Innovative Application of Environmental Technology Simplifies Rapid Response Action Soil Cleanup at MMR

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Abstract

Live fire training activity results in the deposition of spent munitions, propellants, and explosives in impact area soils. In addition to the organic compounds found in propellants and explosives, small arms training also results in the deposition of particulate lead and other heavy metals. Also, firing points accumulate lead and organic compounds used in initiators and propellants. Depending on site-specific characteristics such as soil type, exposure time, and rainfall, erosion and migration of particulate metal as well as migration of explosive compounds may occur. Soils at the Massachusetts Military Reservation (MMR) have been contaminated as a result of such training operations. Contaminants present include particulate metals from various types of ordnance as well as a variety of nitroaromatic compounds that were used as propellants and explosives, and pesticides such as dieldrin.

Traditional treatment methods for remediating explosives and propellants have incorporated biodegradation techniques. While effective on the organic compounds, this approach does not address the metals, which themselves can be toxic to the bioregimes. Physical treatment (soil washing), however, is a proven treatment technology for removing metals from firing range soil. The technology utilizes water and mechanical energy to slurry the soil and separates it into its constituent particles of rock, gravel, sand, silt, and clay.

Utilizing density separation techniques developed primarily for the gold mining industry, physical treatment recovers particulate metal and unspent ammunition. The removal of the particulate metal results in a dramatic reduction in both total and leachable levels for the heavy metals most commonly involved with munitions, which typically include lead, zinc, copper, antimony, cadmium, and arsenic.

Physical treatment also partitions the residual organic or sorbed contaminants from the larger soil grains into the organic matter and/or fine soil fraction. For sites like MMR where the soil contains appreciable amounts of rock, gravel, and sand, physical treatment can significantly reduce the overall volume of soil requiring more expensive residual treatment and/or disposal for these sorbed contaminants, thereby reducing total project cost. And since contaminants are physically removed, long term monitoring and associated liabilities are eliminated.

In initial testing on MMR impact area soils, a volume reduction of up to 98% was achieved using soil washing, with all treated soil meeting reuse requirements. The process was then taken to the field to confirm its effectiveness while remediating the soils from these areas of concern. This paper describes the innovative application of soil washing technology to treat soils from 5 Areas of Concern (AOCs) as part of the Rapid Response Action mandated under Administrative Order #3 at MMR, with the results presented herein.

Background Information

The Camp Edwards training area is part of the MMR, which is located on Cape Cod in Massachusetts. The Massachusetts Army National Guard (MAARNG) conducts training operations at MMR, under the direction of the National Guard Bureau (NGB). Approximately 14,000-acres of MMR constitute the Training Ranges and Impact Area. This portion of the site contains unexploded munitions and potentially other environmental issues as a result of over 60 years use as a military training facility.

Arms that have been used in training operations include but are not limited to:

- All pistol calibers,
- 5.56 mm and 7.62 mm ball and tracer rounds,
- 14.5 mm subcaliber training devices,
- 40 mm High Explosive (HE) and practice grenades,
- Dragon High Explosive Anti-Tank (HEAT) and practice artillery rockets,
- 90 mm recoilless rifle HEAT and practice rounds,
- Explosive charges of C-4, trinitrotoluene (TNT), and det-cord with a weight limit of 40 pounds,
- Bangalore torpedoes,
- Claymore mines, and
- TOW practice rounds.

The Training Ranges and Impact Area are located in a pine/oak woodland which lies directly over the Sagamore Lens, a major groundwater recharge area and a critical water supply for the area. As a result, the public and regulatory agencies scrutinize environmental site work carefully. The AOCs under study are contained within the impact area and an adjacent wetland.

The US EPA issued a Safe Drinking Water Act Administrative Order to the Army National Guard February 27, 1997 requiring a Ground Water Study to determine impacts of military training on sole source aquifer underlying MMR. The Order established enforceable deadlines and reporting procedures, as well as providing for stakeholder participation in the process. The US EPA issued another Administrative Order on January 7, 2000. This Administrative Order specified a series of Rapid Response Actions (RRAs), including remedial actions be implemented at various AOCs to be protective of groundwater at the MMR Camp Edwards Training Site.

To meet these requirements, the EPA required that source control be completed by October 1, 2000, and that site restoration be completed by December 1, 2000.

Remediation Goals

The soil cleanup goals are specific to RRA implementation, and were not meant to apply to other remedial actions at the site. These goals were set to very low concentrations, in order to support requirements of the Drinking Water Standards and the Massachusetts Contingency Plan (MCP) guidance for groundwater impacts from contaminant concentrations in soil. The MCP standards are residential standards, which are the strictest state standards used in assessing the quality of the soil.

Concentrations of the significant explosives (TNT, nitroglycerin, RDX, and HMX) averaged less than 2.50 mg/kg, and if nitroglycerin is omitted, the average falls to less than 0.20 mg/kg. The maximum concentrations are less than 150 mg/kg, and again, if nitroglycerin is omitted, the maximum concentrations are less than 45 mg/kg.

Metals contamination comes mostly from lead, which averages 35 mg/kg at the site but has been found at over 1,250 mg/kg. Practice firing resulted in projectile materials being introduced into a relatively broad area but the munitions fragments and/or unexploded ordnance are likely to be distributed in a very heterogeneous fashion within that area (Jenkins et al., 1996). Projectile materials, consisting mostly of lead and iron, were not found at great depth. Metal fragments tend to leach dissolved organics at a low rate (Jenkins, 1997). Therefore, a reasonable description of the projectile remnants is that each fragment acts as a localized, relatively low-grade source of its component materials.

The pesticide dieldrin has also been found at concentrations averaging 0.120 mg/kg, and as high as 1.8 mg/kg. A listing of the average concentration and cleanup goal for each COC can be found in Table 1.

Traditional Treatment Methods

Most of the remediation performed to date on other sites containing explosives in soils has been at munitions plants and Army depots. At these locations, the concentration of explosives is generally high, with nitroaromatic compounds ranging form 1000 mg/kg to over 133,000 mg/kg. Because these sites were involved in production or handling of munitions, there is little or no contamination from particulate metals in the soil. Therefore, treatment of explosives at these sites focused on biodegradation technologies.

The MMR soil differs from these sites in that the source of the contamination is the result of incomplete combustion in the firing or detonation of explosives as opposed to the deposition of pure product. Only relatively low concentrations coupled with a wide dispersion of the contaminants of concern, including explosives, metals, and pesticides, are found at MMR. In addition, the contaminant levels in the soil prior to treatment are significant lower than the clean up goals at these other sites.

While biodegradation has been proven to be effective on soils with high explosives concentrations, it does not address metal particulates that may be found in the soils, and there is no data to support its effectiveness in treating explosives in soils to the very low levels required at this site. As such, biodegradation as a stand-alone technology was deemed insufficient for dealing with the RRA soils. The lessons learned from this innovative approach treating RRA soils may therefore have applicability to similar armed services training installations, especially those on which artillery target practice and other live fire range operations occur.

Table 1 – RRA Contaminants of Concern

Analyte	Cleanup Standard (mg/kg)	Number of Samples	Average Concentration (mg/kg)	Maximum Concentration (mg/kg)
HMX	0.250	235	0.067	10
Nitroglycerin	2.500	235	2.437	130
RDX	0.120	235	0.223	43
TNT	0.250	235	0.010	2.1
4A-DNT	0.330	235	0.012	0.75
Barium	1,000	205	7	75
Cadmium	30	205	1	36
Copper	1,000	205	16	1,820
Lead	300	205	35	1,270
Dieldrin	0.246	73	0.120	1.8
Di-N-Butyl Phthalate	1,042	115	0.010	0.28
N-Nitrosodiphenylamine	99	115	0.008	0.24

Source: (Ogden, 2000b)

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Soil Washing

While the concept of soil washing is over 100 years old, Brice Environmental pioneered its application in remediating metals-impacted soils in the early 1990's. Since that time, the process has been refined and the equipment streamlined to provide higher throughputs from a physically smaller plant. A description of each processing step follows.

Physical Sizing **-** The physical sizing process uses sequential wet screening steps, the first of which is deagglomeration. Wet screening provides dust-free operation and sharp particle-size fraction separation (cut) points. For each screening step, “plus” and “minus” fractions are generated, with actual cut points based on the treatability study data. The goal of wet screening is to partition the particulate metal contamination into narrow size fractions to facilitate effective gravity separation and to partition the soil particles with organic contaminants into the smallest size fraction for subsequent classification.

Soil Classification/Attrition **-** Sand screws are used to classify sand and gravel fractions by scrubbing contaminant coatings off the particle surfaces and segregating the contaminant-bearing organic matter (humates) and soil fines from the clean sand and gravel fractions. The goal of classification/attrition is to minimize the volume of material requiring subsequent treatment while maximizing the output of clean soil fractions. With sand screws, water flow coupled with screw rotational speed determines the level of attrition scrubbing and subsequent particle size of the fines fraction that is removed from the clean sand fraction.

Gravity Separation - When particulate contaminants are the same size as the surrounding soil particles, gravity separation/density treatment is used to remove the particulates from the same-sized soil matrix. For a typical soil matrix, particulate contaminants usually consist of humates (specific gravity of 0.8 to 1.2) and metals (specific gravity of 8 or more based on metals present). With a specific gravity of 2.5 to 3.5 for typical soil fractions, the particulate contaminants, which are lighter and/or heavier than the same-sized soil particles, are easily separated using mining-based density separation techniques of elutriation and jigging.

Elutriation and jigging are used for humates/soil fines removal and gross particulate removal, respectively. Elutriation uses water flow over weirs to separate the lighter humates and soil fines from heavier/larger sand particles. Jigging uses differential settling in water to separate heavy, metal particles from same-size, but lighter, sand/gravel particles. This approach has seen successful use in both commercial mineral processing and small arms firing range remediation.

Magnetic Separation - To recover artillery fragments and other spent ferrous metal components, self-cleaning magnets are used. They are suspended over the intermediate product conveyors, and automatically remove potentially contaminated tramp iron and other ferrous metals from the product stream after the initial high-pressure wash, depositing the iron in a bin for subsequent recycling. This ensures that the treated soil is free of any magnetic signal.

Dewatering/Water Treatment - To reduce water consumption, process water is recycled within the plant. A clarifier and dewatering screen are used in series to segregate/dewater heavy humates and condition the fines-slurry for subsequent dewatering using a belt filter press. Sand and carbon filtration follows as a polishing step for final rinse spray bars. This enables a counter-current reuse of process waters while minimizing water consumption and associated disposal costs.

Humate removal - A static organic removal screen is incorporated after each classification/elutriation step to recover the "floatable" humates in the aqueous stream. In addition, a high frequency vibratory screen is used after the initial fines dewatering step to remove the "heavy" humates from the fines stream prior to belt filter press dewatering. All of the recovered humates are containerized for subsequent treatment and/or disposal.

Treatability Study

A thorough treatability study is an imperative first step in any soil treatment process. Of equal importance is the need to have representativeness, and not just worst or best case soil samples for testing. This necessitates the need for a large number of grab samples from each area of concern through the full depth of the contaminated matrix, which are subsequently composited into bulk samples for testing.

RRA treatability study sampling locations were based on previous soil sampling results from the Phase 1 and/or Phase 2A sampling programs, which identified grids from the following areas for source removal:

RRA Location	Volume cubic (yards)
KD (Known Distance) Range -	504
J-3 Wetland -	10
Gun Position 7 -	19
APC (Armored Personal Carrier) -	190
Steel Lined Pit (SLP)	less than 1
Total Anticipated RRA Volume	724

A mining-based sampling approach was implemented for collecting representative soil samples from each of the five sites. For each upland grid, the center and four corners were located, and the grid delineated. In addition, the bore holes from the previous sampling effort were located and marked. Prior to sample collection, the areas immediately surrounding these sample locations were avoidance-cleared for UXO.

A soil core approximately 12 to 18 inches in diameter and one foot in depth was collected next to each of the five boreholes located in each grid using a spade shovel. The samples included surficial grasses, etc, but not woody shrubs or scrub trees. As the soil was removed it was placed in a clean five-gallon bucket. Care was taken to keep the sides of each core perpendicular so the sample would be representative of the soil throughout the proposed one foot excavation depth. Each core represented approximately a 5-gallon sample, and each sample was weighed to ensure equal contribution from each sample locations.

A total of five, 5-gallon buckets of soil were collected from each of nine (9) grids. The five buckets, each containing approximately 60 lbs. of soil, were then combined on a large tarp. The tarp was rolled several times in each direction to mix the soil. A 5-gallon composite sample was then collected and retained for treatability testing from the approximately 300 lbs. of mixed soil to represent the soil from each grid. A separate tarp and buckets were used for each grid to prevent cross contamination from grid to grid. The shovel was decontaminated using brushes and deionized water between grids.

The J-3 Wetland grid was sampled using a stainless steel auger. Since most of the grid was in water, previous boreholes could not be identified. Samples from 0 to 1 foot were collected from five different locations within the grid and placed in a 5-gallon bucket. In all, 14 pounds of soil were collected from this grid as a composite sample, which was retained for subsequent treatability testing.

Once at the Brice Treatability Lab, the soil samples were composited to represent the anticipated volume from each area. The composite sample was then homogenized, and advanced to testing. The process steps outlined previously were modeled to simulate field processing. Physical sizing was simulated using a lab scale multideck vibratory screen with spray bars. Classification/attrition was modeled by adding steel shot to a rubber tumbler with the soil/water slurry being tested to deagglomerate and scrub the soil, thereby reducing it to its constituent fractions for further analysis. For the lab study, retention time and soil/water slurry density were used to approximate field conditions. Density separation was simulated using upward water flow in elutriation columns, and lab scale jigs and/or panning with gold pans, with conventional magnets used to separate the ferrous metals from the soil fractions. As a final step, coagulants were used to settle the fines from the wash water, and confirm dosage/effectiveness for subsequent field implementation.

The most practical treatment approach for particulate metal recovery utilized jigs and for recovery of the contaminated organic matter utilized classification/attrition and screening technology with a water-based, closed-loop process. Several of the contaminants were soluble confirming the need for water treatment for dissolved contaminants as well.

Analytical data for the representative feed soil indicated that the complete soil matrix would meet the cleanup goals following organic matter and particulate metal removal. A soil volume reduction step to generate a fine soil fraction for secondary treatment did not appear to be required. However, the limited nature of the treatability study did not fully substantiate that the complete soil will consistently meet the COC cleanup goals via physical treatment only. Whereas the results of the treatability study indicate that the complete soil will meet the cleanup goals following humate and particulate metal removal, there is a tendency of many of the organic COCs to concentrate in the finer (passing a #140 mesh sieve, or “minus 140 mesh”) soil fraction.

The trend in COC distribution and the limited data generated from the treatability study warranted tailoring the physical treatment plant to produce the washed soil (140 mesh plus) and fines (140 mesh minus) as separate output streams. This would allow for each output stream to be analyzed discretely during field processing and either be (1) recombined with the balance of the treated soil or (2) forwarded to secondary treatment pending testing results.

The second scenario could be implemented if testing showed that this output stream failed one or more COC cleanup goals during field scale remediation. Under the first scenario physical treatment could result in up to a 98% volume reduction with humates and particulate metal removal. Under the second, more conservative scenario, physical treatment could result in a 65% volume reduction.

RRA Soil Processing

Using the treatability study data as the basis for process configuration, a demonstration of physical treatment was performed at MMR in the Fall of 2000. Soils were excavated and brought to the soil processing pad for stockpiling. Instead of mixing the soil as it was brought to the treatment pad, soils from different locations were dumped and pushed into one main pile. Thus, the feed soil stockpile consisted of various sub-piles of soil from the five areas instead of a composite mix of all areas.

Post-excavation testing was performed in conjunction with excavation activities and additional quantities of soil were added to the stockpile as well. Approximately 850 cubic yards of soil from the five areas of concern were stockpiled for treatment. This number is higher than the volume totals described for the treatability study because post excavation sampling revealed additional contaminated soils, which were included for treatment.

Soil Processing/Process Modifications - Physical treatment operations commenced on October 23. Soils from the various areas of concern were not mixed into one stockpile for processing. Processing consequently began first with soils that were hauled to the stockpile last since those were the soils accessible on the outside of the soil stockpile. Because space to mix the pile was not available, and large UXO was discovered, only the working face was removed for mixing and processing, as only the face could be avoidance cleared for UXO.

The soil was subsequently processed in three separate "runs", each with a slightly different plant configuration. The goal was to determine which setup was the optimum configuration for moving forward with large-scale treatment of MMR soils. Following is a summary of each run:

- **Run 1 (Oct 23 – Oct. 28) -** The first soils processed were thought to be from the J-3 Wetlands since processed soils contained high percentages of soil fines and organic matter. Since the processing plant was engineered around a soil composite, processing soils containing the fine soils and sediment impacted plant dewatering efficiency. Adjustments were made to the dewatering portion of the plant; however, the processed soil products contained an undesirable percentage of water.

  It is believed that the next soils accessible for processing came from Gun Positions 7 and 16. This assumption is based on the low percentage of soil fines and organic matter observed in the soil as observed in soils at the site prior to excavation.

  The lack of mixing the soils during excavation combined with the space limitations that precluded mixing stockpiled soils meant that the diversity in soil gradation would require additional dewatering equipment. A belt filter press was subsequently ordered to replace the fines dewatering circuitry engineered for the composite soil, as a belt press is able to dewater soil over a wide range of soil gradation.

  While the belt press was enroute processing continued. By October 27, adequate space had opened up at the feed soil stockpile to enable limited mixing to be performed by the loader. It is assumed that soils from the KD Range, APC, Gun Positions 7 and 16, and Steel Lined Pit were accessed and mixed as plant feed soil. Due to space limitations it is unlikely that adequate mixing was accomplished. In addition, the contributions of soil from these areas as compared to the contributions used for the treatability soil composite are unknown. During this time, processing continued to generate wet soil products and recirculating plant water was not processed through carbon treatment due to flow rates exceeding the capacities of the sand filter and carbon units. The process water, which contained soil fines, would have meant either a reduced volume available for reuse in the plant or continual fouling of the filter units. However, the impact of not treating the water may have resulted in soil fines being redeposited on the incoming soil.

- **Run 2 (Oct 30 – Nov 3) -** The belt filter press was installed on October 30. Processing continued on November 1 as shakedown testing was performed with the press. By November 2, press performance had been optimized with soil products containing very low moisture content. The carbon treatment circuit was reactivated with the decrease in water exiting the plant with the soil products and the increased plant efficiency.

  As soil from the stockpile continued to be processed, more and more space became available for soil mixing to be performed. Contributions in the feed soil from the five areas of concern cannot be made with certainty; however, it is presumed that feed soils consisted primarily of KD Range soils followed by APC, Gun Positions 7 and 16 and Steel Lined Pit soils. However, it was noticed that the pressed fines contained visual amounts of fine humates.

- **Run 3 (Nov 4 – Nov 9) -**Another process modification took place on November 3. A high-frequency fine screen deck was modified to remove fine water-soaked humates from the fine soil fraction, which were visible in site soil but were not encountered in the treatability samples. The screen had originally been installed to dewater the soil fines. When the filter press was installed, the screen was taken out of service, but was subsequently modified and put back in service to remove the water-soaked "heavy" humates from the fines stream prior to filter press dewatering.

  The additional removal of fine organic matter from the treatment circuit combined with the treatment efficiency of the belt press resulted in even cleaner plant water. This resulted in the water treatment circuit being able to process at maximum treatment capacity.

From November 4 until process completion on November 9, the treatment plant was functioning at optimal performance. The plant had been modified to handle the diversity in soil gradations making up the feed soil stockpile. During this run, 485 cubic yards of soil were treated. All of the 140 mesh plus material met reuse goals, along with 32 tons of 140mesh minus soil fines. This constitutes a 74% volume reduction, which exceeded the real world projection of 65% from the treatability study report. In addition, 300 pounds of heavy metal particulates/live small arms rounds along with approximately 2 tons of iron fragments and 20 cubic yards of humates/vegetative material were recovered and discretely containerized.

Soil sources making up the material processed for Run 3 are estimated as percentage contributions by locale. Based on the excavated quantities by location it is assumed that the majority of the soil consisted of KD Range and APC soils. Table 2 outlines the average feed soil concentrations, with both the treatability study and field post treatment COC levels for soil meeting reuse criteria.

Table 2 – Post Treatment Contaminants of Concern Levels

Analyte	Cleanup Standard (mg/kg)	Feed Soil Average (1) (mg/kg)	Treatability Study (mg/kg)	RRA Range (mg/kg
HMX	0.250	0.067	0.01	ND
Nitroglycerin	2.500	2.437	ND(2)	ND
RDX	0.120	0.223	ND	ND
TNT	0.250	0.010	ND	ND
4A-DNT	0.330	0.012	ND	ND
Barium	1,000	7	8.7	7.8-16.5
Cadmium	30	1	0.5	ND
Copper	1,000	16	49.2	5.2-15
Lead	300	2,704(3)	263.7	4.6-37.7
Dieldrin	0.246	0.120	0.027	.003-.082
Di-N-Butyl Phthalate	1,042	0.010	0.007	ND
N-Nitrosodiphenylamine	99	0.008	0.001	ND

Source: (Ogden, 2000b)

(1) From site characterization sampling

(2) ND indicates that concentrations were not detected in the samples. For example, the RDX detection limit is 0.120 mg/kg.

(3) From Treatability Study Results, including contribution from particulates.

Summary

The field demonstration was successful in that the optimized process consistently met soil reuse goals while delivering a better than anticipated volume reduction of 74 percent. There were also important lessons learned.

The treatability study that evaluated the initial composite sample indicated that homogenized soils could be treated to meet the cleanup goals established for the project. While the plant was engineered based on a composite sample intended to represent specific quantities in a mixed stockpile, it was successfully reconfigured in the field to process unmixed soil with diverse soil gradations which subsequently required that the soil dewatering system be modified to accommodate the various material types. The field modifications to the dewatering system resulted in an efficient treatment process capable of successfully processing a wide range in soil matrices.

Dewatering efficiency significantly influenced other plant parameters, including water treatment. When soil fines were not able to be completely removed from the plant process water, the sand filter and carbon unit required frequent backwash cycling and consequently could not process water at high flow-through volumes.

The additional soil volumes for RRA processing also contained very large amounts of oversize vegetative matter, which the treatment plant was not equipped to handle. As a result of the oversize, additional labor was required for hand removal of bushes and small scrub oak and pine trees. For future excavations at the site one needs to consider clearing and grubbing prior to soil excavation to streamline treatment operations.

Following plant optimization on November 2, the plant processed the majority of the total soil volume in only five days. AMEC subsequently recommended the final plant configuration to the NGB as the preferred process for future soil treatment at the site. Soil piles treated during Runs 1 and 2 that did not meet reuse goals will be reprocessed with the optimized plant configuration this spring, along with additional RRA soils from other areas. In addition, several secondary treatment technologies are being evaluated as potential secondary treatment for soil not meeting reuse goals after soil washing.

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