.9	3.4
SW	2,607	0.9

* There were 1,125 samples of berm soil collected and analyzed for total lead and TCLP lead (referred to as "pre-excavation" samples). One hundred sixty pre-excavation samples were collected to characterize other metals in the soil, including total copper, total iron, total nickel, and total antimony. There were 286 samples of soil that was excavated from the berms (referred to as "post-excavation" samples) collected to characterize TCLP leachable lead in the excavated soil and to confirm compliance with the Administrative Order. The data shown on this table corresponds to the highest value from pre-excavation or post-excavation samples for each individual range.

MATRIX CHARACTERISTICS AFFECTING TECHNOLOGY COST OR PERFORMANCE [5, 11]

The following table summarizes information about the characteristics of the small arms berms in the Training Range and Impact Area.

Parameter	Value
Soil Classification	Sandy
Clay Content and/or Particle Size Distribution	Soil included stones and other oversize materials captured on 6-inch, 2-inch, and no. 4 screens
Moisture Content	Information not provided
pH	5.0 - 6.5
Total Organic Carbon	Information not provided
Oil and Grease or Total Petroleum Hydrocarbons	Information not provided

SITE GEOLOGY/STRATIGRAPHY [5]

MMR rests on top of the Cape Cod Aquifer which is designated as a "sole source" of drinking water for Cape Cod residents. The layer overlaying the shallow aquifer is highly permeable, sandy soils. As a result of the high permeability of the soils, most of the MMR area serves as a recharge zone for the aquifer.

The Cape Cod aquifer is in the Sagamore lens. MMR affects as much as 80 percent of this lens which is the main source identified to meet future drinking water capacity of Cape Cod. The groundwater flow in the Cape Cod Aquifer moves at 1 to 3 feet per day.

TECHNOLOGY SYSTEM DESCRIPTION

PRIMARY TECHNOLOGY

MAECTITE® (*ex situ* and *in situ* chemical fixation)

SUPPLEMENTAL TECHNOLOGY TYPES

None

SYSTEM DESCRIPTION AND OPERATION [5, 11]

System Description

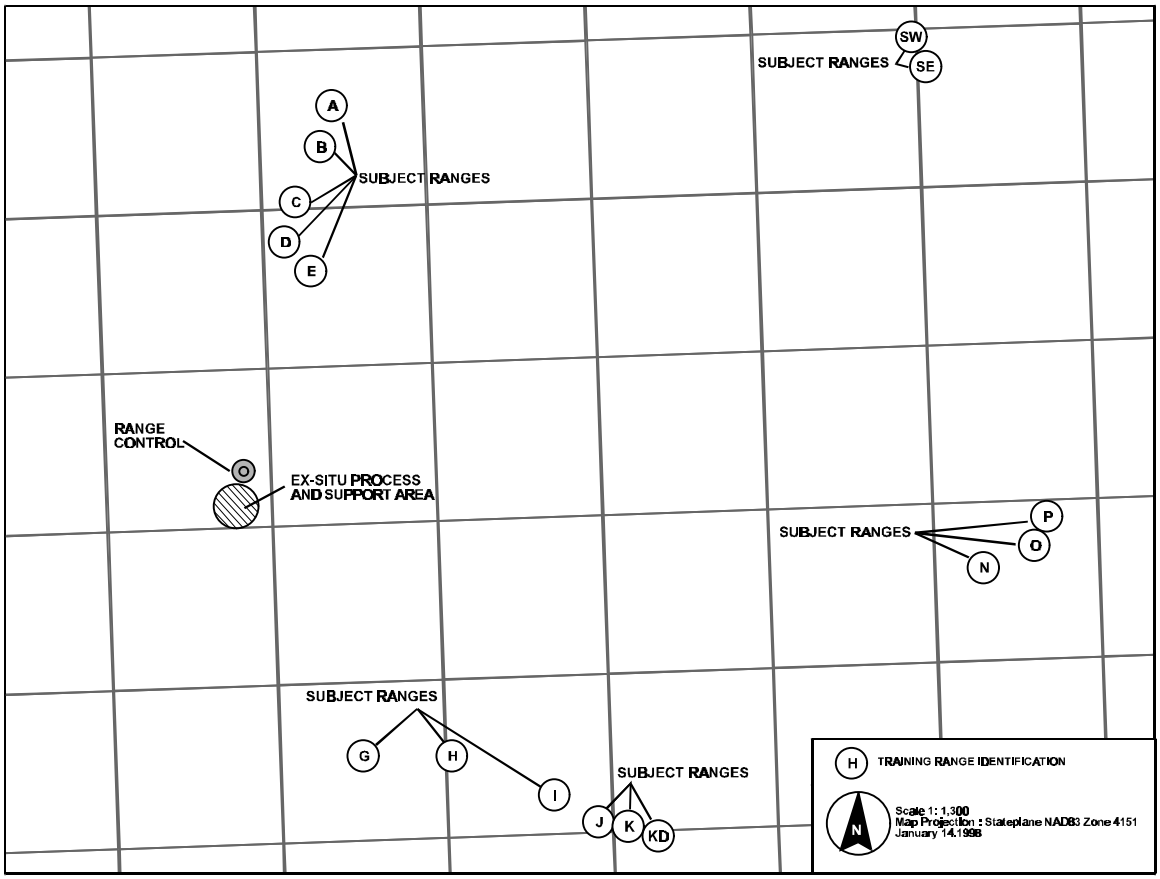
MAECTITE® technology was used to immobilize leachable lead at the berms through chemical fixation. The liquid reagent was applied to the soil and reacted with the lead to produce a geochemically stable synthetic mineral crystal, primarily apatites and mixed apatite-barite minerals, that remained in the soil matrix. According to the vendor, pH does not impact the ability of the MAECTITE® to keep the reaction products insoluble. Contaminated soil was treated with MAECTITE® technology in both *ex situ* and *in situ* applications.

The MAECTITE® process is a proprietary technology of Sevenson, and is covered by several U.S. patents. Information was not provided on the type of chemicals that comprise MAECTITE®.

System Operation

Sixteen small arms ranges within the Training Range and Impact Area were addressed during this application. The ranges were identified as A through E, G through K, KD, N, O, P, SE, and SW, as shown on Figure 1. Appendix A to this report provides a flow chart, prepared by Sevenson, that shows how soil was identified for *ex situ* or *in situ* treatment. Berm soil was excavated and treated *ex situ* when a visual analysis showed the presence of recoverable bullet fragments. Soil remaining in the berms that did not contain bullet fragments but still had a TCLP lead concentration of greater than 5.0 mg/L was treated *in situ*.

Figure 1. Relative Locations of the 16 Training Ranges [5]



<u>*Ex Situ* Treatment</u>

Berm soils with bullet fragments, determined through visual observation, and with TCLP leachable lead concentrations greater than 5.0 mg/L, determined through sampling and analysis, were excavated and transported to the Central Processing Area (shown on Figure 1 as *Ex Situ* Process and Support Area) for treatment. The excavated soils were screened to separate bullet fragments, which were recycled.

There were several delays during soil excavation due to concerns about the presence of unexploded ordnance (UXO) and buried drums. Soil excavation was delayed at Range I (UXO), J (buried drums), and O (suspected UXO related material).

The *ex situ* treatment equipment used at MMR was housed in an enclosed building. Excavated soils were dumped in a pre-processing soil stockpile area; the stockpile area was sprayed with MAECTITE® before the soils were dumped. A dozer pushed the material into a stockpile, and composite samples of the stockpile were collected and analyzed for TCLP leachable lead. The purpose for the pre-processing sampling and analysis was to confirm that the soils to be processed were within an acceptable range of TCLP lead concentrations for the dose rate to be used in the MAECTITE® process.

The pre-processed soil stockpile was fed into the first section of the screening plant using a track excavator. This section consisted of a 6-inch shredder unit; soil was fed into this unit from the top. Oversize rocks were removed by this step and stockpiled elsewhere on site. Material passing through the 6-inch screen moved via conveyor to the top of a screening stack, which consisted of a 2-inch screen and a number 4 screen. Oversize material from the 2-inch screen (stones) were stockpiled separately. Oversize material from the no. 4 screen (bullet fragments, bullet jacketing, small stones) was recycled by site personnel or stockpiled separately.

Soil that passed the 2-inch and no. 4 screens was fed into a pug mill hopper. From the hopper, material was fed onto an inclined conveyor/weight belt for feed measurement and control, and then treated in the pug mill. Liquid MAECTITE® reagents and water were added, along with a proprietary powder, for blending in the pug mill. The chemically-treated material was discharged from the end of the pug mill onto the ground and taken by a rubber-tired loader to post-processing soil stockpile locations. Information was not provided on the form of the material after *ex situ* treatment using MAECTITE®. After treatment, soil was stockpiled on site and used in reconstructing berms.

A total of 17,788 cubic yards of soil were treated *ex situ*, consisting of 400-600 tons of soil treated per day.

In Situ Treatment

In berm areas where TCLP leachable lead concentrations were greater than 5.0 mg/L, but where bullet fragments were not visibly present, *in situ* treatment was performed. *In situ* treatment was performed at 12 of the ranges - Ranges A through D, G through K, and N through P. *In situ* treatment consisted of spraying liquid MAECTITE® reagents on a section of the soil in the berm (if this section required treatment), or by pulling down a section of the berm into the area in front of the berm and spraying liquid MAECTITE® reagents on that soil. Reagents and soil were blended using a track excavator. The depth of blending ranged from 9 inches on the slopes of the berms to 24 inches on more level terrain.

The maximum penetration into a berm to treat soils *in situ* was 18 ft at Range K. This was the distance perpendicular to the original face of the berm that was pulled down and treated. Other ranges that required *in situ* treatment to depths greater than originally anticipated included Ranges B (12 ft), H (14 ft), and I (12 ft). Information was not provided about reconstruction of the berms that had been pulled down.

A total of 5,380 cubic yards of soil were treated *in situ*, consisting of 100-200 cubic yards of soil per day, and from 57 to 1,974 cubic yards per range.

OPERATING PARAMETERS AFFECTING TECHNOLOGY COST OR PERFORMANCE [5, 11]

Parameter	Value	
	Ex situ	***In situ***
System Throughput	1,300 tons per day (maximum) 400-600 tons per day (typical)	511 yds^3 per day (maximum) 100-200 yds^3 per day (typical)
Temperature	ambient	ambient
MAECTITE® Dosage	< 10%	< 10%
Curing Time	4 hours	4 hours
Compressive strength	Not measured	Not measured
Volume increase	< 5%	< 5%
Permeability	Not measured	Not measured
Depth (feet)	Not applicable	24 inches

TIMELINE [5, 11, 12]

- 4/10/97 Administrative Order issued by EPA to National Guard Bureau
- 6/17/97 National Guard Bureau agrees to comply with Administrative Order
- 8/29/97 Draft Work Plan submitted to EPA by Ogden and Sevenson
- 12/24/97 Conditional approval of Work Plan provided by EPA
- 1/21/98 Beginning of site mobilization
- 1/30/98 Final Approval of Work Plan provided by EPA
- 2/16/98 Pre-excavation sampling
- 2/27/98 Excavation, transport, and *ex situ* treatment operations commence
- 3/19/98 *In situ* treatment commences
- 6/8/98 *In situ* treatment completed
- 6/11/98 Completion of excavation, transport, and *ex situ* treatment operations
- 6/26/98 Completion of demobilization

TECHNOLOGY SYSTEM PERFORMANCE

CLEANUP GOALS/STANDARDS [5, 9]

The Administrative Order required that a schedule and work plan be developed to include the following:

1. A project objective of removing the maximum amount of lead munitions from the soil
2. Any necessary bench or field testing
3. A schedule for initiation and completion of lead munitions removal activities
4. Recycling the removed lead munitions, as appropriate
5. Use of soil modifiers to minimize prospective bullet corrosion and lead migration
6. Coordination between lead munitions removal activities, and the installation and use of flexible membrane liners on all berms.

According to the Completion of Work report, a cleanup goal was established as a TCLP leachable lead concentration in soil of <5.0 mg/L.

PERFORMANCE DATA [5]

Table 2 provides a summry of performance data for *ex situ* treatment of soils by MAECTITE® for each of 56 batches of soil (each batch consisted of approximately 500 tons of treated soil). As shown in Table 2, all 56 batches of soil met the cleanup goal of a TCLP leachable lead concentration of <5.0 mg/L, and retreatment was not required. In addition, 96% of the samples of *ex situ* treated soil had a TCLP leachable lead concentration of <0.5 mg/L (one order of magnitude lower than the cleanup goal).

Table 2. Summary of Performance Data for *Ex situ* Treatment of Soils by MAECTITE® [5]

Batch ID (TSP-)	TCLP Leachable Lead (mg/L)	Total Lead (mg/kg)
02 - 05, 07 - 35, 37 - 56	<0.5	<50 to 2,839
01	0.316	1,600
06	0.784	1,985.8
36	1.615	309.8

Table 3 provides a summary of the performance data for *in situ* treatment of soils by MAECTITE® for each of 29 sample locations of treated soil. As shown in Table 3, all 29 sample locations met the cleanup goal of a TCLP leachable lead concentration of <5.0 mg/L, and retreatment was not required. In addition, 97% of the samples of *in situ* treated soil had a TCLP leachable lead concentration of <0.5 mg/L (one order of magnitude lower than the cleanup goal).

Table 3. Summary of Performance Data for *In situ* Treatment of Soils by MAECTITE® [5]

Sample ID (TS-)*	TCLP Leachable Lead (mg/L)	Total Lead (mg/kg)
A-01, B-01 - B-07, C-01, D-01, G-02, H-01 - H-06, I-01 - I-05, J-01 - J-02, K-01, N-01, O-01, P-01	<0.5	<50 to 1,371.5
G-01	0.526	1,036.1

* The letter designation (e.g., A, in A-01) corresponds to the Range identifier.

Ambient air monitoring was conducted from February 27, 1998 to June 2, 1998, at up-wind and down-wind locations at several areas, including ranges and processing areas. Ambient air was collected and analyzed for total lead. The analytical data for 26 sampling dates (unique combinations of location and date) indicates that the down-wind concentration of total lead was consistently less than or equal to the up-wind concentration, with concentrations typically less than detection limit (detection limits varied from 0.0003 to 0.05 mg/m^3). [5]

PERFORMANCE DATA QUALITY [5, 11]

Soil samples were analyzed for TCLP leachable lead using EPA SW-846, Method 1311, followed by Method 7420 in the on-site laboratory, and followed by Method 6010 in an off-site certified laboratory. Ambient air monitoring samples were analyzed by Philip Analytical Services in Reading, Pennsylvania, using either NIOSH Method No. 7105 or ID 121. The available references do not identify any deviations from the analytical QA/QC protocols.

COST OF THE TECHNOLOGY SYSTEM

PROCUREMENT PROCESS [12]

The MAECTITE® process was evaluated by the Army National Guard, bench tested on MMR range soils, and presented to stakeholders at Impact Area Groundwater Study meetings. Sevenson Environmental Services performed the range maintenance project described in this report as a subcontractor to Ogden Environmental and Energy Services, the supervisory contractor named in the SDWA order governing this work.

COST DATA [3, 11]

The actual costs for this application were provided by the National Guard, in the form of an invoice from Ogden dated May 11, 1999, under contract number DAHA-90-94-D-0005, Delivery Order #108. This invoice showed a cumulative billing of $3,945,016, which includes mobilization, excavation, treatment, and other items. Table 4 summarizes the costs for this application. Cost data presented for capital and operation and maintenance (O&M) of the stabilization technology application were used to calculate unit cost. In addition, Table 4 includes other technology-specific costs and other project costs.

The total cost for the MAECTITE® application for the treatment of 23,168 cubic yards of contaminated soil from the small arms berms at MMR was $3.9 million, including $3.5 million in capital and $0.4 million for excavation (other technology-specific costs). The calculated unit cost for this application was $151 per cubic yard of soil (based on a total of 23,168 cubic yards of treated soil).

Sevenson reported that their actual cost for the MAECTITE® application was $2,974,126. This amount is included in the total amount invoiced by Ogden, and shown in Table 4.

Table 4. Actual Project Costs [3]

Cost Category/Element	Cost (1998 $ Basis)	Cost for Calculating Unit Cost ($)
1. Capital Cost for Technology		
Technology mobilization, setup, and demobilization - mobilization (plus travel)	913,636	
Planning and preparation - work plan - negotiation support (plus travel) - meetings and briefings (plus travel) - reports (plus travel)	43,169 25,264.49 85,930.35 125,171	
Site work - survey of berms (plus travel) - berm reconstruction (plus travel)	29,001 70,129	
Equipment and appurtenances - treatment of berms - decontamination	2,182,424.55 31,846	
Startup and testing	0	
Other (Includes nonprocess equipment)	0	
TOTAL CAPITAL COSTS		3,506,571.39

Table 4. Actual Project Costs [3] (continued)

Cost Category/Element	Cost (1998 $ Basis)	Cost for Calculating Unit Cost ($)
2. O&M for Technology**		
Labor	0	
Materials	0	
Utilities and fuel	0	
Equipment ownership, rental, or lease	0	
Performance testing and analysis	0	
Other (Includes nonprocess equipment overhead and health and safety)	0	
TOTAL OPERATION AND MAINTENANCE COSTS		0
3. Other Technology-Specific Costs		
Compliance testing and analysis	0	
Soil, sludge, and debris excavation, collection, and control - excavation of berms	438,445	
Disposal of residues		
4. Other Project Costs	0	
Total cost (year basis for cost)	3,945,016.39	
Total cost for calculating unit cost		3,506,571.39
Quantity treated		23,168 cubic yards of soil
Calculated unit cost		151/cubic yard of soil treated

OBSERVATIONS AND LESSONS LEARNED

COST OBSERVATIONS AND LESSONS LEARNED

The MAECTITE® chemical fixation technology used at MMR had a capital cost of approximately $3.5 million, which corresponds to a unit cost of $151 per cubic yard of soil treated, for treatment of 23,168 cubic yards of soil. This included costs for *ex situ* and *in situ* treatment of berms, as well as mobilization, work plan preparation, negotiation support, meetings and briefings, reports, survey of berms, berm reconstruction, and decontamination. Treatment of berms accounted for approximately 60% of the total cost, and mobilization for another 25%.

In situ treatment was used at those berms and portions of berms which did not contain recoverable bullet fragments, thus limiting the amount of soil that was required to be excavated and treated on an *ex situ* basis.

PERFORMANCE OBSERVATIONS AND LESSONS LEARNED

MAECTITE® was used at MMR on both an *ex situ* and *in situ* basis. All samples met the cleanup goal of <5.0 mg/L of TCLP leachable lead, and soil was not required to be retreated. In addition, 96% of the soil treated *ex situ*, and 97% of the soil treated *in situ*, had a TCLP leachable lead concentration of <0.5 mg/L (one order of magnitude lower than the cleanup goal).

The soil cleanup at this site was completed in a 6 month time frame, from site mobilization through treatment and demobilization.

The treatment vendor used a visual screening process to identify samples with recoverable fragments of metallic lead and identify soil for either *ex situ* or *in situ* treatment.

The treatment vendor reported that the factors that affect cost and performance for the MAECTITE® technology include heavy metal constituents of concern, level of heavy metal contamination, desired reduction in concentrations of leachable metal, volume of material to be treated, whether *in situ* or *ex situ* methods are used, material sizing requirements, final disposition of treated material (i.e., on site or off site), reporting requirements, waste matrix complexities, site configuration, prevailing labor rates, and taxes.

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ACKNOWLEDGMENTS

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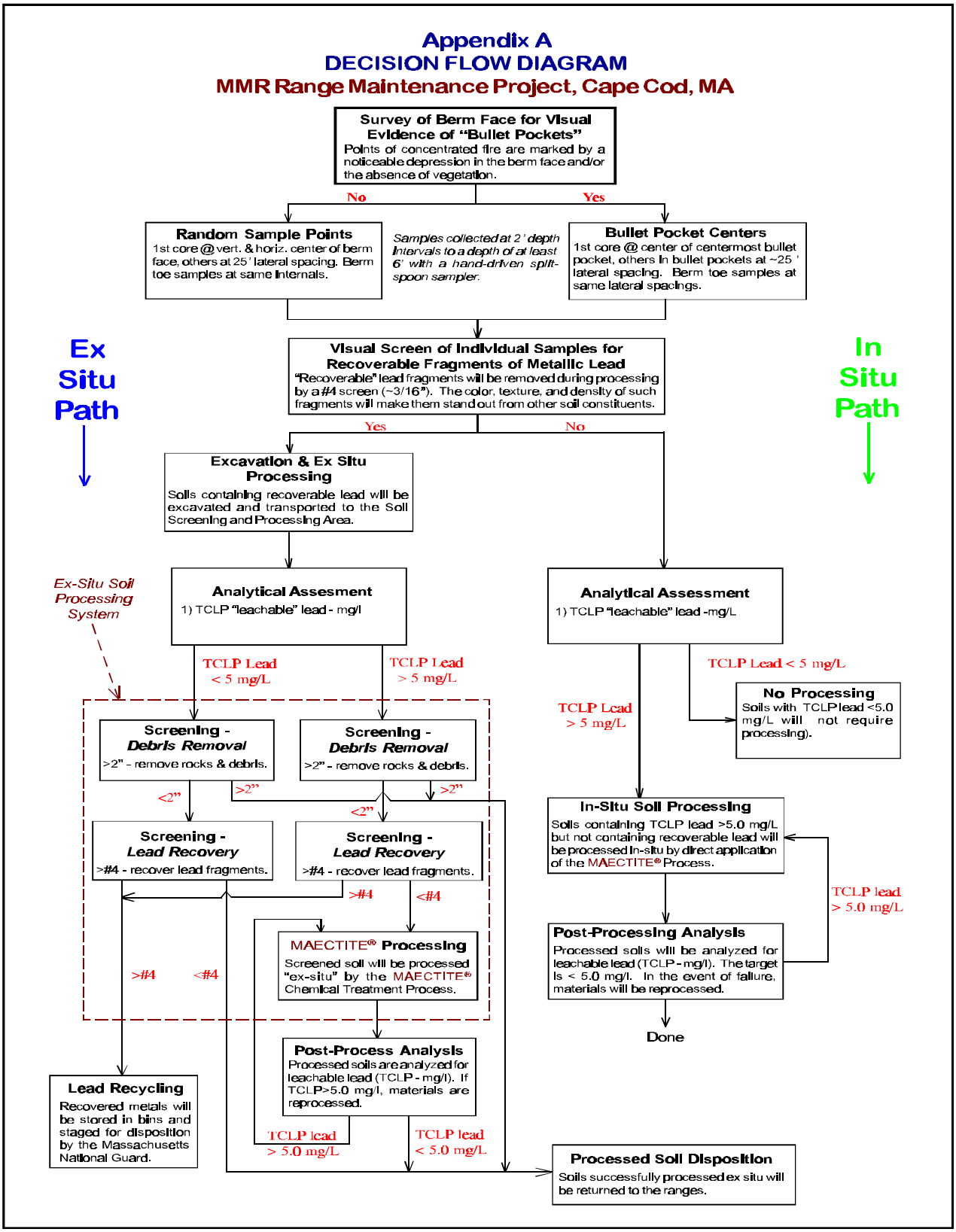
Appendix A
DECISION FLOW DIAGRAM
MMR Range Maintenance Project, Cape Cod, MA
Survey of Berm Face for Visual Evidence of "Bullet Pockets"
Points of concentrated fire are marked by a noticeable depression in the berm face and/or the absence of vegetation.
No
Yes
Random Sample Points
1st core @ vert. & horiz. center of berm face, others at 25' lateral spacing. Berm toe samples at same internals.
Samples collected at 2' depth intervals to a depth of at least 6' with a hand-driven split-spoon sampler.
Bullet Pocket Centers
1st core @ center of centermost bullet pocket, others in bullet pockets at ~25' lateral spacing. Berm toe samples at same lateral spacings.
Ex Situ Path
In Situ Path
Visual Screen of Individual Samples for Recoverable Fragments of Metallic Lead
"Recoverable" lead fragments will be removed during processing by a #4 screen (~3/16"). The color, texture, and density of such fragments will make them stand out from other soil constituents.
Yes
No
Excavation & Ex Situ Processing
Soils containing recoverable lead will be excavated and transported to the Soil Screening and Processing Area.
Ex-Situ Soil Processing System
Analytical Assesment
1) TCLP "leachable" lead - mg/l
Analytical Assessment
1) TCLP "leachable" lead -mg/L
TCLP Lead < 5 mg/L
TCLP Lead > 5 mg/L
TCLP Lead < 5 mg/L
No Processing
Soils with TCLP lead <5.0 mg/L will not require processing).
TCLP Lead > 5 mg/L
Screening - Debris Removal
>2" - remove rocks & debris.
Screening - Debris Removal
>2" - remove rocks & debris.
<2"
>2"
<2"
>2"
Screening - Lead Recovery
>#4 - recover lead fragments.
Screening - Lead Recovery
>#4 - recover lead fragments.
In-Situ Soil Processing
Soils containing TCLP lead >5.0 mg/L but not containing recoverable lead will be processed in-situ by direct application of the MAECTITE® Process.
TCLP lead > 5.0 mg/L
>#4
<#4
MAECTITE® Processing
Screened soil will be processed "ex-situ" by the MAECTITE® Chemical Treatment Process.
Post-Processing Analysis
Processed soils will be analyzed for leachable lead (TCLP - mg/l). The target is < 5.0 mg/l. In the event of failure, materials will be reprocessed.
Done
>#4
<#4
Post-Process Analysis
Processed soils are analyzed for leachable lead (TCLP - mg/l). If TCLP>5.0 mg/l, materials are reprocessed.
Lead Recycling
Recovered metals will be stored in bins and staged for disposition by the Massachusetts National Guard.
TCLP lead > 5.0 mg/L
TCLP lead < 5.0 mg/L
Processed Soil Disposition
Soils successfully processed ex situ will be returned to the ranges.

Source: [11]