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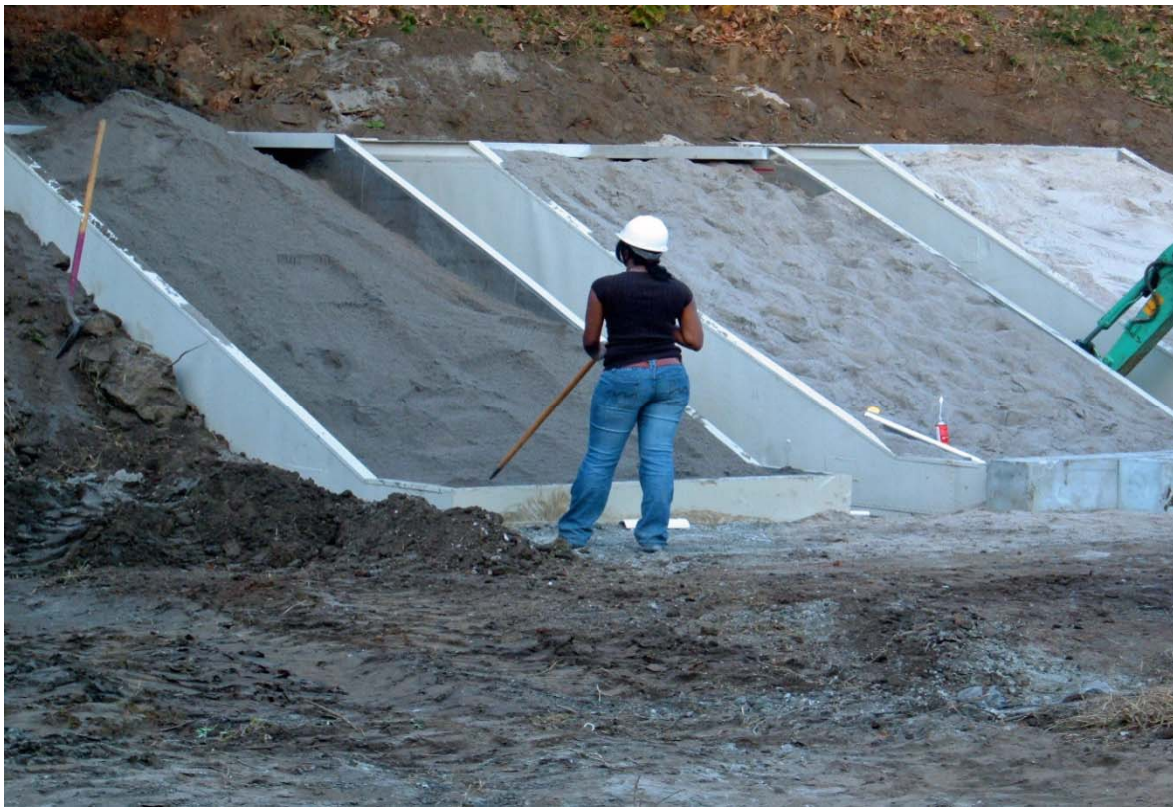
Passive Reactive Berm to Provide Low Maintenance Lead Containment at Active Small Arms Firing Ranges

Field Demonstration

Michelle Wynter, Steven L. Larson, W.A. Martin, Chris S. Griggs, Gregory O'Connor, David Mackie, and Catherine C. Nestler

August 2012



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Abstract

Heavy metals are released into the environment as a result of critical military live-fire training. Preventing heavy-metal migration into and contamination of the local environment is crucial because remediating contaminated soils is resource intensive, difficult, and costly. Previous studies have demonstrated that phosphate amendments have been successfully used as a best management practice (BMP) to immobilize metal contaminants. The Passive Reactive Berm (PRBerm™) technology incorporates phosphate amendments with ballistic sand to immobilize soluble metals (e.g., lead) during the inevitable bullet corrosion process. Treatability studies determined that an amendment ratio of 5% (weight/weight) to sand was sufficient to contain > 90% of soluble lead within the berm material. The technology was field tested on the M-60 small arms firing range (SAFR) at Charleston Air Force Base (CAFB) in Charleston, South Carolina. The CAFB PRBerm™ was tested with a 5% TRAPPS™ amendment (a granular, apatite-based material), alone and in combination with a 5% thermally treated fish bone Apatite™.

For the CAFB PRBerm™, storm water runoff and leachate water samples were collected directly from the SAFR and analyzed for metals, total suspended solids (TSS), and pH. Reduced metals migration in soil leachate and surface water runoff when compared to the traditional earthen berm was observed. The total suspended solids in the leachate and runoff waters from the amended berms increased over the control berm. Results indicated that the pH of the runoff waters from the amended berms remained acidic.

The benefits of the PRBerm™ when compared to the traditional earthen berm, or a fully contained bullet trap, include reduced metals migration in soil leachate and surface water runoff, as well as reduced construction and operation costs. The PRBerm™ has the potential to provide a useful, low-cost tool for defense forces to maintain active firing ranges while managing the inevitable effects of small arms residue corrosion in a low-cost and effective manner.

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Preface

This report contains information that was obtained from field demonstration studies conducted at the Charleston Air Force Base (CAFB) M-60 small arms firing ranges (SAFR). Funding was provided by the Environmental Security Technology Certification Program (ESTCP). The project was designated ESTCP project ER-0406. It was an evaluation of the use of sand as a deceleration medium in SAFR berms in conjunction with appropriate amendments designed to retard the migration of lead into the surrounding environment.

Michelle Wynter of the Environmental Engineering Branch (EP-E), Environmental Laboratory (EL), Engineer Research and Development Center (ERDC), Vicksburg, MS, prepared this report. Co-authors of this report include Dr. Steven L. Larson, W. Andy Martin, Chris S. Griggs, all ERDC-EL; Greg O'Connor, U.S. Army RDECOM-ARDEC Energetics, Warheads, & Environmental Technology Research Division; David Mackie, AMEC Earth and Environment, Somerset, New Jersey; and Cathy C. Nestler, Applied Research and Associates, Inc. (ARA). The authors gratefully acknowledge the technical assistance provided by Milton Beverly, Environmental Research and Development, Inc., (ERAD) and Dr. Catherine Thomas, Jackson State University. A special thanks to the Charleston Air Force Base (CAFB) CAFB Range and Bioenvironmental Engineering personnel for assistance during this project.

This study was conducted under the direct supervision of Dr. Pat Deliman, Technical Director, Environmental Modeling and Assessments, and the general supervision of Warren P. Lorentz, Chief, Environmental Processes and Engineering Division, and of Dr. Elizabeth C. Fleming, Director, EL. At the time of this study, COL Kevin J. Wilson was Commander of the ERDC, and Dr. Jeffery P. Holland was Director of the ERDC.

Unit Conversion Factors

Multiply	By	To Obtain
Acres	4,046.873	square meters
cubic feet	0.02831685	cubic meters
cubic inches	1.6387064 E-05	cubic meters
cubic yards	0.7645549	cubic meters
degrees Fahrenheit	(F-32)/1.8	degrees Celsius
Feet	0.3048	meters
gallons (U.S. liquid)	3.785412 E-03	cubic meters
Inches	0.0254	meters
Microns	1.0 E-06	meters
miles (nautical)	1,852	meters
miles (U.S. statute)	1,609.347	meters
miles per hour	0.44704	meters per second
Mils	0.0254	millimeters
ounces (mass)	0.02834952	kilograms
pounds (mass)	0.45359237	kilograms
square feet	0.09290304	square meters
square inches	6.4516 E-04	square meters
square yards	0.8361274	square meters
tons (2,000 pounds, mass)	907.1847	kilograms
tons (2,000 pounds, mass) per square foot	9,764.856	kilograms per square meter
Yards	0.9144	meters

Acronyms

AFB	Air Force Base
AMC	Air Mobile Command
ASTM	American Society for Testing and Materials
ATC	Aberdeen Test Center
AW	Airlift Wing
BMP	Best Management Practice
BOD	Biological oxygen Demand
CAFB	Charleston Air Force Base
COTS	Commercially available off the shelf
DDI S&S	Distilled Deionized Water Suspend and Settle
DOC	Dissolved Organic Carbon
DoD	Department of Defense
EL	Environmental Laboratory
ERDC	Engineer Research and Development Center
ESTCP	Environmental Security Technology Certification Program
ETL	Engineering Technical Letter
GSL	Geotechnical and Structures Laboratory
HQDA	Headquarters, Department of the Army
HDPE	High-density polyethylene
ICP-AES	Inductively Coupled Plasma Atomic Emission Spectroscopy
ID	Internal diameter
IDL	Instrument detection limit
ISO	International Organization for Standarization
ITRC	Interstate Technology and Regulatory Council
MCLG	Maximum Contamination Level Goal
ND	Non-detect
PRBerm™	Passive Reactive Berm
SACON	Shock absorbing concrete
SAFR	Small arms firing range

SDZ	Safety danger zone
SPLP	Synthetic Precipitate Leaching Procedure
TCLP	Toxicity Characteristic Leaching Procedure
TSS	Total suspended solids
TTF	Thermally-treated fishbones
w/w	weight:weight

Chemical names

Ca	Calcium
Cr	Chromium
Cu	Copper
Fe	Iron
Mn	Manganese
Mo	Molybdenum
Ni	Nickel
P	Phosphorus
Pb	Lead
Sb	Antimony
V	Vanadium
Zn	Zinc

1 Introduction

Background

More than 3,000 active small-arms firing ranges (SAFR) and 9,000 non-military shooting ranges in the USA (Interstate Technology and Regulatory Council (ITRC) 2003) provide training areas for military personnel, law enforcement, and recreational shooters. According to Cao et al. (2003), SAFRs are a significant source of lead (Pb) in the environment around the range. Transport of contaminants in the environment is impacted by such things as soil properties, pH, and weathering of the contaminant. Metals present in SAFR soils can potentially migrate off-site into sensitive environmental receptors (e.g., wetlands, surface-water bodies, groundwater supplies) through surface-water transport (runoff) or by vertical migration (leaching) into the groundwater. Soil type, slope, rainfall intensity, and vegetation influence the release of contaminants by runoff. The resulting environmental contamination could result in state or federal regulatory action, which could ultimately impose constraints on critical military training activities at SAFRs (Figure 1).

The use of earthen backstops (berms) composed of native soil can present environmental and regulatory challenges for installations that contain SAFRs, depending on the physical and chemical properties of the soil, and the proximity of the berm to sensitive environmental receptors. All of the lead entering a berm on a firing range initially is present as metallic lead alloy. As the metallic lead ages within the SAFR berm it undergoes corrosion processes that can result in the release of dissolved lead cations and other metals. Depending on the environment within the berm, the fate of dissolved lead can range from transport to groundwater as soluble lead, transport to surface water as soluble lead, sorption onto electronegative particle surfaces (e.g., clays, organic matter, iron or manganese oxides), precipitation of lead salts (e.g., carbonates, sulfates, sulfides, and phosphates).

Generally, the mobility of dissolved lead is controlled by pH conditions, adsorption/desorption of lead with soil particles, and advective processes such as groundwater or surface-water flow. When conditions aren't optimal, the installation may face regulatory issues, with lead or other heavy metals, potentially being transported off-site (Figure 1). Low pH soil

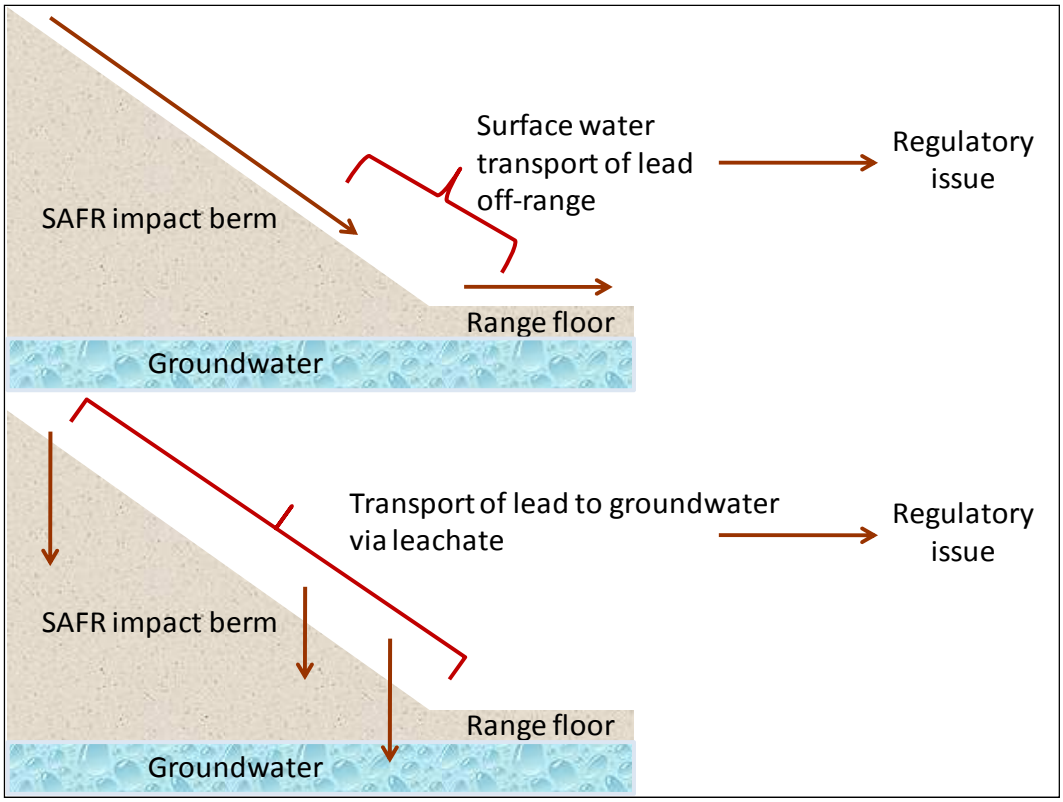

Figure 1. Potential compliance isues on small arms firing ranges.

(acidic soils) generally enhances solubility of Pb, Cu, and Zn, while neutral to basic pH conditions tend to favor the precipitation of metal salts (Anderson and Christensen 1988, Carlon et atl 2004, Impelliteri et al. 2002, Janssen et al. 1997). Soils rich in clay and/or organic matter (i.e., those possessing a net negative charge) typically exhibit high soil/water distribution coefficients (K_d values) for metals such as Pb and Cu, and may thus be effective in retarding their migration to the surrounding environment (Covelo et al. 2007, Hooda and Alloway 1998, Moreno et al. 2006). Iron, however, behaves in the opposite manner; the K_d is decreased in the presence of high concentrations of clay/organic matter (Chen et al. 2006). The erosion and transport of lead-contaminated soils by surface runoff (especially those soils containing a high proportion of silt and clay) can result in the redistribution of lead over relatively large distances.

Soils that are characterized by either high acidity (low pH), high alkalinity (high pH), high permeability, and (or) low soil/water K_d values for lead may be ineffective in retarding the migration of soluble lead into nearby groundwater or surface water bodies. Mechanical erosion and transport of such soils (especially clay-rich soils) may also lead to offsite transport of lead in surface water runoff (Table 1). Conversely, soils characterized by

neutral to slightly basic pH conditions, relatively low permeability, and (or) which exhibit a high K_d value for lead may be effective in limiting the mobility of soluble lead to the surrounding environment (Figure 2).

Table 1. Soil chemistry that promotes transport of Pb off-range in surface water and to groundwater via leachate.

Surface water transport	Leachate transport
High CEC	Low CEC
High percentage of fines (small particle size)	Lower percentage of fines
Extreme pH (acid or alkaline)	Extreme pH (acid or alkaline)
Low permeability	High permeability
High sorption capacity (high K_d)	Low sorption capacity (low K_d)
Potential problem soil types: Silt, clay soils	Potential problem soil types: Sandy soils
Regulatory Issue	Regulatory Issue

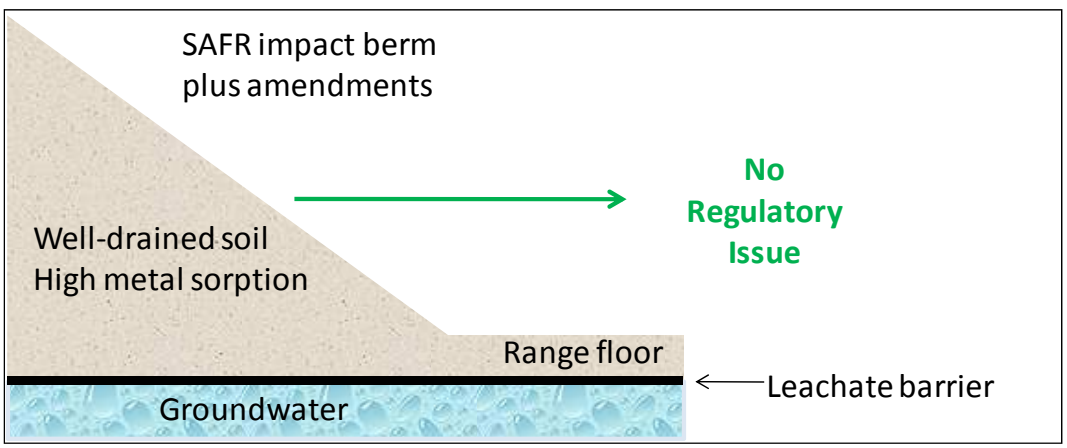

Figure 2. Effect of PRBerm™ technology on regulatory compliance issues.

Impact Berm Deceleration Media

Washed, construction sands that consist principally of silicate minerals (e.g., quartz) — such as those commonly used in masonry and concrete manufacture — may provide a suitable medium for the construction or replacement of SAFR impact berms. Commercially available masonry or concrete sands are relatively low-cost materials and are widely available due to their extensive use in construction. From an operational standpoint, sand has numerous beneficial properties as a deceleration medium at firing ranges, and is generally the material of choice for this purpose. Impact berms made from sand are effective in decelerating fired projectiles safely, with minimal fragmentation, a low risk of ricochet, and relatively little dust

generation. The chemical inertness of silicate sands minimizes berm cementation and hardening, thus ensuring proper deceleration of projectiles. Further, the granularity, low bulk density, and non-cohesive nature of sand facilitate the separation of spent bullet fragments during range maintenance or clearance activities (e.g., by soil screening). Finally, the refractory and non-flammable nature of sand provides additional benefits in ranges where tracer rounds may be used.

From an environmental perspective, the use of silicate mineral sand offers three principal benefits:

1. Washed sand typically contains a low proportion of silt and clay-sized particles, which reduces the potential for Pb transport by storm water runoff.
2. The relatively high hydraulic conductivity of sand minimizes the amount of surface runoff down the berm face.
3. The drainage characteristics (combination of the high permeability and low specific retention) of sand tend to limit the contact time between water and Pb particles, thus inhibiting the in-situ corrosion (weathering) of Pb.

However, from an environmental standpoint, there are a number of disadvantages associated with the use of sand in SAFR berms:

1. Most silicate mineral sands have a negligible pH buffering capacity. The lack of an adequate buffering capacity could lead to a reduction of soil pH to levels where both the rate of Pb corrosion and extent of Pb solubility in water are significantly increased. For this reason, Pb present in an unamended sand berm would be susceptible to leaching by acid precipitation (acid rain).
2. Commercially available washed construction sands typically contain relatively low proportions of clay, silt, and organic (humic) material, and are thus the washed sand is characterized by relatively low K_d values.
3. Further, unamended silicate sands generally contain minimal amounts of carbonates, iron and manganese oxides, sulfides, organic matter, and phosphate compounds, and are generally ineffective in retarding Pb mobility through precipitation reactions and are also difficult to vegetate.

Thus, SAFR berms constructed entirely of unamended silicate sand may be more likely to release soluble Pb into the environment than berms that are constructed using other soil types. This shortcoming can be addressed by

amending construction sand with materials that will buffer soil pH, enhance Pb adsorption, and (or) promote the precipitation of stable Pb salts.

Phosphate Amendments

The bioavailability and environmental risk of a contaminant are directly related to its accessibility to the biota in the soil medium, which is generally controlled by its solubility and mobility (Traina and Laperche 1999). Linking Pb bioavailability to its solubility rather than to its total concentration makes possible the consideration of remediation strategies based on in situ reduction of contaminant solubility, rather than its complete removal or physical isolation (solidification). Due to the high costs of soil excavation and off-site remediation, in situ chemical stabilization with phosphorus (P) based amendments has been investigated as a more efficient and cost-effective method of site remediation (Wilson et al. 2006, Hettiarachchi et al. 2002, Traina and Laperche 1999, Berti and Cunningham 1997, Ma and Rao 1997). Phosphorous-based amendments have been shown to reduce the lead bioavailability to allowable levels through the conversion of relatively soluble/bioavailable forms of lead to relatively insoluble/less bioavailable pyromorphites ($Pb_5(PO_4)_3X_{(s)}$, where X= Cl^-, F^-, OH^-), the most stable forms of lead in oxic surface soils under a wide range of environmental conditions (Traina and Laperche 1999). Although phosphorous amendments have mainly been applied to remediate Pb-contaminated soil, they may also be applicable to other metals associated with firing-range soils such as Cd, Zn, and Cu (Hamon et al. 2002).

Several laboratory and bench-scale remediation studies have demonstrated the effectiveness of the addition of phosphate-based soil amendments in producing highly insoluble Pb phosphate minerals such as pyromorphite and hydroxypyromorphite (Berti and Cunningham 1997, Lambert et al. 1997, Ma and Rao 1997, Lower et al. 1998, Traina and Laperche 1999). When sequestered within these phosphate minerals, Pb has been shown to be far less soluble, as indicated by the results of acid leaching tests (Tardy et al. 2003). Its bioavailability to soil organisms has been demonstrated to be sharply reduced (Berti and Cunningham 1997, Pearson et al. 2000, Traina and Laperche 1999). The U.S. Environmental Protection Agency (USEPA) has recognized that the bioavailability of Pb in contaminated soils varies greatly depending upon its form in the soil. USEPA has suggested that phosphate treatment has the potential for in situ remediation of metals contaminated soils and sediments (USEPA 2001b).

Lead is amphoteric and Pb compounds show the greatest aqueous solubility at the acidic (pH <4) and alkaline (pH>11) ranges. Under acidic conditions, elemental Pb will dissolve, releasing a hydrated cation Pb^{2+}. Under alkaline conditions, elemental Pb will dissolve, theoretically forming the dissolved hydroxide complex $Pb(OH)_3^-$ and ion-pair $Pb(OH)_2$(aqueous) (ITRC 2003).

Several factors affect the amount of Pb that is dissolved in water. In a typical water body, dissolved Pb forms precipitates of Pb hydroxide [$Pb(OH)_2$], Pb carbonate [$PbCO_3$, cerrusite], or basic Pb carbonate [$Pb_3(OH)_2\ (CO_3)_2$, hydrocerrusite]. Overall Pb solubility in a natural system is fundamentally determined by the concentrations of the anions in solution (e.g., the hydroxide and carbonate ions) and by the ionic strength of the solution, which affects the activity coefficients of the ions. These factors can be related to more directly measured parameters such as pH, alkalinity, and total dissolved solids (TDS) (Vaccari 1992).

In any system having water in equilibrium with a solid phase, the metal precipitate that has the lowest solubility will be the only stable solid phase and will increase in its relative concentration at the expense of the more soluble forms. Thus, the presence of Pb with extremely low solubilities, such as Pb phosphates, influences the solubility and availability of the Pb in the environment.

The metalloid, antimony (Sb), has also been detected in shooting range soil at high concentrations (Ackermann et al. 2009, Dermatas et al. 2006, Johnson et al. 2005, Kilgour et al. 2008, Klitzke and Lang 2009). Antimony is added to lead alloy bullet as a hardening agent. Subseqently, Sb is released — along with Pb — during the bullet corrosion process. However, unlike the cation of Pb, Sb forms an oxyanion and the geochemistry is quite different from that of Pb. The geochemistry has been reviewed by Wilson et al. (2010). Antimony is reported to be associated with ferrihydrates, carbonates and oxides in soil. High pH (alkaline conditions) and anoxic conditions increases the dissolution of these complexes and leads to the release of Sb in to the soil pore water and surface water (Chen et al. 2003, Johnson et al. 2005). Therefore, in conditions of well-drained soil, with high concentrations of free carbonate and iron, a low percentage of clays and fines, and a low pH, Sb transport should not be of great concern. However, when soil is amended with P for immobilization of Pb, the Sb may inadvertently be mobilized through competitive reactions with the P (Kilgour et al. 2008).

Thermally Treated Fishbones (TFF)

Fishbone is a form of biogenic apatite produced, mechanically or enzymatically, from fish industry by-products. This results in a composition of clean and dried fish bone and fish hard parts. A study conducted by Shinomiya et al. (1998) investigated the eventual demineralization of mammal bones buried underground for 2 years and determined that phosphorous concentrations initially decreased within the bone and then increased, potentially due to nucleation sites provided by the bone material (Wright et al. 2004). As a soil amendment, fishbone Apatite II™ has several advantages over other forms of natural apatite and terrestrial bone sources (e.g., cow bone). Apatite II™ has low trace metals concentrations and exhibits poor crystallinity compared to other naturally occurring forms of apatite (Conca et al. 2000). Unlike cow bones, Apatite II™ is highly microporous (Wright et al. 2004; Lu et al. 2001), and thus provides a readily available and reactive source of soluble phosphates along with a potential seed crystal for heterogeneous nucleation of lead-pyromorphites (Wright et al. 2004). Depending on the presence of certain metals in solution, a Pb removal efficiency of 37 to 100 percent can be achieved through the process of hydroxyapatite dissolution and hydroxypyromorphite [$Pb_{10}(PO_4)_6(OH)_2$] precipitation (Ma et al. 1994; Wright et al. 2004).

The fishbones used in this study were thermally treated in a muffle furnance at 450 °C to remove any organic matter present to conduct the study at CAFB.

TRAPPS™

TRAPPS™ is a commercially available off-the-shelf (COTS) product, a formulation of apatite and other insoluble phosphate mineral, in which lead is precipitated as stable pyromorphite. According to the manufacturer, TRAPPS™ also does not cause increased mobilization of copper, arsenic, and antimony or release excessive amounts of phosphate (http://www.slateruklimited.co.uk/us/trapps_firing_range.html).

Metal Oxide Amendments

Hydrous oxides of aluminum (Al), iron (Fe), and manganese (Mn) are ubiquitous in soils and strongly implicated in the sorption of metals and a reduction in metal mobility in soil systems (Bradl 2004, Covelo et al. 2007, Ford et al. 1997, Han et al. 2006, Martinez and McBride 1998, Martinez et

al. 1999, Ndiba et al. 2008, Orsetti et al. 2006, Trivedi and Axe 2000). The highest adsorption is found from Pb and Cu; the least adsorption from Cd, Ni, and Zn (Covelo et al. 2007, Ford et al. 1997, Martinez and McBride 1998). Cadmium and Zn were not affected by changes in soil pH but Cu solubility increased (desorption) as the soil pH decreased. The iron hydroxides are generally determined to be more effective at immobilizing Pb and less effective at immobilizing Cd and Cu. However, as the metal oxides aged, the Pb was reported to undergo desorption. Unlike Pb, which had rapid intial sorption into ferrihydite, the metals with lower initial sorption (Mn and Ni) became incorporated into the more stable iron minerals goethite and hematite and remained immobilized (Ford et al. 1997, Martinez and McBride 1998).

Copper, Pb, Ni and Zn have also been reported to adsorb to Mn-oxide. Manganese oxide is a surface acidic oxide with a pH_{pzc} (point of zero charge) of approximately 1.5 to 4.5 (Han et al. 2006). Soil amendment with phosphate reduced the leachability of these complexes by 89% compared to controls (Ndiba et al. 2008).

Regulatory Drivers

The regulatory drivers at CAFB M60 range were derived from a study that was initiated at the Barksdale Air Force Base (BAFB) located near Bosier City, Louisiana. The BAFB state-based surface water regulations served as a benchmark throughout the bench scale, treatability, and field demonstration studies. The regulations used in the field study are listed below (Larson et al. 2007):

- Total lead discharge limit of 0.15 mg/L (150 µg/L)
- Copper discharge limit of 0.5 mg/L (500 µg/L)
- Total Organic Carbon (TOC) discharge limit of 50 mg/L
- pH between 6.0 and 9.0 for the discharge

Total Suspended Solids (TSS) was not a required measurement but since it is an important indicator of the potential metals leaving the range, TSS was an additional parameter that was evaluated. Research performed by the Engineer Research and Development Center - Environmental Laboratory (ERDC-EL) has shown that the majority of the lead in the runoff water occurs as insoluble lead associated with suspended (colloidal) soil particles (Larson et al. 2007).

Amendments can be added to the berm materials (sand or local soil) to aid in the immobilization or stabilization of metals associated with the bullets used at a SAFR. Several amendments are available for in situ and ex situ stabilization; however, the long-term — and often the actual — effects of SAFR training on the longevity of the amendments are seldom evaluated. Two amendments were tested in this study using ballistic sand as the impact media of the berm. These amendments were TRAPPS™ and thermally treated fish bones (TTF) which provide theoretically insoluble metal complexes. The leachate and runoff samples were collected and measured for metals concentrations, TSS, and pH.

2 Experimental Design

Technology Development

Treatability studies conducted by ERDC-EL (Larson et al. 2007a) evaluated sand amendments under laboratory and mesoscale conditions to determine optimum combinations to immobilize soluble metals, such as Pb, in situ. These studies determined that the sand to amendment ratio of 5% (w/w) was sufficient to contain greater than 90% of soluble Pb within the berm material. Lysimeter studies then used regulated artificial rain events to evaluate the metals concentrations, total suspended solids, dissolved organic carbon, and runoff and leachate pH over time for the amended and sand-only (control) berms. Several phosphate-based amendments were evaluated, including Whole Bone and Crushed Bone Apatite II™. By comparing the metals concentrations remaining in solution after 18 hours of tumbling in the toxicity characteristic leaching procedure (TCLP) extraction solution against control soils with no amendments, the amended soils decreased the leaching of Pb from 45 to 99 percent. While all of the amended soils achieved or bettered the TCLP regulatory limit of 5 mg/L for Pb leaching, the apatite-based amendment was most effective at the lowest amendment loading rates.

Apatite II™ and TTF were further investigated for its ability to sequester Pb from solution (Martin et al. 2008). The study reported that organic compounds were formed in the apatite-amended lysimeters during aging and this hindered Pb immobilization. Because Apatite II™ is known to contain up to 40% residual organics (Conca and Wright 2006), the fish bones were treated using several different methods to remove the residual organics. Laboratory and column studies established that thermally treated Apatite II™ prior to use as an amendment allowed for consistent removal, >90%, of soluble lead from solution and reduced the biological oxygen demand (BOD) of the solutions to non-detect levels. For this reason, it was chosen as one of the soil amendments in the PRBerm™ field demonstration.

Technology Description

A typical impact berm cross-section with the PRBerm™ technology application, Figure 3 includes a non-woven geo-membrane / fabric that

serves as a barrier between native soils and ballistic (i.e., sand,media). Amended sand is placed on top of the newly contoured earthen berm. A SACON® or timber toe support can be used at the base of the PRBerm™ to prevent excessive sand erosion from the berm.

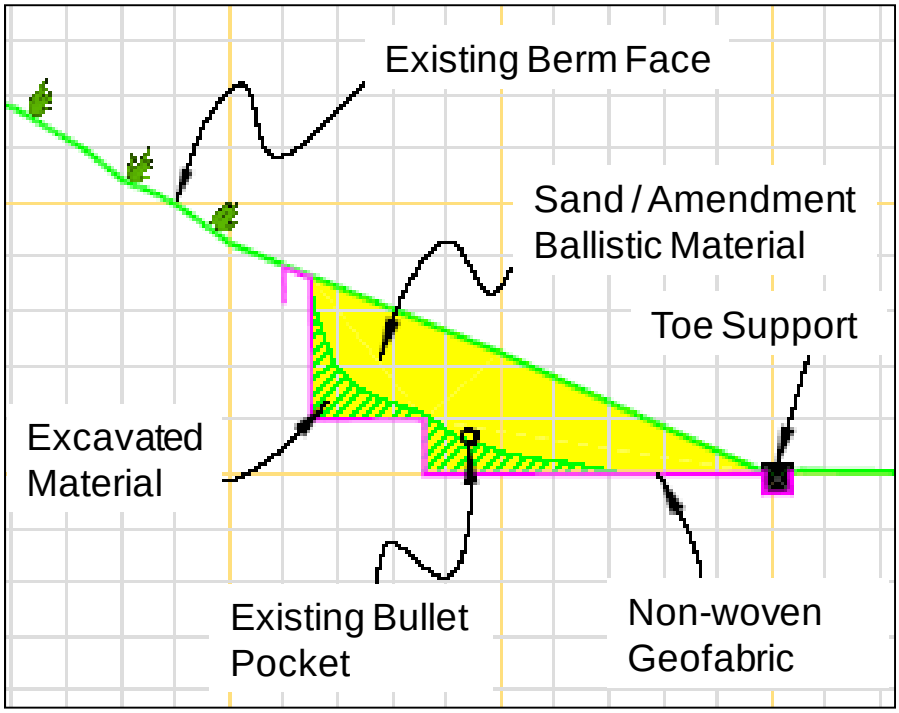

Figure 3. Schematic cross xection of Charleston AFB PRBerm™ technology application.

Pre-construction views of the CAFB M-60 range are provided in Figures 4 and 5. The three firing positions of the CAFB M-60 training range allowed the testing of three different evaluations of the PRBerm™ technology. Based on the results of the treatability study, two combinations of amendments were tested and compared to a control (untreated berm). The amendments were TRAPPS™, and TRAPPS™ plus thermally treated fish bones. The control cell was constructed without amendments in order to provide statistical data for the performance assessment.

The PRBerm™ at CAFB contains 20 foot connex lysimeters that hold the sand and test amendments and are used to collect runoff water and leachate water from the berm through a sample collection system.

Surface water and leachate were sampled from the control and amended berms and analyzed for heavy metals (total and dissolved), TOC, TSS, and pH.

Figure 4. Pre-construction view of the three firing points and impact berm area at the CAFB range. View is through the individual firing positions towards the impact berm.

Figure 5. Pre-construction close up view through the pipe that forms the firing line and looking towards the berm.

Study Objectives

The objectives of the field demonstration were to a provide a field demonstration for the PRBerm™ technology, to assess the environmental benefits, feasibility, and cost of using sand as a deceleration medium in SAFR berms in conjunction with amendments designed to retard the migration of Pb into the surrounding environment. The amendments provide for reduction of Pb solubility through pH buffering of pore fluids within the SAFR berm, as well as the sequestration of Pb through surface adsorption and the precipitation of insoluble Pb salts. This technology application is known as a passive reactive berm (PRBerm™).

The purpose of the field demonstration was to provide range operators with an economical means of controlling the off-site migration of Pb, while maintaining the benefits of sand as a deceleration medium. In particular, this technology was designed to address sites where the native soils available for SAFR berm construction either lack the characteristics necessary to retard the migration of soluble Pb (e.g. acidic soils) or are susceptible to erosion and off-site transport of Pb as a result of their high clay content.

3 Materials and Methods

Charleston Air Force Base (CAFB) M-60 Range

The Charleston Air Force Base, also known as Joint Base Charleston, is a United States Air Force base located in North Charleston, South Carolina (Figure 6). Charleston Air Force Base originated when the city of Charleston purchased land in 1931 to build Charleston Municipal Airport. On 11 December 1941, the Army Air Corps took control of the field and anti-submarine missions were being flown out of Charleston Army Air Field by August 1942. Returned to civilian control after World War II, the United States Air Force began joint use of the facility on 11 July 1952 and the military part of the airfield was renamed Charleston Air Force Base on 1 June, 1953.

Figure 6. Location of Charleston AFB, SC.

Charleston AFB is assigned to Air Mobility Command (AMC). A joint civil-military airport, Charleston AFB shares runways with Charleston International Airport for commercial airline aircraft operations on the south side of the airfield and general aviation aircraft operations on the east side (Figure 7). Charleston AFB is home to Joint Base Charleston 628th Air Base Wing (628 ABW) the "host wing for installation support."

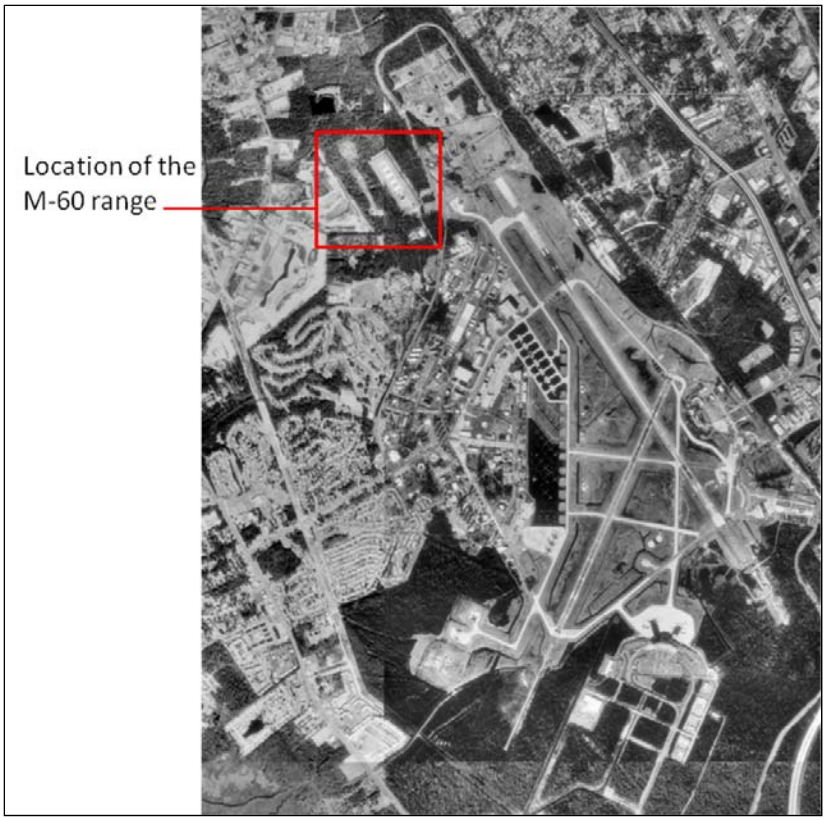

Figure 7. Aerial view of the Charleston Air Force Base with the location of the M-60 range indicated within the red box.

The Charleston AFB M-60 range contains three fixed firing positions that are used for the qualification/familiarization of the 5.56mm (M249) and 7.62mm (M240) weapons systems. Live fire is directed toward an earthen impact berm through 6-foot diameter reinforced concrete pipes that are approximately 24 feet in length. Typically the CAFB personnel fire more than 100,000 rounds of 5.56mm and/or 7.62mm ammunition per year for qualification/familiarization purposes with the range safety danger zone (SDZ) depicted in Figure 8.

The range was closed for renovations prior to the PRBerm™ field demonstration. During the years of closure, weapons upgrades and base operations encroachment had decreased the safety area (i.e., SDZ) around the firing range. The protective eyebrow over the firing positions was no longer adequate to protect surrounding areas from ricochet hazard as observed in the ricochet safety design illustrated in Figure 9.

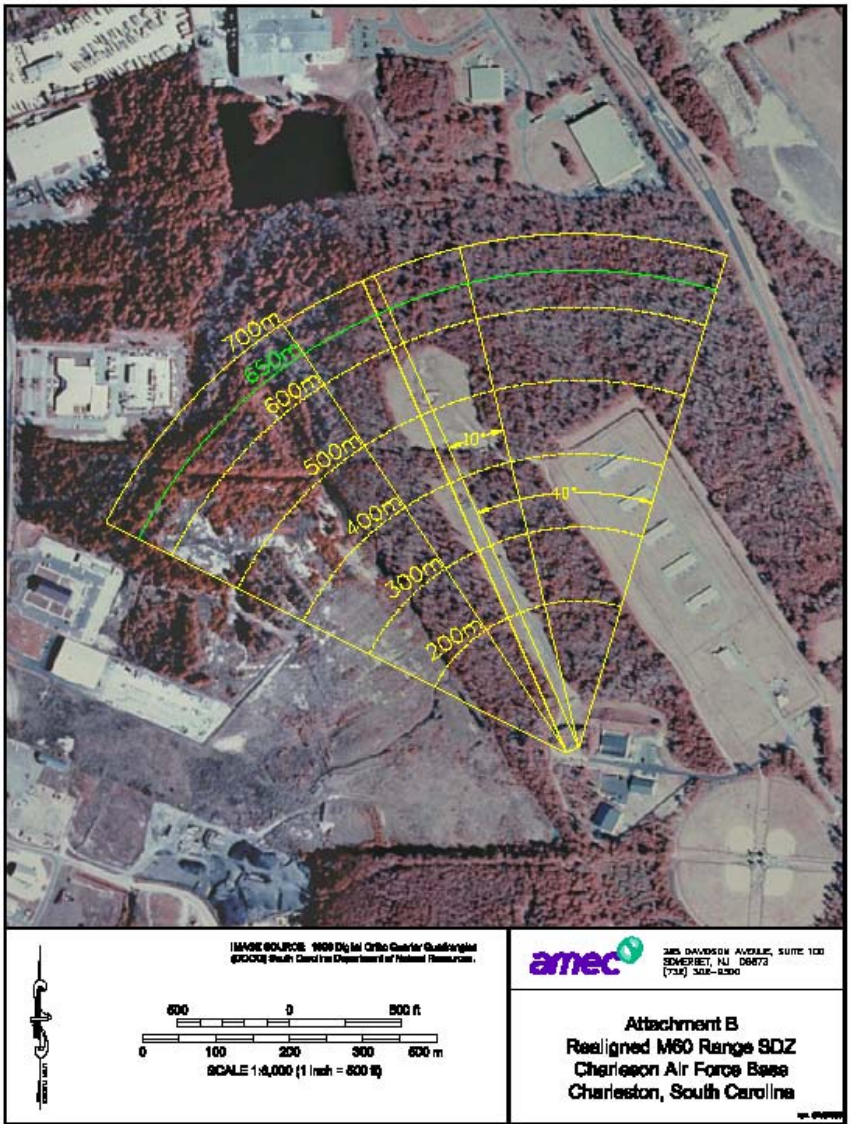

Figure 8. Aerial view of the M-60 range at Charleston AFB indicating possible bullet firing distances.

There is an underground drain at the M60 range that allows the range runoff water to flow under a nearby road and into a stormwater drainage system nearby. The drainage system located at the range provided adequate storm water collection system for runoff water samples leaving the range complex and prevented potential cross contamination of leachate water collection systems (i.e., on-site pooling of water).

Berm Amendments

Two amendments were selected for field testing at the CAFB M-60 range: TRAPPS™ (Slater, UK) and thermally treated fish bones (TTF).

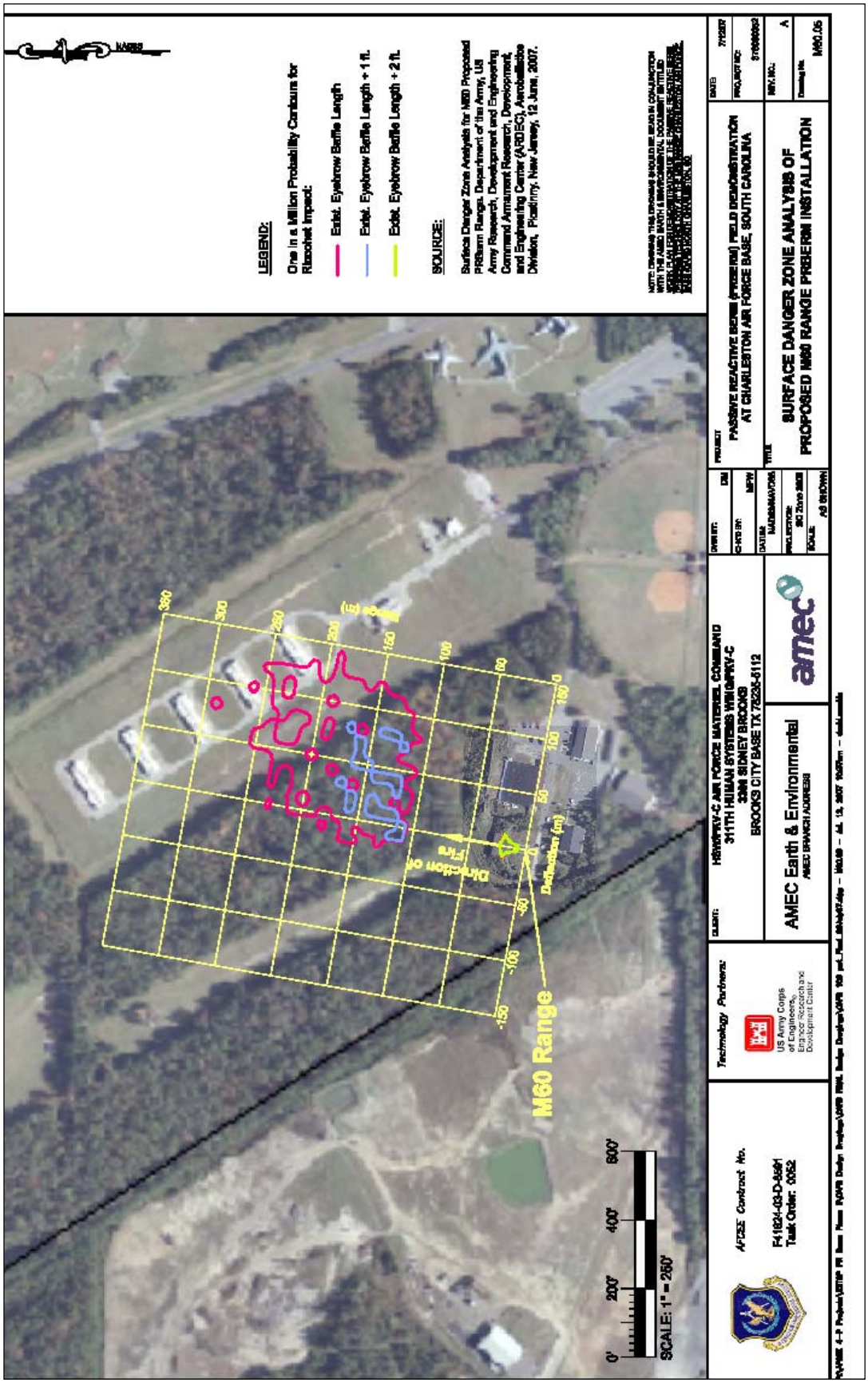

Figure 9. Aerial view of the M-60 range at the CAFB indicating the potential decrease of the ricochet hazard area by construction of a new eyebrow on the firing platform (AMEC).

The TRAPPS™ amendment would be tested alone and with the addition of the TTF. TRAPPS™ is a COTS product, a formulation of apatite and other insoluble phosphate mineral, in which lead is precipitated as stable mineral (e.g. pyromorphite). According to the manufacturer, TRAPPS™ also does not cause increased mobilization of copper, arsenic, and antimony or release excessive amounts of phosphate (Slater, UK 2010).

The second amendment is thermally treated fish bones (TTF). Fishbone is a source of biogenic apatite known to sequester lead from solution (Martin et al. 2008). Thermal treatment removes organic carbon that interferes with lead sorption sites. This increases the treatment effectiveness over the long-term versus increased product cost in the short-term. The TTF was also found, in bench-scale studies, to achieve the regulatory TCLP discharge limit for lead. The use of a limited amount of the TTF in this study provided another opportunity to explore the effects of the TTF on heavy metal immobilization through the TCLP analysis.

Lysimeter Construction

The three lysimeters placed inside the impact berm of the M6-0 range were constructed from International Organization for Standardization (ISO) Standard 20-foot by 8-foot insulated containers by Sea Box, Inc., located in East Riverton New Jersey (Figure 10). The lysimeters were designed for the collection of surface runoff water and leachate. The lysimeters were lined with stainless steel interior and equipped with aluminum “t” channel floors. Polyethylene sheets were placed inside of each lysimeter to create an impermeable lining to the lysimeter and to ensure that the leachate drained towards the well screen located at the down-slope end of the lysimeter. For piping, a 4-inch diameter Schedule 80 polyvinyl-chloride (PVC) “0.010 slot” was wrapped in geotextile fabric. The leachate collection piping passed through the lysimeter walls using water-tight bulkhead fittings sealed with a solvent-weld (Figure 11). The existing drain openings in the bottom of the container were plugged with removable stoppers. The door end of each container was cut back to match the slope of the final grade of the berm face (1:2), and the cut edges of the walls were capped with aluminum.

Construction details of the leachate collection system are shown in Figures 11 and 12. For the lysimeter that contained both TRAPPS™ and thermally treated fish bones, a high-density polyethylene lysimeter measuring 0.787 m (31 in.) by 0.787 m by 0.609 m (24 in.) was placed inside of the stainless steel lysimeter. The polyethylene lysimeter contained 5% TTF. Separate leachate collection piping was attached to the stainless steel lysimeter and the polyethylene lysimeter insert.

Figure 10. Completed field lysimeter prior to transport to the CAFB range.

Figure 11. Interior view of the completed lysimeter demonstrating the ridged bottom to facilitate flow of the leachate from the amended ballistic sand.

Figure 12. Interior view of the completed field lysimeter demonstrating the leachate collection system.

Lysimeter Assembly at the CAFB Range

The amendments used in the three lysimeters placed inside the impact berm of the M60 range are shown in Table 2.

Table 2. Amendment composition in the three field demonstration lysimeters.

Lysimeter Location and Amendment Composition		
Left Lysimeter	Center Lysimeter	Right Lysimeter
Washed ballistic sand mixed with 5% TRAPPS™	Washed ballistic sand mixed with 5% TRAPPS	Washed ballistic sand
5% TTF in a separate container within the Sand/TRAPPS		

Detailed diagrams of the lysimeters and the leachate and surface water collection systems are provided in Figures 13, 14, and 15.

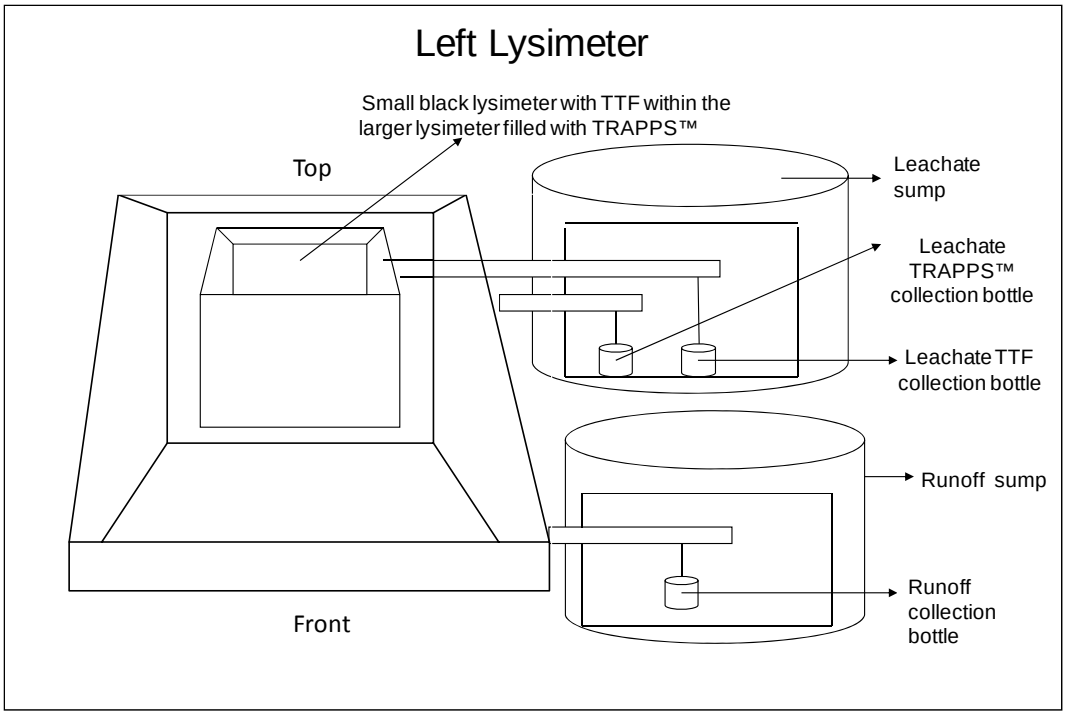

Figure 13. Assembly diagram of the left lysimeter showing arrangement of the leachate and runoff water collection systems.

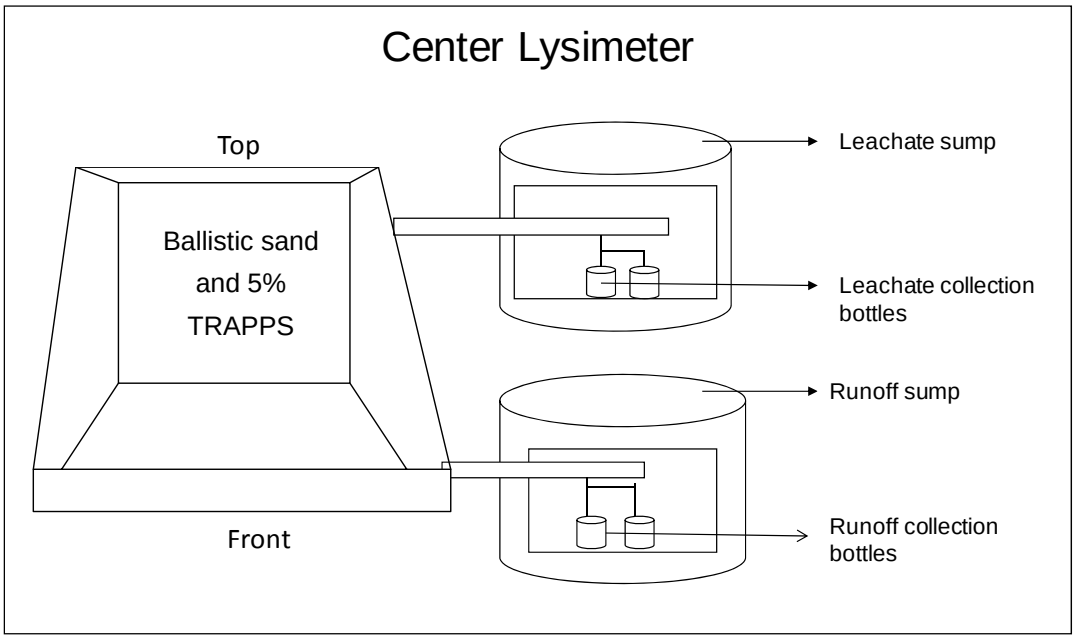

Figure 14. Assembly diagram of the center lysimeter showing arrangement of the leachate and runoff water collection systems.

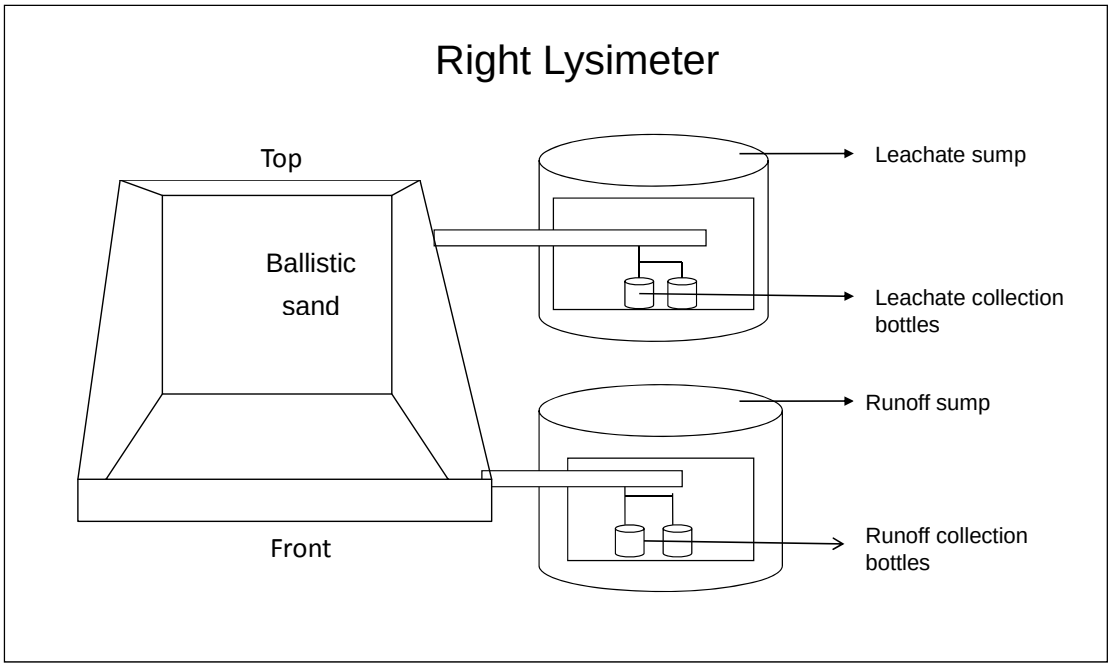

Figure 15. Assembly diagram of the right lysimeter showing arrangement of the leachate and runoff water collection systems.

Approximately 12 tons of sand and approximately 1/3rd ton of amendment was used for construction of the M-60 PRBerm™. Additional sand was used in construction of the plumbing systems and to stabilize the lysimeters, as specified in the design drawings. Additional stockpiled amendment was available to apply to the PRBerm™ should the sample analysis indicate that additional amendment was needed. A series of photographs (Figures 16, 17, 18 and 19) show the sequence of construction steps to install the three lysimeters in the impact berm in front of the firing positions of the M-60 range at the CAFB. The only operational maintenance required on the berm was occasional reshaping of the berm face to prevent formation of bullet pockets and exposure of the lysimeters.

Sample Collection and Analysis

Berm Soil Samples

Initial and final berm fill (i.e., sand) samples were collected to determine metal concentrations, TCLP and SPLP leaching concentrations, DDI suspend and settle concentrations, partition coefficient, and pH. For the final soil sampling, bulk and dimensional samples were collected from each of the lysimeters. The lysimeter dimensional samples were based on the following measurements:

Figure 16. Removal of the old impact berm composed of local soil from under the newly constructed protective eyebrow.

Figure 17. Placement of the three lysimeters in the impact berm in line with the three fixed firing positions.

Figure 18. Placement of the amended ballistic sand in the lysimeters.

Figure 19. The completed impact berm enclosing the three experimental treatment lysimeters on the range, CAFB.

1. 0-4 feet x 0-5 feet
2. 0-4 feet x 5-10 feet
3. 4-8 feet x 0-5 feet
4. 4-8 feet x 5-10 feet

These samples were taken with plastic cores 1-in. in diameter and 8-in. in length. Nine subsamples were collected and analyzed from each lysimeter. Triplicates analysis were performed on each of the nine subsamples.

Analyses for total metals in soils were performed using USEPA SW846 Method 3051 (1999a). The TCLP was performed on both bulk soil and the dimensional core samples using a 1:20 soil:solution ratio. The SPLP was performed only on the bulk soil samples using Extraction Fluid #1 and a 1:20 soil:solution ratio. Toxicity Characteristic Leaching Procedure and SPLP samples were allowed to tumble on the tumbler for 18±2 hours. After removal from the tumbler, samples were allowed to settle for about 30 minutes and filtrates were obtained using 0.45 micron filters attached to 10 mL syringes. The DDI Suspend and Settle Leaching Procedure (DDI S&S) is a variation of the TCLP replacing the acid solution with DDI water. The DDI supend and settle test consitsted of an one (1) hour shake test and 18 hours settling time. After settling, samples were filtered using a 10 mL syringe with a 0.45 micron filter attached to 10 mL syringes. The pH was tested from the filtrates.

A 24-hour partition coefficient was performed on the pre-fired soils following procedures established in Appendix 6 of USEPA (1999b). The metals of interest for these soils were Pb, Cu, and Fe. Stock solutions were prepared using Pb nitrate (CAS#10099-74-8, Fisher Scientific), copper II sulfate pentahydrate (CAS#7758-99-8, Sigma Aldrich) and ferrous sulfate (CAS#7782-63-0, Sigma Aldrich).

A 1:10 soil to solution ratio was used for the 24-hour test. Triplicate samples of 10 grams of soil per sample was weighed into each 125 mL nalgene bottle and 100 mL of each solution was added. Sample bottles were placed on the shaker for 24 hours, removed from the shaker, and allowed to settle for 10 minutes. Liquid samples were filtered using a 0.45 micron syringe filter attached to a 10 mL syringe and stored in the dark at 4 °C until analysis was conducted.

Aqueous Samples

During the PRBerm™ field demonstration, stormwater runoff and leachate samples were collected bi-weekly using natural rain events. Samples were collected by the CAFB Bioenvironmental Engineering personnel under the general supervision of the ERDC-EL Principal Investigator (PI) or a Co-PI.

While flow-or time-averaged sampling may provide a better profile of runoff water quality over the storm event duration, there were logistical problems associated with collecting these samples. The proposed collection locations on the range could not use automated samplers because the equipment could not be located in areas that are in the line of fire. The equipment cannot be protected from being shot unless limits are placed on range use, which is not an option. As a result, manual grab samples were collected from sumps installed in the runoff flow path from each test cell on the berms and as part of the leachate collection system.

Water samples were collected in 1-L plastic bottles. The sampling collection point was then drained. Samples were preserved in accordance with EPA and ASTM preservation guidelines. Samples were properly labeled and tightly sealed to avoid cross contamination during storage and/or shipment. Samples were packaged for shipment in rigid, insulated plastic ice chests. These samples were sent to ERDC-EL for analysis via overnight delivery.

Samples were analyzed in the laboratory for metals (total and dissolved) and TSS. Samples were field filtered using 0.45 micron filters prior to shipping for dissolved metals analysis in the laboratory.

Methods

The methods and procedures detailed in Table 3 were used for chemical and physical analysis of the PRBerm™ samples. Both liquid and samples were analyzed for heavy metals using an Inductively Coupled Plasma (ICP) Atomic Emission Spectroscopy (AES), with a reporting limit of 0.025 mg/L for liquids and 5 mg/kg for soils (Perkin-Elmer Optima 4300 dual view, Perkin-Elmer, USA).

Table 3. Summary of analysis methods and frequency.

Contaminant/Parameter	Analytical Method	Analytical Frequency
Aqueous Samples		
Metals –total and dissolved	SW846-3015[a]	Bi-weekly
Total suspended solids (TSS)	SM 2540D[b]	Bi-weekly
pH	Electrode	Bi-weekly
Soil Samples		
Metals– total and dissolved	SW846-3051[a]	Initial and final
pH	Electrode	Initial and final
TCLP	SW846-1311	Final
SPLP	SW846-1312	Final
DDI S&S	Modified SW846-1311	Final
K_d	24-hr partition coefficient test[c]	Final

[a]USEPA (1999a)

[b]American Public Health Association (1998)

[c]USEPA (1999b)

4 Results and Discussion

Rounds Fired

Records were kept of the bullet type and number of rounds fired into the CAFB PRBerm™ to obtain an accurate account of the total Pb loading on the range. Background metals (Pb) concentration in the washed ballistic sand was determined. The Pb loading on the three lysimeters is detailed in Table 4. The 7.62 mm round, used in the M-60 machine gun, and the 5.56 mm round, used in the M-16 rifle, were both fired on the CAFB range. The lysimeter amended with 5% TRAPPS™ had the most 7.62 mm rounds fired into it and no 5.56 mm rounds fired into it. The smallest number of 7.62 mm rounds fired was 5,100, into both the control and 5% TRAPPS™+ 5% TTF lysimeters. The control lysimeter had 2,400 total 5.56 mm rounds fired and the 5% TRAPPS™+ 5% TTF had almost twice that number.

Table 4. Type and number of rounds fired into each lysimeter on the CAFB range during the field demonstration.

	7.62-mm rounds			5.56-mm rounds		
Date	5% TRAPPS™ + 5% TTF	5% TRAPPS™	Control	5% TRAPPS™ + 5% TTF	5% TRAPPS™	Control
March 27	200	200	200	0	0	0
June 28	100	100	100	0	0	0
July 31	0	3,400	100	2,400	0	2,400
August 18	0	0	0	1,200	0	0
September 10	600	600	0	600	0	0
October 22	4,200	4,200	0	0	0	0
December 4	0	0	4,800	0	0	0
Total	5,100	8,500	5,200	4,200	0	2,400

Aqueous Samples

Volumes Collected

Volumes were taken biweekly. The total volume results are shown in Table 5. The control lysimeter had the greatest total effluent collected. The volume of leachate from the experimental lysimeters ranged from 51% to

63% of the total for the 5% TRAPPS™ and the 5% TRAPPS™+5% TTF, respectively. The volume of runoff water from the experimental lysimeters ranged from 37% to 49% of the total volume for the 5% TRAPPS™ + 5%TTF and the 5% TRAPPS™, respectively. The most runoff was generated from the control lysimeter whereas the 5% TRAPPS™+ 5% TTF provided the most observed leachate.

Table 5. Volume of effluent collected from the PRBerm™ lysimeters during the field demonstration.

Lysimeter	Total leachate (L)	Total Runoff (L)	Total effluent (L)	Leachate (% of total)	Runoff (% of total)	Ratio of Leachate to Runoff
Control -Right	23.02	36.11	59.13	39	61	0.64
5% TRAPPS™-Center	21.94	20.68	42.62	51	49	1.06
5% TRAPPS™ - Left	18.30	[a]16.60	34.90	52	47	1.10
5% TRAPPS™ + 5% TTF – Left (insert)	9.57	[a]16.60	26.17	36	63	0.58

[a]Total runoff for 5% TRAPPS™ + 5% TTF Left (insert) is the same as 5% TRAPPS™- Left. There was only one runoff collection for both.

pH

The measured pH range was from 6.44 to 7.01 with detailed results reported in Figure 20. The unamended lysimeter had the lowest pH in both leachate and runoff water samples. The TTF leachate sample had the highest pH and the 5% TRAPPS™ + 5%TTF sample had the lowest runoff pH. Both amended and unamended lysimeters had acidic pH readings, except for the TTF leachate sample. It has been reported that inducing acidic conditions will promote the solubility of Pb compounds leading to effective Pb immobilization via formation of Pb pyromorphite (Yang et al. 2001).

The pH readings were taken for the pre- and post-firing demonstration soils (Table 6). There was a slight increase in the pH readings of the post-firing soils when compared to the pre-firing soils for all of the lysimeters. The pre- and post-firing soils yielded pH values that were slightly basic, except for the 5% TRAPPS™+ 5% TTF whose pH before firing was slightly below 7.

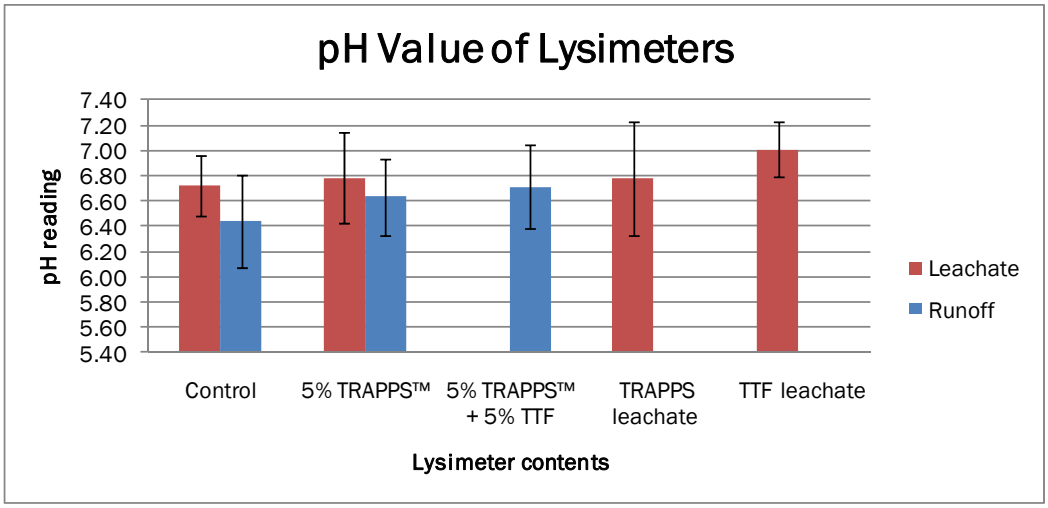

Figure 20. pH of lysimeter leachate and runoff water collected during the PRBerm™ field demonstration at the CAFB M60 range.

Table 6. Soil pH from control and experimental lysimeters pre- and post firing (n=3).

Lysimeter		pH values		
		Avg	Stdev	%Stdev
Control - Right	Pre-firing	7.73	0.15	1.88
	Post-firing	8.06	0.03	0.33
5% TRAPPS™ - Center	Pre-firing	7.29	0.03	0.42
	Post-firing	7.48	0.14	1.90
5% TRAPPS™ - Left	Pre-firing	6.95	0.10	1.42
	Post-firing	7.37	0.03	0.34
5% TRAPPS™ + 5% TTF – Left (insert)	Post-firing	7.09	0.06	0.78

Total Suspended Solids

Suspended solids provide sorption surfaces and a route of transmission for many organic contaminants, heavy metals, and some soil nutrients. The TSS concentrations from the lysimeters varied depending on the amendment. Table 7 shows the average TSS concentration for both leachate and runoff from each of the lysimeters. The lysimeter that was amended with 5% TRAPPS™ had the highest TSS concentration in both the leachate and runoff. High TSS has been correlated to higher concentrations of metals in the water. The 5% TRAPPS™ lysimeter had the highest concentration of TSS in both leachate and runoff water at 4,000 mg/L and 545 mg/L, respectively. However, the TSS values in the leachate were highly variable with a % STDEV of >300.

Table 7. Comparison of total suspended solids concentrations in leachate and runoff water collected during the PRBerm™ demonstration at the CAFB range.

Lysimeter		Total suspended solids (TSS)					
		Runoff Water (mg/L)			Leachate (mg/L)		
		AVG	STEDV	%STDEV	AVG	STEDV	%STDEV
Left	5% TRAPPS™	161	319	199	412	713	173
	5% TRAPPS™ + 5% TTF	NA	NA	NA	410	784	191
Center	5% TRAPPS™	545	850	156	4,176	13,427	322
Right	Control	120	242	202	62	57	91

NA = not applicable

Total Metals

Total (digested) metals varied over a wide range of concentrations in runoff water and leachate from the lysimeters. Table 8 shows the average concentration of total metals in the leachate. The leachate concentration for all metals were high from the 5% TRAPPS™ lysimeter when compared to the other experimental lysimeters. The Pb leachate concentrations ranged from 0.08 mg/L (control lysimeter) to 50 mg/L (5% TRAPPS™ lysimeter).

Table 8. Average concentration of total (digested) metals in lysimeter leachate (mg/L, n=3).

Metal	Lysimeter							
	Control		5% TRAPPS™		Left 5% TRAPPS™		Left 5% TTF	
	AVG*	STDEV	AVG	STDEV	AVG	STDEV	AVG	STDEV
Pb	0.08	0.16	50.13	178.40	7.89	18.82	6.35	13.25
Cr	0.03	0.00	0.09	0.16	0.03	0.01	0.03	0.01
Cu	0.13	0.22	32.74	100.07	4.75	17.42	1.31	2.58
Ni	0.02	0.00	0.08	0.13	0.03	0.01	0.03	0.01
Zn	0.05	0.05	11.03	31.05	0.28	0.49	0.22	0.35
Fe	0.51	0.52	30.51	89.46	4.84	9.66	4.20	6.38
Mn	0.03	0.01	0.32	0.82	0.06	0.08	0.06	0.07
Sb	0.21	0.31	2.26	5.66	0.20	0.36	0.16	0.27
P**	5.00	0.00	70.90	40.01	40.52	26.96	38.55	17.45

*Averages and standard deviations are calculated based on a detection limit of 0.025 mg/L for all metals except for P.

**The detection limit for P is 5.00 mg/L.

The concentrations of total (digested) metals in the runoff water (Table 9) were less in the Left 5% TRAPPS™ + 5% TTF compared to the 5% TRAPPS™ lysimeter for all metals. The 5% TRAPPS™ lysimeter had the highest concentration of total metals in the runoff water of all the experimental lysimeters.

Table 9. Average concentration of total (digested) metals in lysimeter runoff water (mg/L, n=3).

	Lysimeter					
	Control		5% TRAPPS™		5% TRAPPS™ + 5% TTF	
Metal	AVG*	STDEV	AVG	STDEV	AVG	STDEV
Pb	0.62	1.07	9.78	19.48	2.34	5.20
Cr	0.04	0.01	0.05	0.02	0.03	0.00
Cu	0.42	0.55	2.09	3.67	0.54	0.92
Ni	0.04	0.02	0.05	0.01	0.03	0.00
Zn	0.04	0.02	0.05	0.01	0.03	0.00
Fe	0.83	0.99	7.82	14.77	2.46	4.08
Mn	0.04	0.01	0.10	0.12	0.10	0.23
Sb	0.44	1.03	0.50	0.96	0.30	0.41
P**	8.23	3.04	15.81	15.23	7.62	8.80

*Averages and standard deviations are calculated based on a detection limit of 0.025 mg/L for all metals except for P.

**The detection limit for P is 5.00 mg/L.

Soluble Metals

The average concentrations of soluble metals in the lysimeter leachate are shown in Table 10. The metal with the highest leachate concentration in all the lysimeters, excluding P, was Sb. The 5% TRAPPS™ lysimeter had 74.09 mg/L of P compared to the unamended control lysimeter which had 5.00 mg/L of P.

The soluble Pb, Cr, Cu, Zn, and Fe concentrations in the runoff water decreased in both amended lysimeters when compared to the control (Table 11). The soluble Pb concentration in the control runoff water was 0.18 mg/L, 7.62 mm was 0.15 mg/L, and the Left 5% TRAPPS™ was 0.06 mg/L. When compared to the 5% TRAPPS™ lysimeter, the Left 5% TRAPPS™ lysimeter showed the greatest reduction for the soluble Pb, Cu, Ni, and Sb. The Fe concentration in the 5% TRAPPS™ lysimeter runoff water was decreased compared to the Left 5% TRAPPS™.

Table 10. Average concentration of soluble metals in lysimeter leachate (mg/L, n=3).

	Lysimeter							
	Control		5% TRAPPS™		Left 5% TRAPPS™		Left 5% TTF	
Metal	AVG*	STDEV	AVG	STDEV	AVG	STDEV	AVG	STDEV
Pb	0.03	0.01	0.11	0.28	0.03	0.02	0.03	0.01
Cr	0.03	0.00	0.04	0.01	0.03	0.00	0.03	0.00
Cu	0.03	0.02	0.09	0.08	0.03	0.00	0.03	0.00
Ni	0.03	0.00	004	0.01	0.03	0.00	0.03	0.00
Zn	0.03	0.01	0.03	0.00	0.03	0.02	0.06	0.13
Fe	0.04	0.03	0.06	0.05	0.03	0.00	0.03	0.07
Mn	0.03	0.00	0.05	0.01	0.03	0.00	0.03	0.00
Sb	0.30	0.39	0.65	1.51	0.13	0.18	0.09	0.12
P**	5.00	0.00	74.09	48.32	40.13	31.06	38.85	20.00

*Averages and standard deviations are calculated based on a detection limit of 0.025 mg/L for all metals except for P.

**The detection limit for P is 5.00 mg/L.

Table 11. Average concentration of soluble metals in lysimeter runoff water (mg/L, n=3).

	Lysimeter					
	Control		5% TRAPPS™		5% TRAPPS™ + 5% TTF	
Metal	AVG*	STDEV	AVG	STDEV	AVG	STDEV
Pb	0.18	0.29	0.15	0.32	0.06	0.08
Cr	0.04	0.01	0.03	0.01	0.03	0.00
Cu	0.24	0.38	0.23	0.30	0.08	0.10
Ni	0.04	0.01	0.05	0.01	0.03	0.00
Zn	0.04	0.01	0.03	0.01	0.03	0.00
Fe	0.30	0.36	0.15	0.17	0.25	0.51
Mn	0.04	0.01	0.04	0.01	0.04	0.07
Sb	0.38	0.71	0.53	0.92	0.37	0.50
P**	8.33	2.71	9.83	3.92	5.32	1.05

*Averages and standard deviations are calculated based on a detection limit of 0.025 mg/L for all metals except for P.

**The detection limit for P is 5.00 mg/L.

Pb for soils, leachates, and runoffs

Calculations were based on the number of rounds fired multiplied by the metal content in each of the two rounds (Tables 12 and 13). The mass of the soil was the same in each of the lysimeters. The number of rounds varied per lysimeter. The control and the 5% TRAPPS™ + 5% TTF both had the same amount of 7.62 mm rounds fired so the Pb, Cu, Zn, Fe, Mg, and Sb masses were the same. The 5%TRAPPS™ lysimeter had the most metal mass present for all metals for the 7.62 mm rounds. No 5.56 mm rounds were fired in the 5%TRAPPS™ lysimeter as shown in Table 13. The 5% TRAPPS™ + 5% TTF had the most metal mass content for the 5.56 mm round. Table 14 shows the total metal concentrations for both the 7.62 mm and 5.56 mm rounds. The highest Pb concentration was present in the 5%TRAPPS™ lysimeter. The untreated lysimeter (Control) had the least amount of Pb present in the sand.

The control lysimeter had the highest Pb concentration in the soluble runoff (Table 15), but the 7.62 mm lysimeter had the highest Pb concentration in the soil. Surface runoff transports soil particles containing adsorbed lead; this runoff assists in the migration and subsequent desorption of lead from contaminated soils. The mobility of dissolved Pb in the runoff may be due in part to the enhanced solubilization of organo-Pb when organic matter is present in the soil. Zhou and Wong (2001) states that dissolved organic carbon may enhance metal transport, especially in calcareous soil by acting as a carrier through the formation of soluble organo-metal complexes. It is estimated that these mobile, organically complexed forms of Pb could account for large cumulative losses of Pb from the soil (McBride et al. 1997). The high content of P in the 5% TRAPPS™ + 5% TTF lysimeter soil reduced the filtered Pb in the runoff samples through the formation of lead phosphates. Previous work has been completed by (Santillian-Medrano et al. 1975) suggesting that lead pyromorphite is the primary mineral controlling Pb solubility in soils amended with various forms of phosphates.

Berm Soil Samples

pH

For the pre- and post-demonstration soils pH readings were taken. Table 16 shows that there was an increase in the pH readings of the post-demonstration soils when compared to the pre-demonstration soils for all of the lysimeters. The pre-and post-demonstration soils yielded pH values that were in the neutral to alkaline range except for the 5% TRAPPS™+ 5% TTF whose pH before firing was slightly below 7.

Table 12. Calculations based on 7.62 mm round.

Metal	Metal Mass per Round, g	Mass of Sand, kg	Control			*7.62 mm			5% TRAPPS™ + 5% TTF		
			Number of Bullets Fired	Mass per Total Rounds Fired, g	Conc. in Sand, mg/kg	Number of Bullets Fired	Mass per Total Rounds Fired, g	Conc. in Sand, mg/kg	Number of Bullets Fired	Mass per Total Rounds Fired, g	Conc. in Sand, mg/kg
Pb	4.9982	19583	5100	25490.61	1301.63	8500	42484.35	2169.38	5100	25490.61	1301.63
Cu	2.8105			14333.58	731.92		23889.30	1219.86		14333.58	731.92
Zn	0.3091			1576.48	80.50		2627.47	13417		1576.48	80.50
Fe	1.5473			7891.10	402.94		13151.84	671.57		7891.10	402.94
Mg	0.0019			9.69	0.49		16.15	0.82		9.69	0.49
Sb	0.0504			257.04	13.13		428.40	21.88		257.04	13.13
Other metals	0.0326			166.26	8.49		277.10	14.15		166.26	8.49

Table 13. Calculations based on 5.56 mm round.

Metal	Metal Mass per Round, g	Mass of Sand, kg	Control			7.62 mm			5% TRAPPS™ + 5% TTF		
			Number of Bullets Fired	Mass per Total Rounds Fired, g	Conc. in Sand, mg/kg	Number of Bullets Fired	Mass per Total Rounds Fired, g	Conc. in Sand, mg/kg	Number of Bullets Fired	Mass per Total Rounds Fired, g	Conc. in Sand, mg/kg
Pb	4.9982	19583	2400	4928.40	251.66	0	0.00	0.00	4200	8624.70	440.40
Cu	2.8105			2771.28	141.51		0.00	0.00		4849.74	247.64
Zn	0.3091			304.80	15.56		0.00	0.00		533.40	27.24
Fe	1.5473			1525.68	77.91		0.00	0.00		2669.94	136.34
Mg	0.0019			11.76	0.60		0.00	0.00		20.58	1.05
Sb	0.0504			49.68	2.54		0.00	0.00		86.94	4.44
Other metals	0.0326			22.32	1.14		0.00	0.00		39.06	1.99

Table 14. Total concentration in soil for both rounds.

Metals	Control (mg/kg)	5% TRAPPS™ (mg/kg)	5% TRAPPS™ + 5% TTF (mg/kg)
Pb	1553.29	2169.38	1742.03
Cu	873.43	1219.86	979.56
Zn	96.06	134.17	107.74
Fe	480.85	671.57	539.28
Mg	1.10	0.82	1.55
Sb	15.66	21.88	17.56
Other metals	9.63	14.15	10.48

Table 15. Calculated Pb concentration in lysimeters.

Lysimeter	Pb in soil (mg/kg)	Soluble leachate (mg/L)		Soluble runoff (mg/L)		Total leachate (mg/L)		Total runoff (mg/L)	
		Avg.	St. Dev	Avg.	St. Dev	Avg.	St. Dev	Avg.	St. Dev
Control	1553.29	0.0265	0.01	0.1745	0.30	0.0809	0.16	2.3350	5.20
5% TRAPPS™	2169.38	0.1137	0.28	0.1398	0.32	50.1319	178.40	9.7802	19.48
5% TRAPPS™ + 5% TTF	1742.03	0.0365	0.15	0.0637	0.08	11.1417	28.56	0.6163	1.07
5% TRAPPS™	n/a	0.0334	0.02	n/a	n/a	7.8897	18.82	n/a	n/a
5% TTF	n/a	0.0303	0.01	n/a	n/a	6.3549	13.25	n/a	n/a

Table 16. Comparison of pre- and post-demonstration soil pH from the PRBerm™ lysimeters (n=3).

pH	Control		5% TRAPPS™		5% TRAPPS™ + 5% TTF		5% TTF
	Initial	Final	Initial	Final	Initial	Final	Final
Average	7.73	8.06	7.29	7.48	6.95	7.37	7.09
STDEV	0.15	0.03	0.03	0.14	0.10	0.03	0.06
% STDEV	1.88	0.33	0.42	1.90	1.42	0.34	0.78

Total Metals Post-Firing

Table 17 shows the average total (digested) metal concentrations in the post-firing bulk soil samples taken at the conclusion of the field demonstration. The unamended control lysimeter had the highest concentrations of Pb, Cu, Zn, Sb, and As when compared to the amended lysimeters. The lysimeter amended with TRAPPS™ had lower Pb, Cu, Zn, and Sb concentrations than the other amended lysimeter,

Toxicity Characteristic Leaching Potential (TCLP)

The Pb concentration from TCLP (Table 18) was higher than the USEPA regulatory concentration level of 5-mg/L for all lysimeters except for the left lysimeter inset which contained 5% TTF. The amended lysimeters had lower TCLP metal concentrations of Pb, Cu, Zn, Sb, and As when compared to the unamended control lysimeter.

Table 17. Average concentration of total (digested) metals in bulk lysimeter soil post-firing (mg/kg, n=3).

	Lysimeter							
	Control		5% TRAPPS™		Left 5% TRAPPS™		Left 5% TTF	
Metal	AVG	STDEV	AVG	STDEV	AVG	STDEV	AVG	STDEV
Pb	10,215	1,842	2,477	894	6,566	546	186	15
Cr	ND	*	13	0.5	ND	*	24	5
Cu	905	249	354	12	628	12	95	22
Ni	ND	*	8	0.5	ND	*	16	4
Zn	92	24	37	3	62	1	13	2
Fe	656	63	6,742	386	2,078	497	15,537	4,754
Mn	ND	*	39	1	10	2	87	29
Sb	115	16	28	15	74	16	ND	*
Ca	372	26	3,761	92	1,098	7	4,273	213
As	7	2	ND	*	ND	*	ND	*
P**	ND	*	2,942	143	2,098	96	3,729	218

ND = non-detect. The detection limit is 0.025 mg/Kg for all metals except P

*Not applicable

**The detection limit for P is 5.00 mg/Kg.

Table 18. Average TCLP metal concentration of post-firing bulk lysimeter soils (mg/Kg, n=3).

	Lysimeter							
	Control		5% TRAPPS™		Left 5% TRAPPS™		Left 5% TTF	
Metal	AVG	STDEV	AVG	STDEV	AVG	STDEV	AVG	STDEV
Pb	473	9	147	3	64	0.4	2	1
Cr	ND	*	0.1	0	0.1	0	ND	*
Cu	28	0	6	0.1	7	0	ND	*
Ni	<1	0	0.1	0	0.2	0	0.2	0
Zn	3	0	1	0	1	0	0.1	0
Fe	7	0.3	71	2	45	1	6	1
Mn	<1	0	2	0	1	0	1	0
Mo	ND	*	ND	*	ND	*	<1	0
V	ND	*	ND	*	ND	*	ND	*
Sb	5	0.1	<1	0	<1	0	<1	0

ND = non-detect. The detection limit is 0.025 mg/Kg for all metals.

*Not applicable

The unamended control lysimeter, which has a higher total Pb concentration, also has the highest TCLP Pb concentration. In order to compare the Pb leachability ratios, the TCLP Pb was divided by the Total Pb soil concentration. The TCLP Pb was first multiplied by 20 (the ratio of liquid to solid in the TCLP procedure). The highest leachability ratio was in the 7.62 mm lysimeter (119.00%) > control lysimeter (92.68%) > Left 5% TRAPPS™ lysimeter (19.55%), > inset lysimeter (18.15%) (Table 19). The control lysimeter had a leachability ratio smaller than the amended lysimeters.

Table 19. Average TCLP Pb, Total Pb and the Pb leachability ratios (TCLP to total Pb)) in lysimeters.

Lysimeter	TCLP Pb (mg/L)	Total Pb (mg/Kg)	Leachability Ratio (%)
Control	473	10,215	93
5% TRAPPS™	147	2,477	119
Left 5% TRAPPS™	64	6,566	20
Left 5% TTF	2	186	18

Table 20 compares the TCLP metals concentrations in pre-firing soil with those in post-firing soil. TCLP concentrations in the post-firing soil increased for all metals except Ca and P which decreased in the amended lysimeters. There was an increase in post-firing soil Ca concentration for the unamended control lysimeter.

Table 21 shows the concentration of metals after TCLP extraction in the post-firing soil sampled at different dimensions. For the unamended and amended lysimeters, the farther the soil sample was taken from the bottom of the lysimeter, the higher the concentration of Pb, Cu, and Zn was present. The soil samples taken from the control lysimeter at all four dimensions had lower concentrations of all metals listed. The metal concentrations for each dimension varied with the amendments.

DDI Suspend and Settle Leaching Procedure (DDI S&S)

The average concentration of metals in solution determined by the DDI S&S procedure is shown for the bulk soil samples in Table 22. The Pb concentrations ranged from 0.04 to 0.56 mg/L. The Left 5% TRAPPS™ lysimeter had the lowest Pb concentration and the 5% TRAPPS™ lysimeter had the highest Pb concentration.

Table 20. Comparison of average TCLP metal concentrations from pre-firing and post-firing soil (mg/L, n=3).

	Lysimeter treatment													
	Control				5% TRAPPS™				Left 5% TRAPPS™				Left 5% TFF	
	Pre		Post		Pre		Post		Pre		Post		Post	
Metal	AVG	STDEV	AVG	STDEV	AVG	STDEV	AVG	STDEV	AVG	STDEV	AVG	STDEV	AVG	STDEV
Pb	ND	*	473.37	8.52	ND	*	147.40	3.13	ND	*	64.19	0.38	1.69	0.78
Cr	ND	*	ND	*	ND	*	0.05	0.00	ND	*	0.05	0.00	ND	*
Cu	ND	*	28.11	0.12	0.06	0.03	4.62	0.08	ND	*	6.55	0.01	0.20	0.01
Ni	0.03	0.00	0.03	0.00	0.08	0.01	0.28	0.00	0.07	0.01	0.23	0.00	0.16	0.00
Zn	ND	*	2.98	0.04	0.13	0.01	1.19	0.01	0.11	0.00	1.23	0.02	0.09	0.00
Fe	0.42	0.59	6.87	0.32	0.40	0.23	71.02	2.18	0.67	0.31	44.87	0.58	6.39	0.76
Mn	ND	*	0.10	0.01	0.48	0.02	1.51	0.01	0.37	0.04	0.92	0.01	0.60	0.01
Mo	ND	*	ND	*	ND	*	ND	*	ND	*	ND	*	0.03	0.01
V	ND	*	ND	*	ND	*	ND	*	ND	*	ND	*	ND	*
Sb	ND	*	5.32	0.09	ND	*	0.43	0.01	ND	*	0.08	0.00	0.03	0.01
Ca	14.17	3.74	13.22	0.41	169.47	12.56	48.97	0.20	69.21	3.89	34.89	0.16	122.30	2.02
As	ND	*	0.05	0.01	ND	*	ND	*	ND	*	ND	*	ND	*
P**	ND	*	ND	*	12.52	5.06	ND	*	8.20	1.75	ND	*	18.79	0.34

ND = non-detect. The detection limit is 0.025 mg/L except for P.
*not applicable
**The detection limit for P is 5.0 mg/L.

Table 21. Average post-firing TCLP metal concentrations in lysimeters at different dimensions (mg/L, n=3).

	Lysimeter and sampling depth							
	Control				5% TRAPPS™			
Metal	0-4'L:0-5'H	4-8'L:0-5'H	0-4'L:5-10H	4-8'L:5-10'H	0-4'L:0-5'H	4-8'L:0-5'H	0-4'L:5-10H	4-8'L:5-10'H
Pb	153± 38	158 ±50	277 ±78	216 ±43	47± 48	53 ±41	144 ±97	53 ±26
Cr	ND	ND	ND	ND	0.04 ±0.01	0.15± 0.09	0.05 ±0.01	ND
Cu	5±2	8± 2	11± 3	11± 2	3± 2	3 ±2	7±4	4 ±2
Ni	ND	ND	ND	ND	0.21 ±0.08	0.37± 0.09	0.37± 0.08	0.12± 0.06
Zn	0.73± 0.23	0.82± 0.18	1.58± 0.38	1.39± 0.15	0.77± 0.60	0.62± 0.40	1.83± 0.62	0.94± 0.47
Fe	0.91 ±0.73	1.18± 0.49	0.64 ±0.39	0.36±0.24	73± 23	99± 55	63± 21	23 ±11
Mn	0.03± 0.00	0.04± 0.01	0.04 ±0.01	0.04± 0.00	0.86± 0.29	1.28 ±0.30	1.46± 0.36	0.50 ±0.18
Mo	ND	ND	ND	ND	ND	0.07± 0.04	ND	ND
V	ND	ND	ND	ND	ND	0.05 ±0.00	ND	ND
Sb	1.22±0.32	1.43± 0.27	1.52± 0.44	1.23± 0.21	0.50 ±0.29	0.95± 0.85	0.10± 0.05	0.51± 0.24
Ca	5± 1	8± 1	6± 2	7±1	87 ±34	28± 6	52± 22	22±7
As	ND	ND	ND	ND	ND	ND	ND	ND
P*	ND	ND	ND	ND	ND	ND	ND	ND

ND=non-detect. The detection limit is 0.025 mg/L except for P.
*the detection limit for P is 5.0 mg/L.

Table 22. Average metal concentrations (mg/L) for bulk lysimeter soil samples post-DDI suspend and settle (n=3).

	Lysimeter							
	Control		5% TRAPPS™		Left 5% TRAPPS™		Left 5% TTF	
Metal	AVG	STDEV	AVG	STDEV	AVG	STDEV	AVG	STDEV
Pb	0.37	0.01	0.44	0.01	0.04	0.00	0.36	0.05
Cr	ND	*	ND	*	ND	*	ND	*
Cu	0.04	0.00	0.06	0.00	ND	*	0.56	0.02
Ni	ND	*	ND	*	ND	*	ND	*
Zn	ND	*	ND	*	ND	*	0.10	0.00
Fe	0.04	0.00	0.35	0.00	ND	*	ND	*
Mn	ND	*	ND	*	ND	*	ND	*
Mo	ND	*	ND	*	ND	*	ND	*
V	ND	*	ND	*	ND	*	ND	*
Sb	0.15	0.00	0.17	0.00	0.29	0.01	0.20	0.00

ND = non-detect. The detection limit is 0.025 mg/Kg for all metals.

*Not applicable

Table 23 compares the pre and post samples taken at the site after a DDI S&S test. The 5% TTF inset lysimeter only shows the results for post samples taken after firing on the range. For all three lysimeters, the Pb, Cu, and Sb concentrations were higher in the post soils than in the pre soils. There was an increase in the Fe and Ca present for the pre soils in all lysimeters. The other metals were below detection limits.

Table 24 shows the concentration of metals after DDI S&S in the post-firing soil sampled at different dimensions. No phosphorus was detected in the unamended and the amended lysimeter. For the Pb concentration in the control lysimeter, the 0-4'L: 0-5'H sample was greater than the 0-4'L: 5-10'H. The control lysimeter samples taken farthest away from the bottom had higher Cu, Zn, Fe, Sb, and Ca concentrations. For example, the control samples taken at 4-8'L: 5-10'H had higher Pb, Cu, Zn, Sb, and As concentrations compared to samples taken closer to the bottom. The amended lysimeter also had greater Pb, Cu, Sb, and As concentrations for samples taken farthest away from the bottom.

Table 23. Comparison of average DDI S&S metal concentrations from pre-firing and post-firing soil (mg/L, n=3).

	Lysimeter treatment													
	Control				5% TRAPPS™				Left 5% TRAPPS™				Left 5% TTF	
	Pre		Post		Pre		Post		Pre		Post		Post	
Metal	AVG	STDEV	AVG	STDEV	AVG	STDEV	AVG	STDEV	AVG	STDEV	AVG	STDEV	AVG	STDEV
Pb	ND	*	0.37	0.01	ND	*	0.44	0.01	ND	*	0.04	0.00	0.36	0.05
Cr	ND	*	ND	*	ND	*	ND	*	ND	*	ND	*	ND	*
Cu	ND	*	0.04	0.00	ND	*	0.06	0.00	ND	*	ND	*	0.56	0.02
Ni	ND	*	ND	*	ND	*	ND	*	ND	*	ND	*	ND	*
Zn	ND	*	ND	*	ND	*	ND	*	ND	*	ND	*	0.10	0.00
Fe	0.40	0.04	0.04	0.00	1.94	0.32	0.35	0.00	2.13	0.16	ND	*	ND	*
Mn	ND	*	ND	*	ND	*	ND	*	ND	*	ND	*	ND	*
Mo	ND	*	ND	*	ND	*	ND	*	ND	*	ND	*	ND	*
V	ND	*	ND	*	ND	*	ND	*	ND	*	ND	*	ND	*
Sb	ND	*	0.15	0.00	ND	*	0.17	0.00	ND	*	0.29	0.01	0.20	0.00
Ca	7.29	0.87	1.98	0.03	18.06	0.94	3.71	0.07	12.77	1.48	6.03	0.06	11.94	0.06
As	ND	*	ND	*	ND	*	ND	*	ND	*	ND	*	ND	*
P**	ND	*	ND	*	ND	*	ND	*	ND	*	ND	*	18.79	0.20

ND = non-detect. The detection limit is 0.025 mg/L except for P.

*not applicable

**The detection limit for P is 5.0 mg/L.

Table 24. Average post-firing DDI S&S metal concentrations in lysimeters at different dimensions (mg/L, n=3).

	Lysimeter and sampling depth							
	Control				5% TRAPPS™			
Metal	0-4'L:0-5'H	4-8'L:0-5'H	0-4'L:5-10H	4-8'L:5-10'H	0-4'L:0-5'H	4-8'L:0-5'H	0-4'L:5-10H	4-8'L:5-10'H
Pb	1.18±1.91	0.46±0.29	0.90±0.43	0.97±0.48	0.44±0.27	1.43±1.26	1.23±1.80	5.47±7.68
Cr	ND	ND	ND	ND	ND	ND	ND	ND
Cu	0.13±0.12	0.10±0.05	0.15±0.05	0.25±0.24	0.12±0.08	0.16±0.12	0.22±0.16	0.77±1.05
Ni	ND	ND	ND	ND	ND	ND	ND	ND
Zn	0.02±0.02	ND	0.03±0.00	0.03±0.00	ND	ND	0.05±0.04	ND
Fe	0.12±0.07	0.09±0.02	0.15±0.08	0.09±0.05	0.77±0.88	0.45±0.31	0.60±0.21	17.64±24.43
Mn	ND	ND	ND	ND	ND	ND	ND	0.20±0.22
Mo	ND	ND	ND	ND	ND	ND	ND	ND
V	ND	ND	ND	ND	ND	ND	ND	ND
Sb	0.17±0.06	0.13±0.05	0.27±0.12	0.21±0.06	0.12±0.09	0.22±0.07	0.32±0.11	0.13±0.10
Ca	1.16±0.41	1.32±0.42	1.49±0.69	ND	6.39±1.14	ND	ND	ND
As	ND	ND	ND	1.36±0.65	ND	4.94±0.86	4.72±0.68	12.16±8.11
P*	ND	ND	ND	ND	ND	ND	ND	ND

ND=non-detect. The detection limit is 0.025 mg/L except for P.

*the detection limit for P is 5.0 mg/L.

Synthetic Precipitation Leaching Procedure (SPLP)

As can be seen in Table 25, the pre SPLP Fe concentration for the control lysimeter was 0.20 ppm and 0.06 ppm for the post soil SPLP concentration. The Left 5% TRAPPS™ also showed a decrease in the post soil Fe concentration. For the post samples, the inset lysimeter had 0.12 ppm Pb and the control had 2.46 ppm Pb. The post Pb and Cu concentrations for the 7.62 mm and Left 5% TRAPPS™ lysimeters were also less the control lysimeter.

Table 26 shows the SPLP leaching concentrations for the post soils. The Pb concentration was highest in the leachate from the control lysimeter, followed by the 7.62 mm lysimeter, Left 5% TRAPPS™, and the inset lysimeter. The control lysimeter had higher Cu and Zn concentrations compared to the other three samples. More Sb was leached from the Left 5% TRAPPS™ and more Fe from the 7.62 mm lysimeter when compared to the other lysimeters.

Table 25. Comparison of average SPLP metal concentrations from pre-firing and post-firing soil (mg/L, n=3).

	Lysimeter treatment													
	Control				5% TRAPPS™				Left 5% TRAPPS™				Left 5% TFF	
	Pre		Post		Pre		Post		Pre		Post		Post	
Metal	AVG	STDEV	AVG	STDEV	AVG	STDEV	AVG	STDEV	AVG	STDEV	AVG	STDEV	AVG	STDEV
Pb	0.03	0.00	2.46	2.65	0.03	0.00	0.53	0.41	0.03	0.00	0.13	0.01	0.12	0.04
Cr	0.03	0.00	0.03	0.00	0.03	0.00	0.03	0.00	0.03	0.00	0.03	0.00	0.03	0.00
Cu	0.03	0.00	0.62	0.59	0.03	0.00	0.13	0.08	0.03	0.00	0.09	0.00	0.03	0.01
Ni	0.03	0.00	0.03	0.00	0.03	0.00	0.03	0.00	0.03	0.00	0.03	0.00	0.03	0.00
Zn	0.03	0.00	0.15	0.11	0.03	0.00	0.03	0.00	0.03	0.00	0.05	0.00	0.03	0.00
Fe	0.20	0.03	0.06	0.06	0.03	0.00	0.40	0.29	0.24	0.05	0.07	0.01	0.18	0.02
Mn	0.03	0.00	0.03	0.00	0.03	0.00	0.03	0.00	0.03	0.00	0.05	0.00	0.03	0.00
Mo	0.03	0.00	0.03	0.00	0.03	0.00	0.03	0.00	0.03	0.00	0.03	0.00	0.03	0.00
V	0.03	0.00	0.03	0.00	0.03	0.00	0.03	0.00	0.03	0.00	0.03	0.00	0.03	0.00
Sb	0.03	0.00	0.21	0.06	0.03	0.00	0.12	0.01	0.03	0.00	0.38	0.01	0.03	0.00
Ca	4.72	0.13	2.71	1.05	17.50	0.42	4.67	2.25	10.21	5.50	21.73	0.55	8.68	0.62
As	0.03	0.00	0.03	0.00	0.03	0.00	0.03	0.00	0.03	0.00	0.03	0.00	0.03	0.00

ND = non-detect. The detection limit is 0.025 mg/L except for P.

*not applicable

Table 26. Average metal concentrations (mg/L) for bulk lysimeter soil samples post-SPLP (n=3).

	Lysimeter							
	Control		5% TRAPPS™		Left 5% TRAPPS™		Left 5% TTF	
Metal	AVG	STDEV	AVG	STDEV	AVG	STDEV	AVG	STDEV
Pb	2.46	2.65	0.53	0.41	0.13	0.01	0.12	0.04
Cr	0.03	0.00	0.03	0.00	0.03	0.00	0.03	0.00
Cu	0.62	0.59	0.13	0.08	0.09	0.00	0.03	0.01
Ni	0.03	0.00	0.03	0.00	0.03	0.00	0.03	0.00
Zn	0.15	0.11	0.03	0.00	0.05	0.00	0.03	0.00
Fe	0.06	0.06	0.40	0.29	0.07	0.01	0.18	0.02
Mn	0.03	0.00	0.03	0.00	0.05	0.00	0.03	0.00
Mo	0.03	0.00	0.03	0.00	0.03	0.00	0.03	0.00
V	0.03	0.00	0.03	0.00	0.03	0.00	0.03	0.00
Sb	0.21	0.06	0.12	0.01	0.38	0.01	0.03	0.00

ND = non-detect. The detection limit is 0.025 mg/Kg for all metals.

*Not applicable

Partition Coefficient (K_d)

The data generated from the Pb and Sb sorption K_d experiments yielded adsorption isotherms for each soil type in the three lysimeters. Metal soil concentrations were obtained by subtracting the concentration of the given metal from the total mass of metal added to the system. While filtering is a possible source of metal loss, standard procedure for K_d determination using the batch method involves analysis of a filtered solution. The material retained on the filter is defined as insoluble material (USEPA 1999). Complete data for each lysimeter is available in Appendix A. A representative example is given here for linear isotherms obtained from the experimental soils.

Linear Isotherm for Sb III and Sb V

Results from triplicate metal analyses (including average and standard deviation) for each soil is included in Appendix A. A summary of the results of a linear fit determination of sorption K_d using a section of the curve in the linear region (per K_d discussion in USEPA 1999) is provided. In each of the tables, the phrase "r^2 values for all data points" reflect points from all concentrations. The phrase "all data points" refers to the entire plot of C_{is} vs. C_{iw} used to determine the shape of the isotherm. A least squares fit was

performed using selected points in the linear portion of the isotherm to produce a K_d value that is valid for the entire concentration range.

The Sb III K_d values ranged from a high of 15.77 (Left TRAPPS™) to a low of 0.75 (Control) (Table 27). The Sb V K_d values ranged from a high of 1.51 (Left TRAPPS™) to a low of 0.49 (Control). All three lysimeter soils had low K_{d100} values (<10).

Table 27. Summary of Sb(III) and Sb(V) linear K_d data.

	Sb(III)		Sb(V)	
Lysimeter	K	R^2	K	R^2
Control	0.75	1.00	0.49	0.91
5% TRAPPS™	8.81	0.91	0.64	0.98
Left 5% TRAPPS™+ 5% TTF	15.77	0.96	1.51	0.96

5 Conclusions and Recommendations

In a SAFR design where native soil is being replaced with an impact material, the need to control migration of heavy metals from the range is the reduction of Pb in surface and ground water. Leachate in these designed systems can be minimized or eliminated by the use of low permeability barriers during construction and renovation. From the standpoint of mobility, heavy metal cations in the bullet matrix (e.g., Pb and Cu), have a low potential for migration off-range due to the low solubility constants of these metals and their salts in soil (Alloway 1995). Most in situ stabilization amendments at military small arms firing ranges are designed to immobilize or reduce Pb mobility. A variety of phosphate (PO_4) based amendments have been tested for in situ Pb stabilization in soil (Cao et al. 2003; Chen et al. 2006). Phosphate has been shown to sequester Pb in forms that are insoluble and biologically unavailable (Dermatas et al. 2006; Tardy et al. 2003; USEPA 2001a). Application of soluble or solid phase phosphate (such as hydroxyapatite, HAP) amendments have been shown to result in the formation of Pb-phosphate minerals such as pyromorphite [$Pb_5(PO_4)3X$ where X can be Cl^-, OH^-, F^-]. As suggested in Chrysochoou et al. (2007), the influence of phosphorus on co-contaminants such as oxyanions should be addressed.

In order to evaluate the impact of bullets deposited at shooting ranges onto soils and the areas surrounding the range, the behavior of bullets needs to be understood. Concentrations of Pb in pore water from shooting range soils or in groundwater or water bodies nearby are scarce (Labare et al. 2004). Many investigators have tested the leachability of Pb from shooting range soils, but these are mostly batch study experiments (Leuz 2006). Leaching experiments closer to field conditions are needed to better assess the capacity of soils to release Pb and other metals.

The results of this study indicate that variation in the amount and type of rounds fired into berms has an effect on the Pb concentrations contained in leachate and runoff. The control lysimeter had the least amount of rounds fired into the impact area, which caused it to have the lowest Pb concentration. The 7.62 mm lysimeter that was amended with 5% TRAPPS™ had the highest total Pb concentrations in both leachate and

runoff. This is not what was expected due to the fact that this was an amended lysimeter. Based on current controlled treatability studies, it was hypothesized that the amended cells yield a lower concentration of Pb.

The inset lysimeter that contained 5% TTF passed the regulatory limits for Pb, Cr, Ni, As, and Sb. This means that the soil could be disposed of in a non-hazardous waste landfill. If the amount of a particular chemical or metal exceeds the regulatory limits, the sample is considered hazardous and must be handled according to certain regulations. Non-hazardous waste provides a low cost disposal option as compared to hazardous waste. For the TCLP tests, there was a decrease seen in the concentration of Pb for the amended lysimeters when compared to the unamended lysimeter. Even though both amendments decrease Pb concentrations, the inset lysimeter that contained the thermally treated fishbones performed the best.

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Appendix A: Field Data

Aqueous Samples - Volume

Table A1. Volume of leachate and runoff.

	Control		5% TRAPPS™		Left 5% TRAPPS™	Left 5% TTF	5% TRAPPS + 5% TTF
Sample date	leachate	runoff	leachate	runoff	leachate	leachate	runoff
04/08/2009	1.07	2.02	2.01	1.49	0.37	0.50	1.06
04/22/2009	0.98	1.76	1.00	1.81	NS	NS	0.64
05/20/2009	0.96	2.13	2.09	2.12	1.05	1.04	1.00
06/03/2009	1.00	1.75	0.35	1.01	1.07	0.42	1.07
06/17/2009	1.03	2.15	2.14	1.80	1.04	0.12	1.11
07/01/2009	0.86	1.07	NS	NS	1.06	NS	1.09
07/15/2009	1.06	1.41	1.63	0.16	0.87	NS	0.99
07/29/2009	1.05	0.82	NS	NS	NS	NS	NS
08/12/2009	1.19	2.08	1.80	0.32	NS	NS	0.79
08/26/2009	1.17	0.56	2.04	NS	1.06	1.06	NS
09/09/2009	0.98	1.02	1.00	NS	1.00	NS	NS
10/07/2009	0.99	1.24	NS	NS	NS	0.37	0.29
10/21/2009	1.04	1.01	NS	NS	NS	NS	0.68
11/04/2009	NS	1.07	NS	NS	1.07	NS	NS
11/18/2009	1.16	1.19	NS	0.63	0.16	1.15	0.92
12/02/2009	1.07	1.02	NS	0.94	1.04	NS	NS
12/16/2009	1.08	2.07	1.89	1.15	1.03	NS	1.03
12/30/2009	1.06	1.96	0.40	1.63	1.08	1.02	0.42
01/13/2010	1.07	0.66	NS	NS	0.28	NS	NS
01/27/2010	1.07	1.81	1.92	2.12	1.07	1.02	0.98
02/10/2009	1.07	2.11	0.82	NS	0.89	NS	0.94
02/24/2010	NS	1.01	1.47	NS	1.04	0.96	1.02
03/10/2010	NS	NS	NS	NS	NS	NS	NS
03/24/2010	NS	2.15	0.45	2.15	1.08	0.89	0.83
04/07/2010	1.06	0.71	NS	1.26	1.30	NS	0.74
06/17/2010	1.03	1.31	0.93	2.10	1.05	1.02	1.02

NS = no sample

Aqueous Samples - pH

Table A2. pH values of leachate and runoff.

	Control		5% TRAPPS™		Left 5% TRAPPS	Left 5% TTF	5% TRAPPS + 5% TTF
Sample date	leachate	runoff	leachate	runoff	leachate	leachate	runoff
04/08/2009	6.46	6.31	7.11	7.17	7.31	7.24	6.77
04/22/2009	7.06	6.25	7.53	6.83	NS	NS	6.80
05/20/2009	6.83	6.24	6.83	6.99	6.99	7.15	6.57
06/03/2009	6.82	6.03	6.66	6.43	6.81	7.06	6.43
06/17/2009	6.92	6.16	6.54	6.56	7.05	7.51	7.10
07/01/2009	7.06	6.96	NS	NS	7.16	NS	7.14
07/15/2009	6.78	6.05	6.52	6.50	6.30	NS	6.01
07/29/2009	7.13	6.89	NS	NS	NS	NS	NS
08/12/2009	6.77	6.30	6.17	6.70	NS	NS	6.64
08/26/2009	6.97	7.10	6.77	NS	6.76	6.89	NS
09/09/2009	6.60	NS	6.18	NS	6.23	NA	NS
10/07/2009	7.01	6.15	NS	NS	NS	NA	6.56
10/21/2009	6.27	5.81	NS	NS	NS	NS	6.03
11/04/2009	NS	6.61	NS	NS	8.20	NS	NS
11/18/2009	6.36	6.05	NS	6.29	6.44	6.97	7.04
12/02/2009	6.36	5.94	NS	6.00	6.17	NS	NS
12/16/2009	6.45	6.30	6.74	6.59	6.44	NS	6.49
12/30/2009	6.69	6.73	7.07	6.43	6.66	6.78	6.85
01/13/2010	6.66	6.62	NS	NS	6.76	NS	NS
01/27/2010	6.57	6.38	6.66	6.56	6.61	6.84	6.56
02/10/2009	6.69	6.58	6.6	NS	6.83	NS	6.79
02/24/2010	NS	6.52	7.14	NS	6.48	6.93	7.15
03/10/2010	NS	NS	NS	NS	NS	NS	NS
03/24/2010	NS	6.98	7.05	7.03	6.78	6.92	7.06
04/07/2010	6.68	6.65	NS	6.66	6.90	NS	6.82
06/17/2010	6.71	6.98	7.01	6.78	6.70	6.79	6.71

NS = no sample

Aqueous Samples - TSS

Table A3. Total suspended solids (TSS) values of leachate and runoff (ppm).

	Control		5% TRAPPS™		Left 5% TRAPPS	Left 5% TTF	5% TRAPPS + 5% TTF
Sample date	leachate	runoff	leachate	runoff	leachate	leachate	runoff
04/08/2009	73.00	38.00	33.00	235.00	29.00	14.00	31.00
04/22/2009	69.00	25.50	9.00	172.00	NS	NS	10.00
05/20/2009	120.00	50.00	40.00	200.00	50.00	40.00	60.00
06/03/2009	160.00	51.00	20.00	70.00	10.00	5.00	20.00
06/17/2009	159.50	10.50	21.00	51.50	9.00	17.00	763.00
07/01/2009	3.00	66.00	NS	NS	2.50	NS	108.50
07/15/2009	18.00	84.50	175.00	NS	23.50	NS	38.50
07/29/2009	32.50	39.00	NS	NS	NS	NS	NS
08/12/2009	54.00	20.00	7.00	234.50	NS	NS	2.50
08/26/2009	36.50	47.00	45.50	NS	11.50	45.00	NS
09/09/2009	47.00	15.00	0.50	NS	0.50	NES	NS
10/07/2009	20.00	35.00	NS	NS	NS	33.00	NES
10/21/2009	45.00	5.00	NS	NS	NS	NS	5.00
11/04/2009	NS	NES	NS	NS	NES	NS	NS
11/18/2009	65.00	15.00	NS	5.00	5.00	5.00	5.00
12/02/2009	6.00	29.00	NS	28.00	27.00	NS	NS
12/16/2009	45.00	135.00	10.00	30.00	11.00	NS	1070
12/30/2009	5.00	135.00	30.00	925.00	20.00	19.50	20.00
01/13/2010	30.00	20.00	NS	NS	54.00	NS	NS
01/27/2010	220.00	315.00	5350.00	2710	2210	1210.00	30.00
02/10/2009	10.00	160.00	360.00	NS	1190.00	NS	670.00
02/24/2010	NS	15.00	605.00	NS	415.00	280	25.00
03/10/2010	NS	NS	NS	NS	NS	NS	NS
03/24/2010	NS	1190	74510.00	450.00	2140	2610	20.00
04/07/2010	70.00	270.00	NS	310.00	790	NS	10.00
06/17/2010	78.50	101.00	30519.50	2202.5	827	643.50	4.50

ND=non-detect. The detection limit is 0.025 mg/L except for P. *the detection limit for P is 5.0 mg/L.

NS=no sample

Aqueous Samples – Metal Concentrations

Table A4. Digested metal concentration in leachate for control lysimeter (ppm).

Sample date	Pb	Cr	Ni	Zn	Fe	Mn	Cu	Sb	*P
04/08/2009	ND	ND	ND	ND	0.62	ND	ND	ND	ND
04/22/2009	ND	ND	ND	0.06	2.16	ND	ND	ND	ND
05/20/2009	ND	ND	ND	ND	0.69	ND	0.50	ND	ND
06/03/2009	ND	ND	ND	ND	0.98	ND	ND	ND	ND
06/17/2009	ND	ND	ND	ND	0.65	ND	ND	ND	ND
07/01/2009	ND	ND	ND	0.06	0.31	ND	ND	ND	ND
07/15/2009	ND	ND	ND	ND	0.43	ND	ND	0.06	ND
07/29/2009	ND	NA	NA	NA	0.60	ND	ND	ND	ND
08/12/2009	ND	ND	ND	ND	0.35	ND	ND	0.07	ND
08/26/2009	ND	ND	ND	ND	0.42	ND	ND	0.09	ND
09/09/2009	NA	ND	ND	ND	0.39	ND	ND	0.20	NA
10/07/2009	ND	ND	ND	ND	ND	ND	0.06	0.21	ND
10/21/2009	0.05	ND	ND	ND	0.06	ND	NS	ND	ND
11/04/2009	NS	NS	NS	NS	NS	NS	ND	NS	NS
11/18/2009	ND	ND	ND	ND	ND	ND	0.36	0.11	ND
12/02/2009	ND	ND	ND	ND	0.36	ND	NA	0.15	ND
12/16/2009	0.07	NS	NA	NS	NA	ND	0.03	NA	ND
12/30/2009	0.03	ND	ND	ND	0.07	NA	0.90	ND	ND
01/13/2010	0.04	ND	0.04	0.26	0.43	ND	ND	0.47	ND
01/27/2010	0.06	ND	ND	0.07	1.68	0.08	ND	0.50	ND
02/10/2009	NS	NS	NS	0.08	0.12	ND	NS	0.90	ND
02/24/2010	NS	NS	NS	NS	NS	NS	NS	NS	NS
03/10/2010	NS	NS	NS	NS	NS	NS	NS	NS	NS
03/24/2010	NS	NS	NS	NS	NS	NS	0.40	NS	NS
04/07/2010	0.61	ND	ND	0.03	0.30	ND	0.17	0.14	ND
06/17/2010	0.43	NS	NA	NS	0.43	ND	NA	1.23	ND

ND=non-detect. The detection limit is 0.025 mg/L except for P. *the detection limit for P is 5.0 mg/L.

NS=no sample

Table A5. Digested metal concentration in runoff for control lysimeter (ppm).

Sample date	Pb	Cr	Ni	Zn	Fe	Mn	Cu	Sb	*P
04/08/2009	ND	ND	ND	ND	1.33	ND	ND	0.09	ND
04/22/2009	ND	ND	ND	ND	1.67	ND	ND	ND	ND
05/20/2009	ND	ND	ND	ND	0.21	ND	0.08	ND	ND
06/03/2009	ND	ND	ND	ND	0.22	ND	1.12	ND	ND
06/17/2009	ND	ND	ND	ND	0.27	ND	0.09	ND	ND
07/01/2009	ND	ND	NS	0.06	0.36	NS	ND	0.08	ND
07/15/2009	ND	NS	ND	ND	0.54	ND	ND	ND	ND
07/29/2009	ND	ND	ND	ND	0.62	ND	ND	ND	ND
08/12/2009	ND	NS	ND	ND	1.40	ND	ND	ND	ND
08/26/2009	0.16	ND	NS	ND	0.51	NS	ND	ND	ND
09/09/2009	ND	NS	NS	0.10	0.54	NS	0.10	ND	ND
10/07/2009	0.23	NS	ND	0.14	0.74	ND	0.38	0.61	16.22
10/21/2009	ND	ND	NS	ND	0.19	ND	ND	0.40	ND
11/04/2009	ND	NS	ND	0.04	0.14	ND	0.11	0.04	ND
11/18/2009	ND	ND	ND	0.10	0.13	ND	0.15	0.06	ND
12/02/2009	0.03	ND	NS	0.21	0.09	ND	0.32	ND	ND
12/16/2009	NS	NS	NA	ND	4.97	NS	0.09	0.16	ND
12/30/2009	0.68	NS	ND	0.26	0.74	ND	0.55	0.11	ND
01/13/2010	0.37	ND		0.33	0.70	ND	0.94	0.22	ND
01/27/2010	1.77	ND	ND	0.29	1.68	ND	0.94	1.81	ND
02/10/2009	2.25	ND	ND	0.29	1.06	ND	0.87	0.52	ND
02/24/2010	0.50	ND	NS	0.06	0.21	ND	0.30	NS	ND
03/10/2010	NS	NS	NS	NS	NS	ND	NS	NS	NS
03/24/2010	2.49	NS	ND	0.11	0.97	ND	1.66	2.24	ND
04/07/2010	1.56	ND	ND	0.06	0.92	ND	0.54	0.29	ND
06/17/2010	4.31	ND	NA	1.39	0.46	ND	2.03	4.49	ND

ND=non-detect. The detection limit is 0.025 mg/L except for P. *the detection limit for P is 5.0 mg/L.
NS=no sample

Table A6. Digested metal concentration in leachate for 7.62 mm lysimeter (ppm).

Sample date	Pb	Cr	Ni	Zn	Fe	Mn	Cu	Sb	*P
04/08/2009	ND	ND	ND	0.08	0.08	ND	ND	ND	88.26
04/22/2009	ND	ND	ND	121.4	0.46	ND	ND	ND	16.67
05/20/2009	ND	ND	ND	ND	0.09	ND	ND	ND	113.20
06/03/2009	ND	NS	ND	ND	0.27	ND	0.46	ND	41.62
06/17/2009	NS	ND	ND	ND	0.30	ND	ND	ND	123.41
07/01/2009	ND	NS	NS	NS	NS	ND	NS	NS	NS
07/15/2009	NS	ND	ND	0.12	0.19	ND	ND	ND	107.08
07/29/2009	ND	NS	NS	NS	NS	ND	NS	NS	NS
08/12/2009	NS	ND	ND	ND	0.21	NS	ND	ND	117.34
08/26/2009	ND	ND	ND	0.15	0.05	ND	0.43	ND	114.21
09/09/2009	ND	ND	ND	ND	0.12	ND	ND	ND	59.50
10/07/2009	ND	NS	NS	NS	NS	NS	NS	NS	NS
10/21/2009	NS	NS	NS	NS	NS	NS	NS	NS	NS
11/04/2009	NS	NS	NS	NS	NS	NS	NS	NS	NS
11/18/2009	NS	NS	NS	NS	NS	NS	NS	NS	NS
12/02/2009	NS	NS	NS	NS	NS	NS	NS	NS	NS
12/16/2009	0.27	ND	ND	0.10	2.20	NS	0.10	0.09	64.42
12/30/2009	0.12	ND	ND	0.15	0.72	ND	0.06	0.11	54.29
01/13/2010	NS	NS	NS	NS	NS	NS	NS	NS	NS
01/27/2010	70.05	0.07	0.07	1.91	37.59	0.28	13.80	1.55	71.26
02/10/2009	6.43	ND	ND	0.34	4.20	0.04	1.43	0.42	17.34
02/24/2010	8.98	ND	ND	0.51	4.88	0.06	2.02	0.81	24.10
03/10/2010	NS	NS	ND	NS	NS	NS	NS	NS	NS
03/24/2010	0.08	0.68	0.55	38.75	356.40	3.24	393.20	19.59	14.43
04/07/2010	NS	NS	NS	NS	NS	NS	NS	NS	NS
06/17/2010	715.95	0.12	0.12	12.81	80.33	0.66	112.00	13.23	107.30

ND=non-detect. The detection limit is 0.025 mg/L except for P. *the detection limit for P is 5.0 mg/L.

NS=no sample

Table A7. Digested metal concentration in runoff for 7.62 mm lysimeter (ppm).

Sample date	Pb	Cr	Ni	Zn	Fe	Mn	Cu	Sb	*P
04/08/2009	ND	ND	ND	0.19	2.49	ND	0.23	ND	ND
04/22/2009	ND	ND	ND	ND	1.01	ND	ND	ND	ND
05/20/2009	0.11	ND	ND	ND	1.19	ND	0.10	ND	ND
06/03/2009	0.08	ND	ND	ND	1.08	ND	1.09	ND	ND
06/17/2009	ND	ND	ND	ND	0.71	ND	0.05	ND	ND
07/01/2009	NS	NS	NS	NS	NS	NS	NS	NS	NS
07/15/2009	ND	ND	ND	ND	0.19	ND	ND	ND	ND
07/29/2009	NS	NS	NS	NS	NS	NS	NS	NS	NS
08/12/2009	2.03	ND	ND	0.14	6.97	ND	0.63	0.08	ND
08/26/2009	NS	NS	NS	NS	NS	NS	NS	NS	NS
09/09/2009	NS	NS	NS	NS	NS	NS	NS	NS	NS
10/07/2009	NS	NS	NS	NS	NS	NS	NS	NS	NS
10/21/2009	NS	NS	NS	NS	NS	NS	NS	NS	NS
11/04/2009	NS	NS	NS	NS	NS	NS	NS	NS	NS
11/18/2009	ND	ND	ND	ND	0.23	ND	0.16	0.06	ND
12/02/2009	0.05	ND	ND	0.31	0.13	ND	0.49	0.03	6.16
12/16/2009	0.39	ND	ND	0.07	1.09	ND	0.19	ND	8.09
12/30/2009	14.56	ND	ND	0.53	0.37	0.15	2.86	0.43	29.17
01/13/2010	NS	ND	NS	NS	NS	NS	NS	NS	NS
01/27/2010	45.54	0.10	0.08	1.42	49.73	0.41	9.34	1.35	47.60
02/10/2009	NS	NS	NS	NS	NS	NS	NS	NS	NS
02/24/2010	NS	NS	NS	NS	NS	NS	NS	NS	NS
03/10/2010	NS	NS	NS	NS	NS	NS	NS	NS	NS
03/24/2010	19.22	ND	ND	0.61	17.53	0.14	3.94	1.79	12.58
04/07/2010	0.65	ND	ND	ND	1.03	0.05	0.38	0.16	ND
06/17/2010	63.95	0.07	0.07	1.70	33.61	0.32	11.87	3.37	53.56

ND=non-detect. The detection limit is 0.025 mg/L except for P. *the detection limit for P is 5.0 mg/L.

NS=no sample

Table A8. Digested metal concentration in leachate for 5% TTF (ppm).

Sample date	Pb	Cr	Ni	Zn	Fe	Mn	Cu	Sb	*P
04/08/2009	ND	ND	ND	ND	10.41	ND	ND	ND	50.62
04/22/2009	NS	NS	NS	NS	NS	NS	NS	ND	NS
05/20/2009	0.11	ND	ND	0.07	0.47	ND	ND	ND	55.30
06/03/2009	ND	ND	ND	ND	0.15	ND	0.61	ND	42.68
06/17/2009	0.57	ND	ND	ND	0.20	ND	ND	ND	23.78
07/01/2009	NS	NS	NS	NS	NS	NS	NS	NS	NS
07/15/2009	NS	NS	NS	NS	NS	NS	NS	NS	NS
07/29/2009	NS	NS	NS	NS	NS	NS	NS	NS	NS
08/12/2009	NS	NS	NS	NS	NS	NS	NS	NS	NS
08/26/2009	0.11	ND	ND	0.07	0.51	NS	ND	ND	50.03
09/09/2009	NS	NS	NS	NS	NS	NS	NS	NS	NS
10/07/2009	ND	ND	ND	ND	0.07	NS	0.07	ND	5.05
10/21/2009	NS	NS	NS	NS	NS	ND	NS	NS	NS
11/04/2009	NS	NS	NS	NS	NS	NS	NS	NS	NS
11/18/2009	ND	ND	ND	ND	ND	ND	ND	ND	36.34
12/02/2009	NS	NS	NS	NS	NS	NS	NS	NS	NS
12/16/2009	NS	NS	NS	NS	NS	NS	NS	NS	NS
12/30/2009	0.36	ND	ND	ND	0.53	ND	0.07	0.06	35.17
01/13/2010	NS	NS	NS	NS	NS	NS	NS	NS	NS
01/27/2010	18.14	ND	0.03	0.57	13.13	0.24	3.49	0.40	53.48
02/10/2009	NS	NS	NS	NS	NS	NS	NS	NS	NS
02/24/2010	3.93	ND	ND	0.22	3.17	ND	0.84	0.26	27.23
03/10/2010	NS	NS	NS	NS	NS	NS	NS	NS	NS
03/24/2010	44.75	0.03	0.05	1.18	18.96	0.19	8.80	0.98	18.51
04/07/2010	NS	NS	NS	NS	NS	NS	NS	NS	NS
06/17/2010	8.18	ND	ND	0.34	2.76	ND	1.77	0.19	64.37

ND=non-detect. The detection limit is 0.025 mg/L except for P. *the detection limit for P is 5.0 mg/L.

NS=no sample

Table A9. Digested metal concentration in leachate for 5% TRAPPS™ (ppm).

Sample date	Pb	Cr	Ni	Zn	Fe	Mn	Cu	Sb	*P
04/08/2009	ND	ND	ND	ND	1.93	ND	0.11	ND	ND
04/22/2009	NS	NS	NS	NS	NS	ND	NS	ND	NS
05/20/2009	ND	ND	ND	ND	0.19	ND	ND	ND	50.19
06/03/2009	ND	ND	ND	ND	ND	ND	0.35	ND	49.42
06/17/2009	ND	ND	ND	ND	0.11	ND	ND	ND	53.70
07/01/2009	ND	ND	ND	0.15	0.09	ND	ND	ND	47.05
07/15/2009	ND	ND	ND	0.09	0.32	ND	ND	ND	38.09
07/29/2009	NS	NS	NS	NS	NS	NS	NS	NS	NS
08/12/2009	NS	NS	NS	NS	NS	NS	NS	NS	NS
08/26/2009	ND	ND	ND	ND	0.07	ND	ND	ND	49.72
09/09/2009	ND	ND	ND	ND	ND	NS	ND	ND	64.67
10/07/2009	NS	ND	NS	NS	NS	NS	NS	NS	NS
10/21/2009	NS	NS	NS	NS	NS	NS	NS	NS	NS
11/04/2009	ND	NS	ND	ND	0.03	ND	ND	ND	ND
11/18/2009	ND	ND	ND	ND	ND	ND	ND	ND	51.46
12/02/2009	ND	ND	ND	ND	0.05	ND	0.2166	ND	103.60
12/16/2009	0.37	ND	ND	0.11	0.33	ND	0.41	0.14	39.80
12/30/2009	0.16	ND	ND	0.05	0.45	ND	0.05	0.08	23.92
01/13/2010	0.12	ND	0.04	0.07	0.28	ND	0.20	0.06	ND
01/27/2010	32.18	0.04	0.04	0.96	23.15	0.19	6.27	0.75	46.34
02/10/2009	20.80	0.03	0.03	0.70	16.05	0.13	4.11	0.56	29.76
02/24/2010	8.53	ND	0.03	0.77	5.68	0.05	1.73	0.27	11.22
03/10/2010	NS	NS	NS	NS	NS	NS	NS	NS	NS
03/24/2010	78.41	0.06	0.06	1.98	35.08	0.32	78.41	1.51	22.46
04/07/2010	ND	ND	ND	ND	ND	ND	ND	ND	20.27
06/17/2010	16.91	ND	0.03	0.43	8.12	0.08	3.01	0.47	93.80

ND=non-detect. The detection limit is 0.025 mg/L except for P. *the detection limit for P is 5.0 mg/L.

NS=no sample

Table A10. Digested metal concentration in runoff for Left TRAPPS™ (ppm).

Sample date	Pb	Cr	Ni	Zn	Fe	Mn	Cu	Sb	*P
04/08/2009	ND	ND	ND	0.06	0.10	ND	ND	ND	43.37
04/22/2009	ND	NA	ND	ND	0.26	ND	ND	ND	ND
05/20/2009	ND	ND	ND	ND	0.79	ND	0.11	ND	ND
06/03/2009	ND	ND	ND	ND	0.37	ND	0.48	ND	ND
06/17/2009	0.90	ND	ND	0.34	16.51	0.15	0.38	ND	ND
07/01/2009	0.21	ND	ND	0.19	2.98	0.07	0.13	ND	ND
07/15/2009	ND	ND	ND	ND	0.39	ND	ND	ND	ND
07/29/2009	NS	NS	NS	NS	NS	NS	NS	NS	NS
08/12/2009	ND	ND	ND	ND	0.50	1.04	0.08	ND	ND
08/26/2009	NS	ND	NS	NS	NS	NS	NS	NS	NS
09/09/2009	NS	NS	NS	NS	NS	NS	NS	NS	NS
10/07/2009	ND	NS	ND	ND	0.12	ND	0.07	0.03	11.29
10/21/2009	0.07	ND	ND	0.05	0.21	ND	0.08	ND	8.12
11/04/2009	NS	NS	NS	NS	NS	NS	NS	NS	NS
11/18/2009	NS	NS	NS	0.03	0.03	ND	0.03	0.05	ND
12/02/2009	NS	NS	NS	NS	NS	NS	NS	NS	NS
12/16/2009	20.07	ND	ND	0.52	6.70	0.06	3.48	0.63	ND
12/30/2009	0.34	ND	ND	0.03	0.50	0.13	0.13	0.24	ND
01/13/2010	NS	NS	NS	NS	NS	NS	NS	NS	NS
01/27/2010	2.19	ND	ND	0.16	0.47	ND	0.55	0.28	ND
02/10/2009	12.03	ND	ND	0.38	5.11	0.04	2.29	1.11	ND
02/24/2010	0.87	ND	ND	0.05	5.68	ND	0.26	0.81	ND
03/10/2010	NS	NS	NS	NS	NS	NS	NS	NS	NS
03/24/2010	0.38	ND	ND	0.03	0.24	ND	0.15	0.94	ND
04/07/2010	5.90	ND	ND	0.10	5.19	0.04	1.62	0.14	ND
06/17/2010	1.22	ND	ND	0.09	0.52	0.01	0.37	1.19	7.07

ND=non-detect. The detection limit is 0.025 mg/L except for P. *the detection limit for P is 5.0 mg/L.

NS=no sample

Table A11. Soluble metal concentration in leachate for control lysimeter (ppm).

Sample date	Pb	Cr	Ni	Zn	Fe	Mn	Cu	Sb	*P
04/08/2009	ND	ND	ND	ND	0.03	ND	ND	0.05	ND
04/22/2009	ND	ND	ND	ND	0.04	ND	ND	ND	ND
05/20/2009	ND	ND	ND	ND	0.05	ND	ND	0.03	ND
06/03/2009	ND	ND	ND	ND	ND	ND	0.50	0.05	ND
06/17/2009	ND	ND	ND	ND	ND	ND	ND	0.06	ND
07/01/2009	ND	ND	ND	ND	0.15	ND	ND	ND	ND
07/15/2009	ND	ND	ND	ND	0.04	ND	ND	0.04	ND
07/29/2009	ND	ND	ND	ND	ND	ND	ND	0.05	ND
08/12/2009	ND	ND	ND	ND	0.04	ND	ND	0.09	ND
08/26/2009	ND	ND	ND	ND	0.06	ND	ND	0.11	ND
09/09/2009	ND	ND	ND	ND	0.03	ND	ND	0.24	ND
10/07/2009	ND	ND	ND	0.08	ND	ND	ND	0.04	ND
10/21/2009	ND	ND	ND	ND	ND	ND	0.06	0.15	ND
11/04/2009	NS	NS	NS	NS	NS	NS	NS	NS	NS
11/18/2009	ND	ND	ND	ND	ND	ND	ND	0.12	ND
12/02/2009	ND	ND	ND	ND	0.04	ND	0.36	0.14	ND
12/16/2009	ND	ND	ND	ND	ND	ND	0.05	0.34	ND
12/30/2009	ND	ND	ND	ND	ND	ND	0.03	0.35	ND
01/13/2010	ND	ND	ND	ND	ND	ND	0.90	0.49	ND
01/27/2010	ND	ND	ND	ND	ND	ND	ND	0.69	ND
02/10/2009	NS	NS	NS	ND	ND	ND	ND	1.08	ND
02/24/2010	NS	NS	NS	NS	NS	NS	NS	NS	NS
03/10/2010	NS	NS	NS	NS	NS	NS	NS	NS	NS
03/24/2010	NS	NS	NS	NS	NS	NS	NS	NS	NS
04/07/2010	0.06	ND	ND	ND	ND	ND	0.40	0.92	ND
06/17/2010	ND	ND	ND	ND	ND	ND	0.17	1.43	ND

ND=non-detect. The detection limit is 0.025 mg/L except for P. *the detection limit for P is 5.0 mg/L.

NS=no sample

Table A12. Soluble metal concentration in runoff for control lysimeter (ppm).

Sample date	Pb	Cr	Ni	Zn	Fe	Mn	Cu	Sb	*P
04/08/2009	ND	ND	ND	0.05	0.67	ND	0.06	0.10	ND
04/22/2009	ND	ND	ND	ND	0.69	ND	ND	0.06	ND
05/20/2009	ND	ND	ND	ND	0.34	ND	0.08	0.08	ND
06/03/2009	ND	ND	ND	ND	0.12	ND	ND	ND	ND
06/17/2009	ND	ND	ND	ND	0.19	ND	ND	ND	ND
07/01/2009	ND	ND	ND	ND	0.06	ND	ND	0.06	ND
07/15/2009	ND	ND	ND	ND	0.37	ND	ND	ND	ND
07/29/2009	ND	ND	ND	ND	0.27	ND	ND	ND	ND
08/12/2009	ND	ND	ND	ND	0.91	ND	0.08	ND	ND
08/26/2009	ND	ND	ND	0.36	0.36	ND	0.04	ND	ND
09/09/2009	ND	ND	ND	0.28	0.28	ND	0.03	ND	ND
10/07/2009	0.07	ND	ND	0.34	0.13	ND	0.10	ND	ND
10/21/2009	ND	ND	ND	ND	0.16	ND	0.07	ND	ND
11/04/2009	0.04	ND	ND	ND	0.12	ND	0.10	0.03	ND
11/18/2009	0.07	ND	ND	ND	0.09	ND	0.11	0.06	ND
12/02/2009	ND	ND	ND	ND	0.04	ND	0.28	ND	ND
12/16/2009	0.09	ND	ND	ND	1.67	ND	0.10	0.09	ND
12/30/2009	0.05	ND	ND	ND	0.20	ND	0.68	0.08	ND
01/13/2010	0.06	ND	ND	ND	0.19	ND	0.11	0.56	ND
01/27/2010	0.52	ND	ND	0.07	0.15	ND	0.53	0.90	ND
02/10/2009	1.20	ND	ND	0.09	0.16	ND	0.54	1.23	ND
02/24/2010	0.14	ND	ND	ND	0.21	ND	0.25	0.57	ND
03/10/2010	NS	NS	NS	NS	NS	NS	NS	NS	NS
03/24/2010	0.50	ND	ND	ND	0.05	ND	1.14	1.08	ND
04/07/2010	0.43	ND	ND	ND	0.14	ND	0.37	0.8	ND
06/17/2010	0.73	ND	ND	0.14	0.06	0.02	1.62	3.18	ND

ND=non-detect. The detection limit is 0.025 mg/L except for P. *the detection limit for P is 5.0 mg/L.

NS=no sample

Table A13. Soluble metal concentration in leachate for 7.62 mm lysimeter (ppm).

Sample date	Pb	Cr	Ni	Zn	Fe	Mn	Cu	Sb	*P
04/08/2009	ND	ND	ND	ND	0.23	ND	ND	ND	92.36
04/22/2009	ND	ND	ND	ND	ND	ND	ND	ND	15.65
05/20/2009	ND	ND	ND	ND	ND	ND	ND	ND	135.43
06/03/2009	ND	ND	ND	ND	ND	ND	0.46	ND	50.02
06/17/2009	ND	ND	ND	ND	ND	ND	ND	ND	146.23
07/01/2009	NS	NS	NS	NS	NS	NS	NS	NS	NS
07/15/2009	ND	ND	ND	ND	ND	ND	ND	ND	128.73
07/29/2009	NS	NS	NS	NS	NS	NS	NS	NS	NS
08/12/2009	ND	ND	ND	ND	ND	ND	ND	ND	135.29
08/26/2009	ND	ND	ND	ND	ND	ND	0.43	0.06	129.56
09/09/2009	ND	ND	ND	ND	ND	ND	ND	ND	66.73
10/07/2009	NS	NS	NS	NS	NS	NS	NS	NS	NS
10/21/2009	NS	NS	NS	NS	NS	NS	NS	NS	NS
11/04/2009	NS	NS	NS	NS	NS	NS	NS	NS	NS
11/18/2009	NS	NS	NS	NS	NS	NS	NS	NS	NS
12/02/2009	NS	NS	NS	NS	NS	NS	NS	NS	NS
12/16/2009	ND	ND	ND	ND	ND	ND	0.10	0.07	80.27
12/30/2009	ND	ND	ND	ND	ND	ND	0.06	0.16	50.93
01/13/2010	NS	NS	NS	NS	NS	NS	NS	NS	NS
01/27/2010	0.18	0.07	ND	ND	0.06	ND	13.80	0.60	59.83
02/10/2009	0.08	ND	ND	ND	ND	ND	1.43	0.38	13.34
02/24/2010	0.05	ND	ND	ND	ND	ND	2.02	0.86	22.34
03/10/2010	NS	NS	NS	NS	NS	NS	NS	NS	NS
03/24/2010	0.09	0.68	ND	ND	ND	ND	393.20	2.00	10.51
04/07/2010	NS	NS	NS	NS	NS	NS	NS	NS	NS
06/17/2010	1.15	0.12	ND	0.04	0.14	ND	112.00	5.96	48.23

ND=non-detect. The detection limit is 0.025 mg/L except for P. *the detection limit for P is 5.0 mg/L.
NS=no sample

Table A14. Soluble metal concentration in runoff for 7.62 mm lysimeter (ppm).

Sample date	Pb	Cr	Ni	Zn	Fe	Mn	Cu	Sb	*P
04/08/2009	ND	ND	ND	ND	0.66	ND	0.06	ND	10.65
04/22/2009	ND	ND	ND	ND	0.19	ND	ND	ND	ND
05/20/2009	ND	ND	ND	ND	0.40	ND	ND	ND	ND
06/03/2009	ND	ND	ND	ND	0.15	ND	ND	ND	ND
06/17/2009	ND	ND	ND	ND	0.21	ND	ND	ND	ND
07/01/2009	NS	NS	NS	NS	NS	NS	NS	NS	NS
07/15/2009	ND	ND	ND	ND	0.07	ND	ND	ND	ND
07/29/2009	NS	NS	NS	NS	NS	NS	NS	NS	NS
08/12/2009	ND	ND	ND	ND	0.04	ND	0.17	0.07	ND
08/26/2009	NS	NS	NS	NS	NS	NS	NS	NS	NS
09/09/2009	NS	NS	NS	NS	NS	NS	NS	NS	NS
10/07/2009	NS	NS	NS	NS	NS	NS	NS	NS	NS
10/21/2009	NS	NS	NS	NS	NS	NS	NS	NS	NS
11/04/2009	NS	NS	NS	NS	NS	NS	NS	NS	NS
11/18/2009	0.06	ND	ND	ND	ND	ND	0.11	0.05	ND
12/02/2009	ND	ND	ND	ND	ND	ND	0.34	ND	ND
12/16/2009	ND	ND	ND	ND	ND	ND	0.11	0.08	ND
12/30/2009	0.13	ND	ND	ND	0.08	ND	0.26	0.33	21.85
01/13/2010	NS	NS	NS	NS	NS	NS	NS	NS	NS
01/27/2010	0.21	ND	ND	ND	0.15	ND	0.38	0.74	ND
02/10/2009	NS	NS	NS	NS	NS	NS	NS	NS	NS
02/24/2010	NS	NS	NS	NS	NS	NS	NS	NS	NS
03/10/2010	NS	NS	NS	NS	NS	NS	NS	NS	NS
03/24/2010	ND	ND	ND	ND	ND	ND	0.29	1.88	ND
04/07/2010	0.17	ND	ND	ND	0.09	ND	0.36	1.55	ND
06/17/2010	1.28	ND	ND	ND	0.11	0.08	1.21	3.09	ND

ND=non-detect. The detection limit is 0.025 mg/L except for P. *the detection limit for P is 5.0 mg/L.
NS=no sample

Table A15. Soluble metal concentration in leachate for 5% TTF (ppm).

Sample date	Pb	Cr	Ni	Zn	Fe	Mn	Cu	Sb	*P
04/08/2009	ND	ND	ND	ND	ND	ND	ND	ND	57.93
04/22/2009	NS	NS	NS	NS	NS	NS	NS	NS	NS
05/20/2009	ND	ND	ND	ND	ND	ND	ND	ND	68.48
06/03/2009	ND	ND	ND	ND	ND	ND	ND	ND	50.00
06/17/2009	ND	ND	ND	ND	ND	ND	ND	ND	29.73
07/01/2009	NS	NS	NS	NS	NS	NS	NS	NS	NS
07/15/2009	NS	NS	NS	NS	NS	NS	NS	NS	NS
07/29/2009	NS	NS	NS	NS	NS	NS	NS	NS	NS
08/12/2009	NS	NS	NS	NS	NS	NS	NS	NS	NS
08/26/2009	ND	ND	ND	ND	ND	ND	ND	ND	55.25
09/09/2009	NS	NS	NS	NS	NS	NS	NS	NS	NS
10/07/2009	0.04	ND	ND	0.47	ND	ND	0.26	ND	8.20
10/21/2009	NS	NS	NS	NS	NS	NS	NS	NS	NS
11/04/2009	NS	NS	NS	NS	NS	NS	NS	NS	NS
11/18/2009	ND	ND	ND	ND	ND	ND	ND	ND	32.84
12/02/2009	NS	NS	NS	NS	NS	NS	NS	NS	NS
12/16/2009	NS	NS	NS	NS	NS	NS	NS	NS	NS
12/30/2009	ND	ND	ND	ND	ND	ND	ND	0.05	32.53
01/13/2010	NS	NS	NS	NS	NS	NS	NS	NS	NS
01/27/2010	0.07	ND	ND	ND	ND	ND	0.07	0.14	49.21
02/10/2009	NS	NS	NS	NS	NS	NS	NS	NS	NS
02/24/2010	ND	ND	ND	ND	ND	ND	0.04	0.23	17.73
03/10/2010	NS	NS	NS	NS	NS	NS	NS	NS	NS
03/24/2010	ND	ND	ND	ND	ND	ND	ND	0.44	9.56
04/07/2010	NS	NS	NS	NS	NS	NS	NS	NS	NS
06/17/2010	ND	ND	ND	ND	ND	ND	0.09	0.06	54.78

ND=non-detect. The detection limit is 0.025 mg/L except for P. *the detection limit for P is 5.0 mg/L.

NS=no sample

Table A16. Soluble metal concentration in leachate for 5% TRAPPS™ (ppm).

Sample date	Pb	Cr	Ni	Zn	Fe	Mn	Cu	Sb	*P
04/08/2009	ND	ND	ND	ND	ND	ND	ND	ND	45.05
04/22/2009	NS	NS	NS	NS	NS	NS	NS	NS	NS
05/20/2009	ND	ND	ND	ND	ND	ND	ND	ND	58.64
06/03/2009	ND	ND	ND	ND	ND	ND	ND	ND	62.10
06/17/2009	ND	ND	ND	ND	ND	ND	ND	ND	58.31
07/01/2009	ND	ND	ND	ND	ND	ND	ND	ND	62.15
07/15/2009	ND	ND	ND	ND	ND	ND	ND	ND	47.59
07/29/2009	NS	NS	NS	NS	NS	NS	NS	NS	NS
08/12/2009	NS	NS	NS	NS	NS	NS	NS	NS	NS
08/26/2009	ND	ND	ND	ND	ND	ND	ND	ND	58.41
09/09/2009	ND	ND	ND	ND	ND	ND	ND	ND	75.18
10/07/2009	NS	NS	NS	NS	NS	NS	NS	NS	NS
10/21/2009	NS	NS	NS	NS	NS	NS	NS	NS	NS
11/04/2009	ND	ND	ND	ND	ND	ND	ND	ND	ND
11/18/2009	ND	ND	ND	ND	ND	ND	ND	ND	47.53
12/02/2009	ND	ND	ND	ND	ND	ND	ND	ND	17.46
12/16/2009	ND	ND	ND	ND	ND	ND	ND	0.03	52.01
12/30/2009	ND	ND	ND	ND	ND	ND	ND	0.09	5.01
01/13/2010	ND	ND	ND	ND	ND	ND	ND	0.09	ND
01/27/2010	0.07	ND	ND	ND	ND	ND	ND	0.32	33.02
02/10/2009	0.09	ND	ND	ND	ND	ND	0.06	0.34	14.85
02/24/2010	0.05	ND	ND	0.09	ND	ND	0.07	0.21	ND
03/10/2010	NS	NS	NS	NS	NS	NS	NS	NS	NS
03/24/2010	ND	ND	ND	ND	ND	ND	ND	0.51	7.11
04/07/2010	0.05	ND	ND	ND	0.04	ND	ND	0.59	18.41
06/17/2010	ND	ND	ND	ND	ND	ND	0.12	0.34	124.70

ND=non-detect. The detection limit is 0.025 mg/L except for P. *the detection limit for P is 5.0 mg/L.

NS=no sample

Table A17. Soluble metal concentration in runoff for Left TRAPPS™ (ppm).

Sample date	Pb	Cr	Ni	Zn	Fe	Mn	Cu	Sb	*P
04/08/2009	0.07	0.03	0.03	0.03	0.21	0.03	0.07	0.03	5.00
04/22/2009	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	5.00
05/20/2009	0.06	0.03	0.03	0.03	0.12	0.03	0.06	0.03	5.00
06/03/2009	0.03	0.03	0.03	0.03	0.10	0.03	0.03	0.03	5.00
06/17/2009	0.030	0.03	0.03	0.03	1.57	0.03	0.03	0.03	5.00
07/01/2009	0.03	0.03	0.03	0.03	1.72	0.03	0.03	0.03	5.00
07/15/2009	0.03	0.03	0.03	0.03	0.23	0.03	0.06	0.03	5.00
07/29/2009	NS	NS	NS	NS	NS	NS	NS	NS	NS
08/12/2009	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	6.68
08/26/2009	NS	NS	NS	NS	NS	NS	NS	NS	NS
09/09/2009	NS	NS	NS	NS	NS	NS	NS	NS	NS
10/07/2009	0.03	0.03	0.03	0.12	0.10	0.03	0.03	0.03	5.00
10/21/2009	0.03	0.03	0.03	0.03	0.13	0.03	0.03	0.03	9.38
11/04/2009	NS	NS	NS	NS	NS	NS	NS	NS	NS
11/18/2009	0.03	0.03	0.03	0.03	0.03	0.03	NS	0.05	5.00
12/02/2009	NS	NS	NS	NS	NS	NS	NS	NS	NS
12/16/2009	0.32	0.03	0.03	0.04	0.06	0.32	0.04	0.41	5.00
12/30/2009	0.03	0.03	0.03	0.03	0.03	0.03	0.07	0.27	5.00
01/13/2010	NS	NS	NS	NS	NS	NS	NS	NS	NS
01/27/2010	0.11	0.03	0.03	0.03	0.04	0.03	0.22	0.34	5.00
02/10/2009	0.26	0.03	0.03	0.03	0.07	0.03	NS	1.11	5.00
02/24/2010	0.05	0.03	0.03	0.03	ND	0.03	NS	0.96	5.00
03/10/2010	NS	NS	NS	NS	NS	NS	NS	NS	NS
03/24/2010	0.03	0.03	0.03	0.03	0.03	0.03	0.13	1.14	5.00
04/07/2010	0.03	0.03	0.03	0.03	0.03	0.03	0.23	1.16	5.00
06/17/2010	0.03	0.03	0.03	0.03	0.03	0.03	0.74	1.42	5.00

ND=non-detect. The detection limit is 0.025 mg/L except for P. *the detection limit for P is 5.0 mg/L.

NS=no sample

TCLP Analysis

Table A18. Pre TCLP leaching concentrations for bulk soil samples (n=3; ppm).

	Control			7.62 mm			Left 5% TRAPPS™		
Metal	rep. 1	rep. 2	rep. 3	rep. 1	rep. 2	rep. 3	rep. 1	rep. 2	rep. 3
Pb	ND	ND	ND	ND	ND	ND	ND	ND	ND
Cr	ND	ND	ND	ND	ND	ND	ND	ND	ND
Cu	ND	ND	ND	ND	ND	ND	ND	ND	ND
Ni	0.03	0.03	0.03	0.07	0.07	0.08	0.06	0.07	0.08
Zn	ND	ND	ND	0.14	ND	0.12	0.11	0.11	0.11
Fe	0.07	1.10	0.09	0.16	0.61	0.42	0.88	0.81	0.31
Mn	ND	ND	ND	0.46	0.50	0.47	0.33	0.37	0.41
Mo	ND	ND	ND	ND	ND	ND	ND	ND	ND
V	ND	ND	ND	ND	ND	ND	ND	ND	ND
Sb	ND	ND	ND	ND	ND	ND	ND	ND	ND
Ca	10.46	17.94	14.10	183.80	160.4	164.2	67.41	73.67	66.55
As	ND	ND	ND	ND	ND	ND	ND	ND	ND

ND=none detect; the detection limit is 0.025 ppm.

Table A19. Post TCLP leaching Pb, Cr, Cu, Ni, Zn, and Fe concentrations for bulk soil samples (n=3; ppm).

	Control			7.62 mm			Left 5% TRAPPS™			Inset lysimeter (5% TTF)		
Metal	rep. 1	rep. 2	rep. 3	rep. 1	rep. 2	rep. 3	rep. 1	rep. 2	rep. 3	rep. 1	rep. 2	rep. 3
Pb	483.00	470.30	466.80	151.00	145.30	145.90	63.85	64.60	64.13	2.59	1.32	1.16
Cr	ND	ND	ND	0.05	0.05	0.05	0.05	0.05	0.05	ND	ND	ND
Cu	28.23	28.00	28.10	4.56	4.71	4.59	6.56	6.54	6.56	0.21	0.19	0.19
Ni	0.03	0.03	0.03	0.27	0.27	0.28	0.24	0.23	0.23	0.17	0.16	0.17
Zn	3.02	2.98	2.95	1.18	1.19	1.20	1.24	1.23	1.21	0.09	0.09	0.09
Fe	7.22	6.60	6.79	70.21	73.49	69.35	44.95	45.40	44.25	6.93	5.53	6.71

ND=none detect; the detection limit is 0.025 ppm.

Table A20. Post TCLP leaching Mn, Mo, V, Sb, Ca, and As concentrations for bulk soil samples (n=3; ppm).

	Control			7.62 mm			Left 5% TRAPPS™			Inset lysimeter (5% TTF)		
Metal	rep. 1	rep. 2	rep. 3	rep. 1	rep. 2	rep. 3	rep. 1	rep. 2	rep. 3	rep. 1	rep. 2	rep. 3
Mn	0.11	0.10	0.10	1.50	1.51	1.51	0.9	0.92	0.92	0.59	0.60	0.61
Mo	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
V	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Sb	5.22	5.38	5.35	0.43	0.43	0.42	0.07	0.08	0.04	0.03	0.03	0.03
Ca	13.66	13.17	12.84	49.00	49.15	48.76	34.97	35.00	34.71	120.00	123.10	122.30
As	0.03	0.06	0.06	ND	ND	ND	ND	ND	ND	ND	ND	ND

ND=none detect; the detection limit is 0.025 ppm.

DDI S&S Leaching Analysis

Table A21. Pre DDI leaching concentrations for bulk soil samples (n=3; ppm).

	Control			7.62 mm			Left 5% TRAPPS™		
Metal	rep. 1	rep. 2	rep. 3	rep. 1	rep. 2	rep. 3	rep. 1	rep. 2	rep. 3
Pb	ND	ND	ND	ND	ND	ND	ND	ND	ND
Cr	ND	ND	ND	ND	ND	ND	ND	ND	ND
Cu	ND	ND	ND	ND	ND	ND	ND	ND	ND
Ni	ND	ND	ND	ND	ND	ND	ND	ND	ND
Zn	ND	ND	ND	ND	ND	ND	ND	ND	ND
Fe	0.43	0.36	0.40	2.25	1.62	1.97	2.29	1.97	2.14
Mn	ND	ND	ND	ND	ND	ND	ND	ND	ND
Mo	ND	ND	ND	ND	ND	ND	ND	ND	ND
V	ND	ND	ND	ND	ND	ND	ND	ND	ND
Sb	ND	ND	ND	ND	ND	ND	ND	ND	ND
Ca	7.24	6.44	8.18	18.60	16.97	18.60	12.19	11.67	14.46
As	ND	ND	ND	ND	ND	ND	ND	ND	ND

ND=none detect; the detection limit is 0.025 ppm.

Table A22. Post DDI Suspend and Settle Pb, Cr, Cu, Ni, Zn, and Fe concentrations for bulk soil samples (n=3; ppm).

	Control			7.62 mm			Left 5% TRAPPS™			Inset lysimeter (5% TTF)		
Metal	rep. 1	rep. 2	rep. 3	rep. 1	rep. 2	rep. 3	rep. 1	rep. 2	rep. 3	rep. 1	rep. 2	rep. 3
Pb	0.37	0.36	0.39	0.44	0.44	0.43	0.05	0.42	0.04	0.32	0.35	0.43
Cr	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Cu	0.54	0.57	0.58	0.06	0.06	0.06	ND	ND	ND	0.54	0.57	0.58
Ni	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Zn	0.10	0.09	0.93	ND	ND	ND	ND	ND	ND	0.10	0.09	0.09
Fe	ND	ND	ND	0.35	0.35	0.35	ND	ND	ND	ND	ND	ND

ND=none detect; the detection limit is 0.025 ppm.

Table A23. Post DDI Suspend and Settle leaching Mn, Mo, V, Sb, Ca, and As concentrations for bulk soil samples (n=3; ppm).

	Control			7.62 mm			Left 5% TRAPPS™			Inset lysimeter (5% TTF)		
Metal	rep. 1	rep. 2	rep. 3	rep. 1	rep. 2	rep. 3	rep. 1	rep. 2	rep. 3	rep. 1	rep. 2	rep. 3
Mn	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Mo	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
V	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Sb	0.21	0.21	0.20	0.17	0.17	0.17	0.29	0.29	0.28	0.21	0.21	0.20
Ca	11.91	12.01	11.90	3.72	3.63	3.76	5.95	6.07	6.06	11.91	12.01	11.89
As	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

ND=none detect; the detection limit is 0.025 ppm.

SPLP Leaching Analysis

Table A24. Pre SPLP leaching concentrations for bulk soil samples (n=3; ppm).

	Control			7.62 mm			Left 5% TRAPPS™		
Metal	rep. 1	rep. 2	rep. 3	rep. 1	rep. 2	rep. 3	rep. 1	rep. 2	rep. 3
Pb	ND	ND	ND	ND	ND	ND	ND	ND	ND
Cr	ND	ND	ND	ND	ND	ND	ND	ND	ND
Cu	ND	ND	ND	ND	ND	ND	ND	ND	ND
Ni	ND	ND	ND	ND	ND	ND	ND	ND	ND
Zn	ND	ND	ND	ND	ND	ND	ND	ND	ND
Fe	0.23	0.17	0.20	ND	ND	ND	0.29	0.24	0.18
Mn	ND	ND	ND	ND	ND	ND	ND	ND	ND
Mo	ND	ND	ND	ND	ND	ND	ND	ND	ND

Metal	Control			7.62 mm			Left 5% TRAPPS™		
	rep. 1	rep. 2	rep. 3	rep. 1	rep. 2	rep. 3	rep. 1	rep. 2	rep. 3
V	ND	ND	ND	ND	ND	ND	ND	ND	ND
Sb	ND	ND	ND	ND	ND	ND	ND	ND	ND
Ca	4.88	4.63	4.67	17.97	17.15	17.38	16.52	7.64	6.46
As	ND	ND	ND	ND	ND	ND	ND	ND	ND

ND=none detect; the detection limit is 0.025 ppm.

Table A25. Post SPLP Pb, Cr, Cu, Ni, Zn, and Fe concentrations for bulk soil samples (n=3; ppm).

Metal	Control			7.62 mm			Left 5% TRAPPS™			Inset lysimeter (5% TTF)		
	rep. 1	rep. 2	rep. 3	rep. 1	rep. 2	rep. 3	rep. 1	rep. 2	rep. 3	rep. 1	rep. 2	rep. 3
Pb	1.63	5.43	0.33	0.54	0.12	0.94	0.13	0.12	0.14	0.16	0.11	0.08
Cr	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Cu	0.51	1.25	0.08	0.14	0.04	0.21	0.09	0.08	0.09	0.04	0.04	ND
Ni	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Zn	0.17	0.24	ND	ND	ND	ND	0.06	0.05	0.05	ND	ND	ND
Fe	0.13	ND	ND	0.50	0.08	0.63	0.09	0.07	0.07	0.17	0.20	0.16

ND=none detect; the detection limit is 0.025 ppm.

Table A26. Post SPLP Mn, Mo, V, Sb, Ca, and As concentrations for bulk soil samples (n=3; ppm).

Metal	Control			7.62 mm			Left 5% TRAPPS™			Inset lysimeter (5% TTF)		
	rep. 1	rep. 2	rep. 3	rep. 1	rep. 2	rep. 3	rep. 1	rep. 2	rep. 3	rep. 1	rep. 2	rep. 3
Mn	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Mo	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
V	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Sb	0.23	0.26	0.15	0.13	0.13	0.11	0.38	0.37	0.38	ND	ND	ND
Ca	3.77	2.68	1.68	3.53	3.21	7.23	22.29	21.19	21.70	8.63	9.33	8.09
As	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

ND=none detect; the detection limit is 0.025 ppm.

Soil Samples – Metal Concentrations

Table A27. Digested post soil concentrations Pb, Cr, Cu, Ni, Zn, and Fe (n=3; ppm).

	Control			7.62 mm			Left 5% TRAPPS™			Inset lysimeter (5% TTF)		
Metal	rep. 1	rep. 2	rep. 3	rep. 1	rep. 2	rep. 3	rep. 1	rep. 2	rep. 3	rep. 1	rep. 2	rep. 3
Pb	9227	9077	12340	1862	3502	2068	6147	7180	6367	186	171	201.8
Cr	ND	ND	ND	12.48	12.68	13.35	ND	ND	ND	30.08	22.34	19.69
Cu	1190	790.6	733.7	355.6	340.7	364.3	614.40	639.00	630.30	99.05	71.49	115.7
Ni	ND	ND	ND	7.764	8.566	8.662	ND	ND	ND	20.77	14.48	12.29
Zn	119.8	80.55	76.98	34.84	36.43	40.36	60.72	63.40	62.06	14.99	10.57	14.00
Fe	646.5	598.5	723.8	6386	7152	6689	2485	1524	2224	20730	11400	14480

ND=none detect; the detection limit is 0.025 ppm.

Table A28. Digested post soil concentrations for Mn, Mo, V, Sb, Ca, As, and P (n=3; ppm).

	Control			7.62 mm			Left 5% TRAPPS™			Inset lysimeter (5% TTF)		
Metal	rep. 1	rep. 2	rep. 3	rep. 1	rep. 2	rep. 3	rep. 1	rep. 2	rep. 3	rep. 1	rep. 2	rep. 3
Mn	ND	ND	ND	38.29	39.62	39.89	11.81	8.172	11.10	120.4	67.79	72.38
Mo	ND	ND	ND	5.061	ND	6.526	ND	ND	ND	10.84	10.67	7.215
V	ND	ND	ND	ND	ND	ND	ND	ND	ND	12.74	6.508	7.385
Sb	107.9	104.2	133	19.2	45.8	20.31	62.17	92.57	68.03	ND	ND	ND
Ca	358.1	355.6	402.6	3700	3716	3866	1092	1105	1097	4514	4107	4199
As	5.643	6.293	8.809	ND	ND	ND	ND	ND	ND	ND	ND	ND
P	ND	ND	ND	2815	3096	2914	2207	2063	2024	3977	3570	3639

ND=none detect; the detection limit is 0.025 ppm.

Table A29. Post soil digests concentrations for control lysimeter at 0-4L:0-5H.

Sample	Pb	Cr	Cu	Ni	Zn	Fe	Mn
1	1386.00	ND	102.17	ND	14.05	231.90	ND
2	554.60	ND	46.32	ND	7.59	170.27	ND
3	1441.33	ND	86.18	ND	12.73	126.90	ND
4	1275.00	ND	85.82	ND	10.56	127.40	ND
5	1266.00	ND	147.10	ND	14.92	135.03	ND
6	1506.00	ND	122.37	ND	14.32	169.50	ND
7	5236.33	ND	614.30	ND	62.16	418.83	ND
8	5124.00	ND	468.00	ND	47.95	342.50	ND
9	4611.00	ND	362.73	ND	37.63	618.20	ND

ND = none detect; the detection limit is 5 ppm for all metals except for P. The detection limit for P is 5 ppm.

Sample	Mo	V	Sb	Ca	As	P
1	ND	ND	18.78	180.97	ND	87.53
2	ND	ND	7.52	303.50	ND	124.53
3	ND	ND	13.47	233.53	ND	106.57
4	ND	ND	10.39	234.53	ND	70.69
5	ND	ND	16.19	201.10	ND	107.55
6	ND	ND	13.65	102.57	ND	79.50
7	ND	ND	49.78	281.87	ND	71.02
8	ND	ND	55.09	236.13	ND	112.90
9	ND	ND	43.65	718.73	ND	124.43

ND = none detect; the detection limit is 5 ppm for all metals except for P. The detection limit for P is 5 ppm.

Table A30. Post soil digests concentrations for control lysimeter at 0-4L:5-10H.

Sample	Pb	Cr	Cu	Ni	Zn	Fe	Mn
1	1696.30	ND	239.77	ND	25.54	450.47	ND
2	13043	ND	1131.50	ND	116.27	713.3	ND
3	4933.70	ND	467.27	ND	48.97	520.6	ND
4	6850.30	ND	410.93	ND	42.30	394.47	ND
5	7553.30	ND	590.93	ND	62.39	416.2	ND
6	7162.70	ND	626.65	ND	67.31	423.43	ND
7	5797.30	ND	568.05	ND	61.46	336	ND
8	6023.70	ND	718.75	ND	71.517	408.2	ND
9	6199.30	ND	614.75	ND	64.89	417.1	ND

ND = none detect; the detection limit is 5 ppm for all metals except for P. The detection limit for P is 5 ppm.

Sample	Mo	V	Sb	Ca	As	P
1	ND	ND	14.29	257.67	ND	109.19
2	ND	ND	156.53	366	9.36	146.40
3	ND	ND	68.48	451.57	ND	128.43
4	ND	ND	66.65	411.33	ND	92.36
5	ND	ND	159.50	329.30	5.53	129.41
6	ND	ND	199.23	404.27	ND	101.34
7	ND	ND	185.63	719.80	ND	92.89
8	ND	ND	102.50	348.20	5.78	134.73
9	ND	ND	215.25	390.40	ND	132.97

ND = none detect; the detection limit is 5 ppm for all metals except for P. The detection limit for P is 5 ppm.

Table A31. Post soil digests concentrations for control lysimeter at 4-8L:0-5H (ppm).

Sample	Pb	Cr	Cu	Ni	Zn	Fe	Mn
1	5779.00	ND	535.50	ND	54.51	608.83	ND
2	4205.50	ND	385.90	ND	42.94	440.00	ND
3	2727.00	ND	247.40	ND	27.79	304.20	ND
4	5261.30	ND	320.87	ND	35.55	316.30	ND
5	4367.30	ND	360.55	ND	39.375	180.20	ND
6	753.13	ND	42.16	ND	6.52	121.03	ND
7	7904.00	ND	837.10	ND	86.76	766.43	ND
8	5996.50	ND	922.30	ND	100.62	567.00	ND
9	142.50	ND	12.69	ND	ND	131.53	ND

ND = none detect; the detection limit is 5 ppm for all metals except for P. The detection limit for P is 5 ppm.

Sample	Mo	V	Sb	Ca	As	P
1	ND	ND	85.29	348.33	5.77	96.86
2	ND	ND	67.98	307.00	ND	133.90
3	ND	ND	28.62	341.07	ND	115.90
4	ND	ND	60.21	251.20	ND	79.80
5	ND	ND	52.12	189.33	ND	116.90
6	ND	ND	7.44	157.27	ND	88.89
7	ND	ND	121.67	365	5.58	80.41
8	ND	ND	66.56	478.87	5.17	122.23
9	ND	ND	ND	355.47	ND	133.83

ND = none detect; the detection limit is 5 ppm for all metals except for P. The detection limit for P is 5 ppm.

Table A32. Post soil digests concentrations for control lysimeter at 4-8L:5-10H (ppm).

Sample	Pb	Cr	Cu	Ni	Zn	Fe	Mn
1	16043	ND	1144	ND	121.13	723.9	ND
2	6120	ND	625.73	ND	66.823	352.97	ND
3	4728	ND	458.03	ND	46.907	342.4	ND
4	17400	ND	1302.3	ND	134.7	713.8	ND
5	10995	ND	682.05	ND	71.425	541.83	ND
6	7083.3	ND	469.07	ND	53.823	252.1	ND
7	7287.3	ND	776.23	ND	80.837	718.1	ND
8	6392	ND	723.97	ND	74.71	510.07	ND
9	2094.3	ND	217.37	ND	23.037	288.43	ND

ND = none detect; the detection limit is 5 ppm for all metals except for P. The detection limit for P is 5 ppm.

Sample	Mo	V	Sb	Ca	As	P
1	ND	ND	425.80	591.17	12.44	110.80
2	ND	ND	59.06	383.80	6.51	147.90
3	ND	ND	41.89	450.13	ND	130.10
4	ND	ND	246.33	388.33	13.39	94.00
5	ND	ND	368.43	305.93	6.08	130.90
6	ND	ND	78.91	573.70	ND	102.84
7	ND	ND	83.53	414.30	5.37	94.39
8	ND	ND	76.83	525.47	5.18	136.23
9	ND	ND	29.82	492.23	ND	127.63

ND = none detect; the detection limit is 5 ppm for all metals except for P. The detection limit for P is 5 ppm.

Table A33. Post soil digests concentrations for 7.62 mm lysimeter at 0-4L:0-5H (ppm).

Sample	Pb	Cr	Cu	Ni	Zn	Fe	Mn
1	1320.33	11.67	235.63	6.69	25.30	5376.67	33.32
2	1525.00	12.23	306.73	6.95	29.88	5857.33	33.51
3	3714.33	15.81	433.40	7.83	38.67	6361.67	38.16
4	1486.67	16.62	167.03	9.84	20.38	6852.00	44.14
5	1082.53	11.09	141.20	7.50	15.49	4465.33	36.63
6	71.77	15.78	70.43	8.46	8.82	5620.00	39.76
7	276.07	15.82	69.25	8.33	10.12	7615.67	36.20
8	876.17	8.97	125.35	5.85	12.66	4378.33	29.68
9	167.33	16.99	65.57	9.57	9.63	6843.33	42.95

ND = none detect; the detection limit is 5 ppm for all metals except for P. The detection limit for P is 5 ppm.

Sample	Mo	V	Sb	Ca	As	P
1	6.07	ND	11.01	5487.00	ND	1559.00
2	5.21	ND	17.00	3560.33	ND	1597.38
3	6.09	ND	41.80	3026.67	ND	1367.77
4	7.26	ND	16.71	5710.67	ND	1683.12
5	ND	ND	14.96	12411.33	ND	2171.97
6	ND	ND	ND	4196.67	ND	2385.04
7	ND	ND	ND	3580.33	ND	2434.27
8	ND	5.45	ND	8295.00	ND	1442.02
9	ND	6.28	ND	5840.00	ND	1756.10

ND = none detect; the detection limit is 5 ppm for all metals except for P. The detection limit for P is 5 ppm.

Table A34. Post soil digests concentrations for 7.62 mm lysimeter at 0-4L:5-10H (ppm).

Sample	Pb	Cr	Cu	Ni	Zn	Fe	Mn
1	7989.67	20.90	597.90	13.11	57.53	10304	57.59
2	2520.00	23.58	315.50	17.02	27.16	12020	87.15
3	9483.67	17.10	644.27	12.77	73.44	9436	44.16
4	7352.50	21.33	526.50	ND	70.04	11440	50.34
5	12315.00	18.61	1232.33	ND	129.77	11430	47.89
6	2360.33	16.97	312.43	ND	18.98	8062	47.13
7	5877.33	17.76	687.30	6.42	101.80	6598.67	34.92
8	7213.33	20.01	647.55	15.55	79.51	6639.00	35.08
9	NS	NS	NS	NS	NS	NS	NS

ND = none detect; the detection limit is 5 ppm for all metals except for P. The detection limit for P is 5 ppm.

Sample	Mo	V	Sb	Ca	As	P
1	ND	7.94	61.66	1506.33	ND	3186.07
2	ND	9.42	ND	2522.67	ND	1310.47
3	ND	10.65	62.53	3432.67	16.94	2214.37
4	ND	10.65	58.83	3842.33	ND	2448.16
5	ND	10.65	56.25	3175	37.11	3128.41
6	ND	8.67	ND	1865.67	15.60	2421.01
7	17.80	10.37	102.43	2156.33	ND	1889.29
8	18.42	ND	114.54	4580.67	ND	2632.13
9	NS	NS	NS	NS	NS	NS

ND = none detect; the detection limit is 5 ppm for all metals except for P. The detection limit for P is 5 ppm.

Table A35. Post soil digests concentrations for 7.62 mm lysimeter at 4-8L:0-5H (ppm).

Sample	Pb	Cr	Cu	Ni	Zn	Fe	Mn
1	7128.00	12.05	632.45	14.12	67.15	6556.67	37.53
2	1847.50	13.52	223.33	11.47	31.76	5414.00	32.88
3	206.53	17.34	76.69	7.43	14.60	6435.00	40.04
4	1507.50	19.64	117.17	10.86	13.84	8384.00	44.02
5	206.83	15.03	56.42	8.50	12.04	6867.50	36.62
6	167.70	17.21	69.71	10.41	10.41	7690.33	34.14
7	6631.50	15.36	278.30	9.25	32.12	7701.50	32.60
8	1773.50	15.43	197.00	10.09	26.59	7146.33	34.33
9	3471.00	14.77	131.50	8.43	24.42	7211.00	33.90

ND = none detect; the detection limit is 5 ppm for all metals except for P. The detection limit for P is 5 ppm.

Sample	Mo	V	Sb	Ca	As	P
1	15.07	9.67	75.35	5252.00	ND	1269.37
2	13.22	ND	29.61	4801.67	ND	2117.55
3	14.73	ND	8.32	5031.00	ND	2097.80
4	10.26	6.77	31.45	4580.67	ND	2090.40
5	5.37	6.66	ND	3441.00	ND	1262.15
6	ND	5.33	ND	1891.67	ND	1225.99
7	3.71	6.11	35.99	2220.33	ND	1263.16
8	5.99	5.34	15.95	2145.67	ND	1235.08
9	5.60	4.87	39.07	2859.67	ND	1226.60

ND = none detect; the detection limit is 5 ppm for all metals except for P. The detection limit for P is 5 ppm.

Table A36. Post soil digests concentrations for Left 5% TRAPPS™ lysimeter at 4-8L:5-10H (ppm).

Sample	Pb	Cr	Cu	Ni	Zn	Fe	Mn
1	113.24	27.91	75.46	17.91	10.07	14745.00	65.45
2	2042.33	32.69	202.77	18.26	21.17	13035.00	73.34
3	2042.33	32.69	202.77	18.26	21.17	13035.00	73.34
4	1921.00	12.73	288.10	5.93	25.29	3563.00	20.70
5	1693.00	24.57	666.10	13.45	45.47	9347.00	49.17
6	ND	14.31	16.71	8.23	5.73	2984.00	25.77
7	11220.00	25.55	617.70	12.97	101.35	3494.33	60.84
8	7820.00	16.48	716.35	10.55	69.57	8498.50	48.72
9	591.00	7.40	85.98	6.70	9.26	2398.00	22.91

ND = none detect; the detection limit is 5 ppm for all metals except for P. The detection limit for P is 5 ppm.

Sample	Mo	V	Sb	Ca	As	P
1	12.24	7.29	ND	5009.67	ND	2490.33
2	14.50	6.49	15.32	4520.67	ND	1908.33
3	14.50	6.49	15.32	3299.67	ND	2176.67
4	13.23	8.30	19.14	4752.67	ND	1421.54
5	10.86	ND	23.67	3515.33	ND	3085.72
6	ND	ND	ND	2431.67	ND	1427.59
7	7.92	6.05	122.90	4171.00	ND	2043.87
8	11.96	ND	83.70	3864.67	ND	2242.79
9	ND	ND	7.16	3242.33	ND	1994.65

ND = none detect; the detection limit is 5 ppm for all metals except for P. The detection limit for P is 5 ppm.

Table A37. Post soil digests concentrations for Left 5% TRAPPS™ lysimeter at 0-4L:0-5H (ppm).

Sample	Pb	Cr	Cu	Ni	Zn	Fe	Mn
1	9273	ND	501.7	ND	52.52	1913.5	9.66
2	5090	ND	525.25	ND	55.85	1973	9.56
3	1603	ND	347.77	ND	36.47	2986.33	13.16
4	1586.33	ND	246.67	ND	28.19	1964.00	9.28
5	5261.67	9.20	750.50	6.52	85.25	5861.67	30.31
6	358.7	13.59	229.83	9.32	30.6	7372.67	41.50
7	4044	ND	540.27	ND	37.65	1180	6.93
8	2545.67	7.06	1342.53	5.52	27.97	4309.33	22.53
9	2342.33	7.99	282.90	5.54	42.51	4609.33	24.09

ND = none detect; the detection limit is 5 ppm for all metals except for P. The detection limit for P is 5 ppm.

Sample	Mo	V	Sb	Ca	As	P
1	ND	ND	114.45	934.80	ND	2140.67
2	ND	ND	63.11	1260.50	ND	2379.05
3	ND	ND	17.33	1341.67	ND	2182.77
4	ND	ND	15.64	1261.33	ND	2298.12
5	ND	ND	59.37	ND	ND	2486.97
6	ND	ND	ND	4779.67	ND	2500.04
7	ND	ND	40.65	1445.67	ND	2249.27
8	ND	ND	22.28	3539.67	ND	2257.02
9	ND	ND	19.89	3372	ND	2571.10

ND = none detect; the detection limit is 5 ppm for all metals except for P. The detection limit for P is 5 ppm.

Table A38. Post soil digests concentrations for Left 5% TRAPPS™ lysimeter at 0-4L:5-10H (ppm).

Sample	Pb	Cr	Cu	Ni	Zn	Fe	Mn
1	NS	NS	NS	NS	NS	NS	NS
2	NS	NS	NS	NS	NS	NS	NS
3	1226.00	16.23	159.57	ND	22.34	9459	76.72
4	813.60	ND	146.81	ND	18.18	188.30	ND
5	8445.67	ND	452.57	ND	47.43	849.37	ND
6	2150.33	11.41	218.00	ND	28.81	4976	27.93
7	4947.33	ND	850.10	ND	90.07	837.60	ND
8	3786.33	6.06	301.45	ND	72.98	4705.67	21.60
9	2375.67	19.73	463.10	ND	54.01	9968.67	52.82

ND = none detect; the detection limit is 5 ppm for all metals except for P. The detection limit for P is 5 ppm.

Sample	Mo	V	Sb	Ca	As	P
1	NS	NS	NS	NS	NS	NS
2	NS	NS	NS	NS	NS	NS
3	8.41	ND	9.17	2725.00	ND	4201.07
4	ND	ND	ND	502.30	ND	2125.47
5	ND	ND	116.33	689.33	ND	3029.37
6	5.23	ND	23.91	3056.33	ND	3263.16
7	ND	ND	49.13	781.27	ND	3943.41
8	ND	ND	39.86	2202.00	ND	3469.34
9	9.41	ND	23.26	3928.33	ND	2704.29

ND = none detect; the detection limit is 5 ppm for all metals except for P. The detection limit for P is 5 ppm.

Table A39. Post soil digests concentrations for Left 5% TRAPPS™ lysimeter at 4-8L:0-5H (ppm).

Sample	Pb	Cr	Cu	Ni	Zn	Fe	Mn
1	NS	NS	NS	NS	NS	NS	NS
2	NS	NS	NS	NS	NS	NS	NS
3	NS	NS	NS	NS	NS	NS	NS
4	NS	NS	NS	NS	NS	NS	NS
5	NS	NS	NS	NS	NS	NS	NS
6	NS	NS	NS	NS	NS	NS	NS
7	NS	NS	NS	NS	NS	NS	NS
8	3304	12.84	221.40	ND	28.56	7617.33	39.32
9	744.77	6.53	74.28	ND	11.57	4212.00	18.81

ND = none detect; the detection limit is 5 ppm for all metals except for P. The detection limit for P is 5 ppm.

Sample	Mo	V	Sb	Ca	As	P
1	NS	NS	NS	NS	NS	NS
2	NS	NS	NS	NS	NS	NS
3	NS	NS	NS	NS	NS	NS
4	NS	NS	NS	NS	NS	NS
5	NS	NS	NS	NS	NS	NS
6	NS	NS	NS	NS	NS	NS
7	NS	NS	NS	NS	NS	NS
8	ND	ND	ND	4212.33	ND	2184.37
9	ND	ND	ND	2384.00	ND	2065.89

ND = none detect; the detection limit is 5 ppm for all metals except for P. The detection limit for P is 5 ppm.

Table A40. Post soil digests concentrations for Left 5% TRAPPS™ lysimeter at 4-8L:5-10H (ppm).

Sample	Pb	Cr	Cu	Ni	Zn	Fe	Mn
1	6822.67	9.31	623.53	ND	68.87	5314.00	28.85
2	1763.50	7.71	162.90	ND	21.79	3289.67	18.11
3	3030.33	ND	302.77	ND	34.34	937.53	6.03
4	4728.67	6.00	423.37	ND	41.71	2765.67	15.25
5	3710.33	ND	475.63	ND	53.68	1206.33	7.48
6	6368.00	ND	692.95	ND	76.43	1934.00	12.25
7	5866.33	ND	784.83	ND	85.75	1189.50	6.89
8	6950.00	ND	505.17	ND	58.44	804.57	5.21
9	NS	NS	NS	NS	NS	NS	NS

ND = none detect; the detection limit is 5 ppm for all metals except for P. The detection limit for P is 5 ppm.

Sample	Mo	V	Sb	Ca	As	P
1	ND	ND	76.12	3587.00	ND	2912.80
2	ND	ND	16.65	2473.00	ND	2872.07
3	ND	ND	29.76	1084.67	ND	2477.15
4	ND	ND	50.40	1763.67	ND	3307.66
5	ND	ND	38.33	1392.33	ND	2444.83
6	ND	ND	67.81	1748.67	ND	2946.74
7	ND	ND	64.51	1622.33	ND	2604.93
8	ND	ND	82.33	1212.00	ND	3305.33
9	NS	NS	NS	NS	NS	NS

ND = none detect; the detection limit is 5 ppm for all metals except for P. The detection limit for P is 5 ppm.

Soil Partition Coeficient Determination (K_d)

Table A41 Linear K_d Data: Triplicate data for each lysimeter for Sb(III).

Sb III Initial conc. (ppm)	Control Sb III Final conc. (ppm)	7.62 mm Sb III Final conc. (ppm)	5% TRAPPS™ + 5% TTF Sb III Final conc. (ppm)
0.95-1	0.5263	0.5411	0.3506
0.95-2	0.5826	0.3485	0.1225
0.95-3	0.5825	0.3451	0.0896
8.80-1	7.466	4.143	1.351
8.80-2	7.76	5.133	1.075
8.80-3	7.835	4.097	N/A
23.40-1	20.87	14.96	6.207
23.40-2	20.45	N/A	7.528
23.40-3	21.34	15.15	7.607
47.36-1	43.2	23.57	16.27

Sb III Initial conc. (ppm)	Control Sb III Final conc. (ppm)	7.62 mm Sb III Final conc. (ppm)	5% TRAPPS™ + 5% TTF Sb III Final conc. (ppm)
47.36-2	43.6	26.90	22.57
47.36-3	44.35	22.12	13.16
95.66-1	90.81	43.48	50.44
95.66-2	90.51	53.53	50.06
95.66-3	92.15	44.55	43.28

Table A42. Linear K_d Data: Triplicate data for each lysimeter for Sb(V).

Sb V Initial conc. (ppm)	Control Sb V Final conc. (ppm)	7.62 mm Sb V Final conc. (ppm)	5% TRAPPS™ + 5% TTF Sb V Final conc. (ppm)
0.87-1	N/A	N/A	0.8367
0.87-2	0.9793	0.8576	0.8466
0.87-3	0.9512	N/A	0.8075
9.06-1	8.999	8.628	8.197
9.06-2	N/A	8.751	8.303
9.06-3	9.006	8.582	1.361
23.14-1	22.75	21.87	20.94
23.14-2	22.65	22.11	19.22
23.14-3	23.07	22.46	19.90
47.92-1	45.46	45.64	40.62
47.92-2	46.62	44.42	40.71
47.92-3	45.38	45.21	41.12
101.1-1	89.92	94.16	83.41
101.1-2	90.92	92.45	83.79
101.1-3	91.03	91.92	82.45

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14. ABSTRACT

Heavy metals are released into the environment as a result of critical military live-fire training. Preventing heavy-metal migration into and contamination of the local environment is crucial because remediating contaminated soils is resource intensive, difficult, and costly. Previous studies have demonstrated that phosphate amendments have been successfully used as a best management practice (BMP) to immobilize metal contaminants. The Passive Reactive Berm (PRBerm™) technology incorporates phosphate amendments with ballistic sand to immobilize soluble metals (e.g., lead) during the inevitable bullet corrosion process. Treatability studies determined that an amendment ratio of 5% (weight/weight) to sand was sufficient to contain > 90% of soluble lead within the berm material. The technology was field tested on the M-60 small arms firing range (SAFR) at Charleston Air Force Base (CAFB) in Charleston, South Carolina. The CAFB PRBerm™ was tested with a 5% TRAPPS™ amendment (a granular, apatite-based material), alone and in combination with a 5% thermally treated fish bone Apatite™.

For the CAFB PRBerm™, storm water runoff and leachate water samples were collected directly from the SAFR and analyzed for metals, total suspended solids (TSS), and pH. Reduced metals migration in soil leachate and surface water runoff when compared to the traditional earthen berm was observed. The total suspended solids in the leachate and runoff waters from the amended berms increased over the control berm. Results indicated that the pH of the runoff waters from the amended berms remained acidic.

The benefits of the PRBerm™ when compared to the traditional earthen berm, or a fully contained bullet trap, include reduced metals migration in soil leachate and surface water runoff, as well as reduced construction and operation costs. The PRBerm™ has the potential to provide a useful, low-cost tool for defense forces to maintain active firing ranges while managing the inevitable effects of small arms residue corrosion in a low-cost and effective manner.

15. SUBJECT TERMS
Heavy metals; Passive reactive berm V; Lead containment; Active small arms firing rages; Heavy-metal migration prevention; Phosphate amendments; Metal contaminant immobilization; Berm material; Thermally treated fish bone Apatite™; TRAPPS™ amendment

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