

# IMPLEMENTATION GUIDANCE MANUAL

## Grenade Range Management Using Lime for Dual Role of Metals Immobilization and Explosives Transformation

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## Executive Summary

The Department of Defense (DoD) operates numerous hand grenade ranges (HGR) for training purposes. Live fire training creates a potential source zone for munitions constituents such as metals and explosives. Fragmentation grenades, typically containing Composition B (60% RDX, 39% TNT, 1% wax binder) within a steel shell casing, constitute the majority of hand grenades used at fixed position ranges. Explosives have been detected in HGR soils at levels from the low parts per billion ( $\mu\text{g}/\text{kg}$ ) up to percent levels. RDX has been detected in leachate waters below live fire HGRs and in surface waters leaving range impact areas (Jenkins et al., 2001, Pennington et al., 2001; 2002). The migration of metals and explosives, in both soluble and particulate forms, from the impact areas of the ranges occurs through a variety of mechanisms, including (1) transport in surface water following rain and storm events, (2) transport with soil particulates following rain and storm events, and (3) leaching through the subsurface towards groundwater. Effective management of metals and explosives on HGRs requires an understanding of the natural and engineered processes controlling their fate and transport at these sites.

This project is based on the premise that increased alkalinity, caused by lime addition to soil, will result in (1) significantly decreased water solubility of heavy metals present in the soils and (2) base-catalyzed transformation of explosives that will eliminate migration of RDX- and TNT-based explosives from the range area. In addition, the demonstrated technology would meet the criteria for active range management in that it would be inexpensive; easily applied in remote locations; effective on heterogeneous contaminant distributions; effective over large areas; effective on multiple compounds; nonintrusive, to the extent possible; and able to be incorporated into normal range maintenance operations.

Hydrated lime ( $\text{Ca}[\text{OH}]_2$ ) was chosen as the soil amendment for its ability to increase soil pH into the range necessary to transform explosives to environmentally friendly end products and for its ability to stabilize metals. The munitions constituents of concern to this study were RDX and metals, particularly iron and zinc. During the course of the 20-month demonstration, soil samples, pore water, surface water, and air samples were collected, along with meteorological (MET) data, to determine the effectiveness of lime as a management approach to reduce migration of munitions constituents from the range. The application of  $\text{Ca}(\text{OH})_2$  to an HGR to provide a mechanism for both metals immobilization and explosives transformation was demonstrated at the Fort Jackson, South Carolina Remagen HGR. It was determined during the treatability study that an application of 1% lime (w:w) was needed to elevate the Fort Jackson HGR soil above the desired pH of 11.5. This equated to approximately 1 ton of lime, which was added to the test bay and mixed to a depth of 15.24 cm (6 in). Several techniques were used to apply the lime in the bays. These varied from simply opening bags on the range by hand and raking to give a uniform color distribution to using a drop-seed spreader. A hydroseeder was used during the final lime application in order to evaluate the effect of consecutive liming and watering on dust control. In order to mix the lime into the HGR soil to the required depth, several techniques were evaluated, including a garden rotor tiller, a small disc, a cultivator, and a rake. Prior to the demonstration, suction lysimeters were placed in the test bay and the control bay to monitor changes in pore water with lime treatment. Both HGRs had surface water samplers placed at the edge of the bays to collect surface water as it flowed off of the impact area and into the surrounding range.

The surface water samplers were triggered by water levels in the storm water runoff path. Air monitors at the Fort Jackson HGR were placed in front of the throwing pits in Bays 2 and 4 for a total of six typical training days (24 hours). Six air samples were collected over several months and analyzed for Calcium (Ca), which was used as a tracer for the  $\text{Ca}(\text{OH})_2$  in the dust associated with the hand grenade detonations. MET data was collected at Fort Jackson for 20 months. The temperature and rainfall directly affect the percent moisture in the HGR soil, which controls the efficiency of the alkaline hydrolysis reaction responsible for transforming the explosives and stabilizing the metals.

The results indicate that application of lime can reduce the migration of munitions constituents from the HGRs. RDX was transformed by the alkaline hydrolysis reaction in the soil, and soil concentrations were reduced by more than 90%. In addition, the metals were stabilized in the soil, with reduction in the concentrations of both iron and zinc leaving the range via surface water and leachate.

There was concern over the possibility of negative impacts on groundwater and receiving surface waters from the lime treatment of the soil. The impact area of the treated bay had to be maintained at a pH >10.5 in order to accomplish the alkaline hydrolysis transformation of the RDX. However, the water leaving the source zone had a desired pH <9.5. It was determined that for the soil, climate, and range use conditions at the Fort Jackson HGR, the bay would have to be limed on a quarterly basis to maintain the pH above 10.5. The pore water pH for the limed bay averaged slightly less than for the control bay, indicating that the hydroxide ion was completely neutralized before the leachate from the bay could impact the groundwater. The pH of the surface water runoff collected from the limed bay remained at approximately 6.3. The surface soil pH in the off-site area collecting this water averaged 7.4, approximately 1 standard unit (SU) above the control bay. Therefore, there was no evidence of impact from the lime outside the treated area.

The air monitoring results indicated that the Ca (used as a tracer for the hydroxide) levels in the air samples from the limed bay were similar to, if not the same as, the Ca levels in the air samples from the control bay. Application of the lime in the HGR bays requires only Level D personal protective equipment (PPE), modified by the addition of a particulate respiratory mask and, possibly, the substitution of goggles as protective eyewear.

The cost of the technology is approximately \$400 per lime application. The time investment is measured in hours and no specialized equipment or operator training are required. This technology demonstrated that application of lime is a low-cost treatment that can be incorporated into normal range management operations and practices.

The primary end user for this innovative in situ technology will be active hand grenade training ranges. Technology transfer efforts include the Marine Corps, the U.S.-German Data Exchange Agreement, the Environmental Quality and Technology (EQT) Program—Distributed Sources Program, Armament Research Development and Engineering Center (ARDEC)—Environmental Technology Division, and the Huntsville Center of Expertise for Range Design.

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## List of Acronyms

ARDEC	Armament Research, Development and Engineering Center
ATSDR	Agency for Toxic Substances and Disease Registry
ATV	all terrain vehicle
bgs	below ground surface
Ca[OH] <sub>2</sub>	hydrated lime
CEC	cation exchange capacity
DEA	data exchange agreement
DoD	Department of Defense
EOD	Explosive Ordnance Disposal
EQT	Environmental Quality Technology Program
ERDC-EL	Engineer Research and Development Center – Environmental Laboratory
ESTCP	Environmental Security Technology Certification Program
FRTR	Federal Remediation Technologies Roundtable
HA	health advisory
HGR	hand grenade range
HMX	1,3,5,7 - tetranitro - 1,3,5,7 - tetrazocane
MET	meteorological
MNX	hexahydro - 1 - nitroso - 3,5 - dinitro - 1,3,5 - triazine
MSDS	Material Safety Data Sheet
ppb	parts per billion
PPE	personal protective equipment
ppm	parts per million
RDX	hexahydro-1,3,5-trinitro-1,3,5-triazine
SU	standard unit
SW	surface water
TNT	2,4,6-trinitrotoluene
TSS	total suspended solids
USACE	U. S. Army Corps of Engineers
USEPA	U. S. Environmental Protection Agency
UXO	unexploded ordinance

# **1 Guidance Document Overview**

## **1.1 Guidance Document**

This document provides instructions for the hand grenade range (HGR) managers to successfully characterize an HGR and apply hydrated lime ( $\text{Ca}[\text{OH}]_2$ ) to immobilize metals and transform explosives. This document will also provide range managers with the tools necessary to continue the grenade range management practice by successfully monitoring and applying lime to the range.

## **1.2 Guidance Document Layout**

The guidance document provides the basic scientific background and justification for the use of lime in the metals immobilization and explosives transformation at HGRs. The reference to lime in the document refers to the use of  $\text{Ca}[\text{OH}]_2$ . The results and trends that of the research that supports this management technology are generalized in this guidance document and may be further investigated as backup material by reading the technical reports and cost and performance report supporting the research (Larson et al. 2007a; Larson et al. 2007b; Larson et al. 2007c, in review, Larson et al. 2007d).

This document gives step-by-step instructions on the method used to calculate the quantity of lime to be added to the HGR soil in order to meet the reactive pH requirements of the technology.

Different methods of adding the lime to the soil are discussed, ranging from opening bags and raking the lime by hand, to using an all terrain vehicle (ATV) equipped with drop spreader and disc and using a hydroseeder for additional water.

Instructions are provided for monitoring the pH of surface water runoff. Options are provided for including lime application with regular range maintenance activities. And, finally, instructions are included for monitoring soil pH in the reactive zone to determine when lime re-application is necessary.





## 2.2 Technology Development

### 2.2.1 Alkaline Hydrolysis of Explosives

Design and construction of new HGRs provides an opportunity to consider cost-effective pollution prevention opportunities. In some cases, local soil might have adequate alkalinity to hydrolyze explosives prior to migration of munitions constituents off site. In most cases, however, native soil pH levels are below the alkalinity level (pH of 10.5) required for effective explosives transformation by alkaline hydrolysis. Amendment of impact areas with  $\text{Ca}[\text{OH}]_2$ , or other low cost hydroxide sources, can transform existing grenade impact areas into managed systems for in situ explosives transformation. Similarly, introduction of a hydroxide source into the impact area soil during range construction may prevent long-term costs resulting from explosives or metals migration to surface water or groundwater.

The transformation of TNT in basic solutions was established by Janowsky (1891). More recent studies have determined that a variety of explosive and energetic compounds can be degraded by alkaline destruction (Karasch et al., 2002). Additional studies have shown that the application of  $\text{Ca}(\text{OH})_2$  to solution and soils containing TNT and RDX will result in breakdown products such as nitrate and nitrite (Emmrich, 1999, 2001).

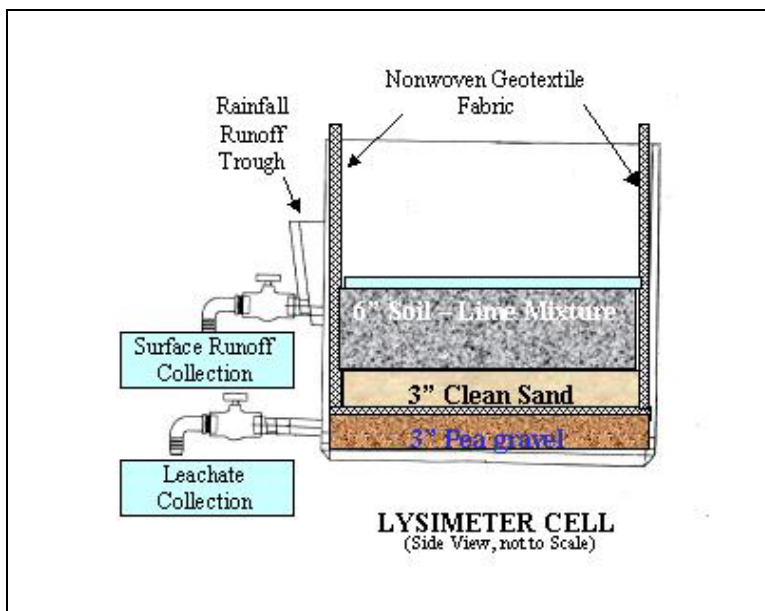
Balakrishnan et al. (2003) examined the degradation intermediates and end products produced by alkaline hydrolysis of RDX and 1,3,5,7 - tetranitro - 1,3,5,7 - tetrazocane (HMX) in solution at a pH greater than or equal to 10. They indicated that the initial step in alkaline hydrolysis is denitration of the ring, which causes ring cleavage, followed by spontaneous decomposition. The nontoxic degradation breakdown products of RDX, HMX, and hexahydro - 1 - nitroso - 3,5 - dinitro - 1,3,5 - triazine (MNX) were nitrite ( $\text{NO}_2^-$ ), nitrous oxides ( $\text{N}_2\text{O}$ ), nitrogen ( $\text{N}_2$ ), ammonia ( $\text{NH}_3$ ), formaldehyde (HCHO), formic acid (HCOOH), and carbon dioxide ( $\text{CO}_2$ ). Balakrishnan et al. (2003) showed that the degradation rate of HMX is slower than RDX, but the rate increases as the pH is raised.

A bench-scale simulation using TNT-laden soil was performed to study the explosives transformation under typical soil moisture conditions (Hansen et al., 2003). The soil was placed in a pan, dry lime was applied to the soil at 5% of the dry soil weight, and then water was added to the surface to adjust the soil moisture to 31.5%. TNT concentrations were reduced from 55 ppm to 10 ppm in 10 days. Soils from many army ammunition plants and firing ranges were tested at bench-scale with the addition of 5% lime and water. RDX exhibited 74% removal in 21 days (Davis et al., 2006).

### 2.2.2 Treatability Studies

A mesoscale lysimeter study was performed by the U.S. Army Corps of Engineers (USACE) Engineer Research and Development Center-Environmental Laboratory (ERDC-EL) with range soils from Fort Jackson to set design parameters for the field demonstration. The lysimeter study involved the addition of lime to site soil and simulated one year of typical rainfall. A schematic cross-section of the lysimeter cell is shown in **Figure 1**. Parameters such as pH, RDX, and TNT concentrations, metals concentrations, and total suspended solids (TSS) were monitored in soil, leachate, and runoff water to determine the effectiveness of the technology. In addition, factors such as the soil cation exchange capacity (CEC) and soil buffering were reviewed to determine optimal lime dosages for the field demonstration (Larson et al., 2007a).

The treatability study demonstrated the reduction of RDX in leachate and runoff leaving the limed soil as compared to the unlimed soil. In addition, the metals were stabilized and a lower concentration of metals was transported via leachate and runoff from the limed soil than from the unlimed soil (Larson et al., 2007a).



**Figure 1: Cross-section of the laboratory lysimeter cells used to evaluate leachate and runoff conditions using simulated rain events**

### **2.3 Hand Grenade Management Field Demonstration Results**

A field demonstration was conducted at Fort Jackson, South Carolina HGR. The objective of the field demonstration was to evaluate a technology to control active grenade range contaminant mobility and promote contaminant degradation. This technology is low cost and minimally resource-intensive. The field demonstration measurement parameters were similar to those used in the treatability study performed by ERDC-EL (Larson et al., 2007a). The results obtained and observations made from the treatability study, and the subsequent field demonstration, were used to develop this guidance document. The results are detailed in Larson et al. (2007b) and Larson et al. (2007c) and summarized here according to the study performance goals.

Effective management of metals and explosives on HGRs requires an understanding of the natural and engineered processes controlling their fate and transport at these sites. The migration of metals and explosives, in both soluble and particulate forms, from the impact areas of the ranges occurs through a variety of mechanisms, including transport in surface water following rain and storm events, transport with soil particulates following rain and storm events, and leaching through the subsurface towards groundwater.

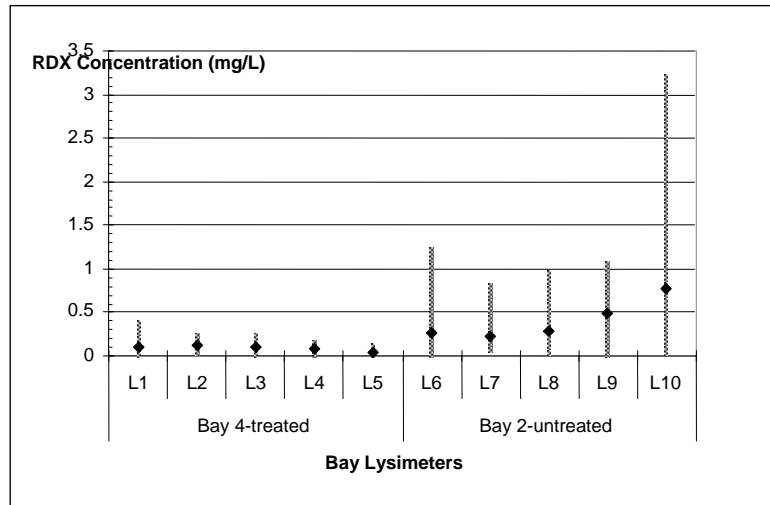
The objective of the treatability study and field demonstration test were to evaluate and develop a management technology to control active grenade range contaminant mobility and promote on-site contaminant degradation. The contaminants, explosives and metals, would be transformed/degraded (explosives) or stabilized (metals) to permanently reduce the concentrations leaving the impact areas. In addition, the demonstrated technology would meet the criteria for active range management in that it would be inexpensive; easily applied in remote locations; effective on heterogeneous contaminant distributions; effective over large areas; effective on multiple compounds; nonintrusive, to the extent possible; and able to be incorporated into normal range operations.

Ca(OH)<sub>2</sub> was chosen as the soil amendment for its ability to transform explosives to environmentally friendly end products (Brooks et al., 2003; Davis et al., 2007b) and stabilize metals (Mckinley et al., 2001, Gray et al., 2006, Larson et al., 2007a). HGR soils were collected from Fort Jackson, South Carolina for characterization and preliminary treatability studies (Larson et al., 2007a). Two lysimeter studies were conducted using the HGR soils with different lime concentrations and varying environmental conditions. Lysimeter Study I used native HGR soils with an annual rainfall equivalent of 119.4 cm per year. Lysimeter Study II used HGR soil amended with hand grenade residue containing composition B, an annual rainfall equivalent of 29.8 cm per year, and an increased lime addition to the treated cells. The decreased rainfall amount in Lysimeter Study II was used primarily to reduce the washout effects associated with the larger rainfall volume of Lysimeter Study I.

Attainment of the study objective in the field was evaluated through the following metrics. The results of this study indicate that Ca[OH]<sub>2</sub> amendment to HGR soils was effective in achieving these goals.

**1. Reduce RDX and TNT concentrations by greater than 90% in the pore water leaching from the source area based on baseline and control area concentrations.**

*Results:* The optimal baseline explosives concentrations were not obtained in the three months prior to the initial liming event due to unexpected drought conditions. Although not optimal, semi-baseline values were obtained twice during the course of the study. Two lysimeter samples were obtained during a period when there was an inadequate lime concentration in the soil above the lysimeters. These two data points show that in Bay 4 significant masses of RDX would leach towards groundwater without the lime treatment. The untreated Bay 2 was used as the pore water control. As stated in Larson et al. (2007b, 2007c), based on the average pore water concentration in the untreated bay, there was a 77% reduction in RDX concentration in pore water from the treated bay. Individual sampling events achieved >80% reduction (**Figure 2**). Although this did not achieve the goal set in Objective 1, it was a statistically significant reduction in explosive concentration and confirmed that alkaline hydrolysis was capable of transforming the explosive residues from the hand grenades. These reductions were achieved even though there was continuous loading of explosives onto the HGR bays through uninterrupted training. No TNT was detected in the pore water lysimeter samples from either HGR bay.



**Figure 2. Pore water RDX concentration by bay and lysimeter with high and low concentration profiles (avg, n varies from 7 to 10)**

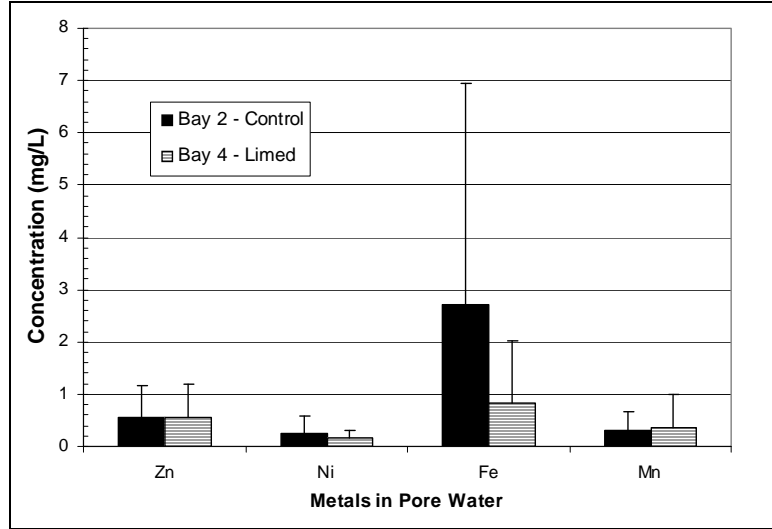
- 2. Reduce RDX and TNT concentrations by greater than 90% in the surface water running from the source area based on baseline and control area concentrations.**

*Results:* As reported for the in-ground lysimeters (pore water), baseline explosives concentrations were not obtained at all sites in the three months prior to the initial liming event due to the unexpected drought conditions. In addition, there was difficulty in obtaining surface water samples due to the soil clay and fine soil properties of the Remagen HGR. However, serving as a baseline, surface water samples were obtained for surface water #1 both before and after the September 2006 liming event. Baseline samples were also obtained for surface water #2 both before and after the December 2005 liming event. In these events, there was a 60% decrease in the surface water RDX concentration. In addition, the offsite #3 soil RDX concentration went from 1.23 ppm in July 2006 to non detect (Reporting Limit=0.01 ppm) in October 2006, or a greater than 99% reduction in the RDX concentration. Again, off-site #3 is where the water pools at the end of Bay 4; there is potentially RDX lost as pore water leachate at the off-site sample area, but the off-site sample area did not have suction lysimeters as part of the field demonstration so this cannot be confirmed. As stated in the results, the final surface water samples of the field demonstration indicated a reduction in surface water RDX concentration of >96%, from the control. No TNT was detected in the surface water samples.

- 3. Reduce metals (Fe, Zn, Mn, Cr, Pb [if present], Ni, and V) concentrations by greater than 90% or demonstrate no significant increase in metals migration in the pore**

**water leaching from the source area based on baseline and control area concentrations.**

*Results:* **Figure 3** compares the concentration of soluble metals in the soil pore water over the duration of the field study from the treated and untreated bays. Of the metals whose extractability from soil was decreased by treatment with lime (Fe, Mn, Cr, and V), only Fe and Mn appeared in the soil pore water collected by the lysimeters. Of those metals whose extractability appeared unchanged by the lime treatment (Zn, Pb, and Ni), only Zn and Ni were found in the soil pore water. The concentrations of Zn, Ni, and Mn in the two bays were not significantly different statistically, but they did not increase in the treated bay. The concentration of Fe in the pore water was significantly decreased (70%) in the leachate from the treated bay. Metals in the soil appear to be stabilized by hydroxide addition to the soil. This is also supported by the decreased variability between replicates in the metal concentrations in the pore water from the treated bay (Bay 4).



**Figure 3. Soluble metals in soil pore water from treated and untreated HGR bays**

- 4. Reduce metals (Fe, Zn, Mn, Cr, Pb[if present], Ni, and V) concentrations by greater than 90% or demonstrate no significant increase in metals migration in the surface water running from the source area, based on baseline and control area concentrations.**

*Results:* The most prominent metal in the surface water samples was Zn. The average concentration of Zn in the final three surface water samples from the lime-amended bay (Bay 4) was 0.046 mg/L, a greater than 98% reduction from the control.

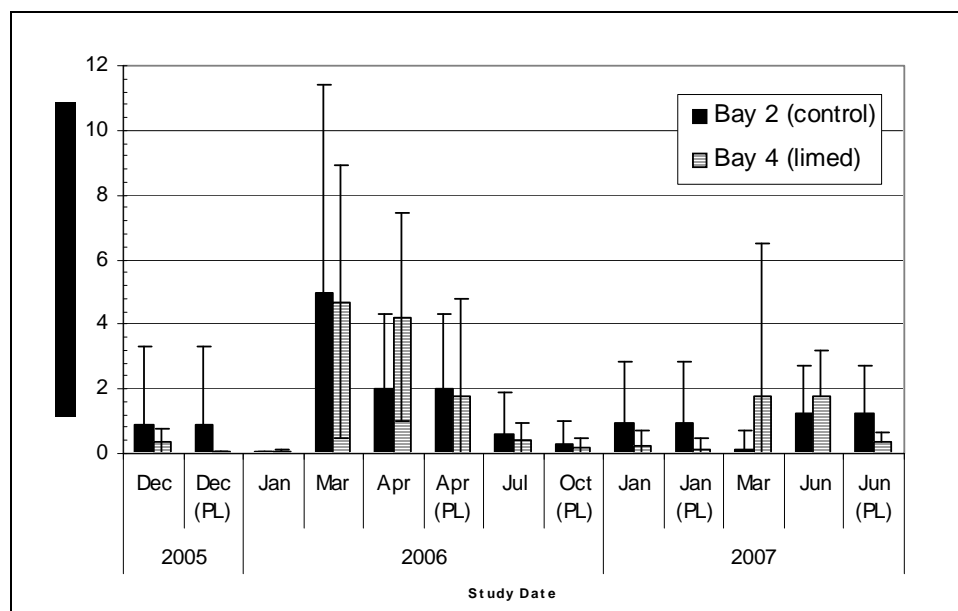
5. **Assess the overall effectiveness and potential side effects of the lime amendment technology, including the following:**
  - a. **Evaluate explosives reductions and soil stabilization, or reductions, of metals (total and dissolved), in the surface water and pore water samples. Compare results from the treated (lime added) and control (no lime added) impact areas.**

*Results:* Decreased concentrations of RDX were detected leaving the range in the pore water and the surface waters in the limed bay versus the control bay. The metals appear to be stabilized, i.e., there was a decreased concentration of metals entering the pore water and the metals that did leach from the soil were detected at lower concentrations than the metals leaving the untreated soil. No metal detected in the pore water or the surface water increased in concentration as a result of the lime amendment.

- b. **Maintain or reduce explosives concentrations in soil at the source area. Since continuous loading of explosives will occur, maintaining explosives concentrations in soil below baseline levels will be an appropriate objective.**

*Results:* Soil samples were taken prior to and 24 hours after most liming events. Baseline RDX concentrations were established in December 2005 for each HGR bay. Following the initial liming event in that month, the RDX concentration in the treated bay decreased by 84% over the baseline, and 94% from the control, Bay 2 (**Figure 4**). Soil moisture in each bay continued to drop with the lack of precipitation, hindering the alkaline hydrolysis reaction and allowing the RDX concentration in each bay to increase. With the resumption of rain and a liming event in April, the RDX concentration in the treated bay decreased significantly, from 4.2 to 1.8 mg/kg (a 57% decrease), while the concentration in the untreated bay remained constant (2.0 mg/kg). Across the impact area of the treated bay (Bay 4), RDX demonstrated a range of concentration that was decreased from the control by 23 to 97%.

When the soil pH fell below the treatment goal of 10.5, the RDX concentrations in the soil increased. The correlation of low surface soil pH with the high concentrations of surface soil RDX for March 2006, April 2006 (pre-liming), April 2006 (post-liming), March 2007, and June 2007 would be expected (**Table 1**). Maintaining the high surface soil pH involves a combination of sufficiently short lime application intervals and range management practices. This requirement can be minimized at a base hydrolysis reactive impact area range by incorporating the lime treatment into the regular range maintenance program through mixing lime with the topsoil prior to its addition to the bays.



**Figure 4. Average soil RDX concentration by bay during the field demonstration (PL = post lime)**

**Table 1. Bay 4 pre- and post-lime soil RDX concentrations (n=3)**

Sample Area	2005			2006			2007		
	RDX (mg/kg)		% Decrease in RDX Soil Conc. [Increase]	RDX (mg/kg)		% Decrease in RDX Soil Conc.	RDX (mg/kg)		% Decrease in RDX Soil Conc.
	Dec (pre)	Dec (post)		Apr (pre)	Apr (post)		June (pre)	June (post)	
	6-Dec-05	7-Dec-05		19-Apr-06	20-Apr-06		7-June-07	8-June-07	
1	0.052	0.098	[87]	4.153	0.123	97	1.362	0.217	84
2	0.027	0.052	[89]	2.181	0.179	92	1.398	0.208	85
3	0.043	0.047	[9]	6.040	0.106	98	3.015	0.215	93
4	0.127	0.045	64	8.630	7.267	16	1.512	0.637	58
5	0.293	0.059	80	2.328	0.020	99	0.903	0.657	27
6	0.419	0.064	85	8.811	6.234	29	0.556	0.207	63
7	1.001	0.032	97	1.234	0.020	98	0.873	0.381	56
8	0.719	0.033	95	0.323	0.087	73	4.778	0.145	97

- c. Determine ability to maintain pH above 10.5 in the source area and below 12.5 outside the source area.**

*Results:* The results of the field pH and the laboratory-verified pH are shown in **Table 2** for the first year of the field study. This data illustrates, first, the increase in soil pH in the reactive impact area of the throwing bay in response to the lime application. Secondly, the data confirms



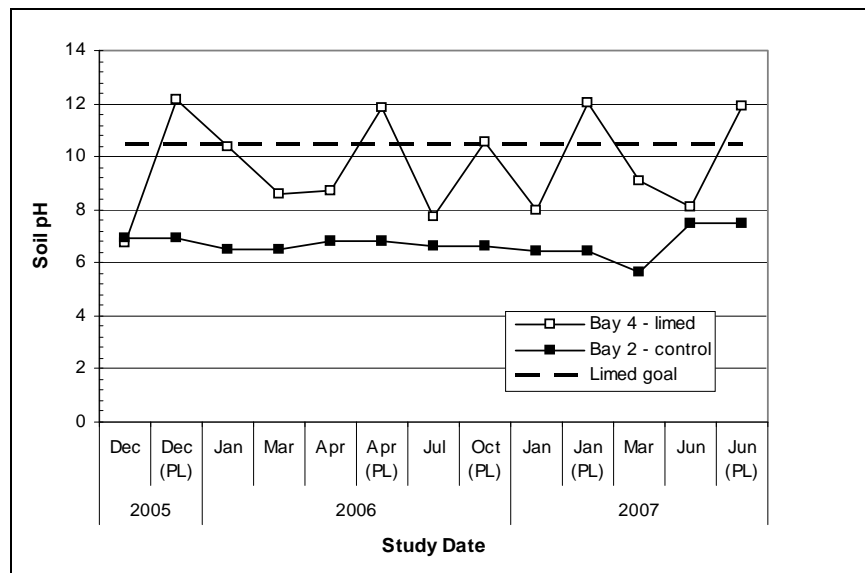
that for management purposes pH strip paper is an acceptable substitute for laboratory analysis in determination of soil pH. The pH paper is subject to interpretation by the user so there is some difference in the pH range from the paper to the probe. However, with experience, the soil pH can be determined using pH paper and can provide a guide for the re-application of lime.

It was determined that for the soil, climate, and range use conditions at the Fort Jackson HGR, the bay would have to be limed on a quarterly basis to maintain the pH above 10.5 (Figure 5).

**Table 2. Field and laboratory measured soil pH**

Date	Bay 2 (Control)		Bay 4 (Limed)		
	pH Probe	pH Paper <sup>a</sup>	pH Probe	pH Paper	
2006	Jan	6.5	6.0	10.3 <sup>c</sup>	12.0 <sup>c</sup>
	Mar	6.5	6.5	8.4 <sup>b</sup>	10.5 <sup>b</sup>
	Apr	6.9	5.5	11.9 <sup>c</sup>	12.5 <sup>c</sup>
	Jul	6.6	6.5	7.8	9.0
2007	Jan	6.4	6.3	8.0 <sup>b</sup>	6.8 <sup>b</sup>
				12.1 <sup>c</sup>	12.3 <sup>c</sup>

<sup>a</sup> pH paper is subjective and variable based on the interpretation of the user  
<sup>b</sup> sample taken pre-liming  
<sup>c</sup> sample taken post-liming



**Figure 5. Soil pH profile for Fort Jackson, Bays 2 and 4, during the field demonstration based on average pH for each bay at each sampling event**

As seen in **Table 3**, the pore water pH for the limed bay averaged slightly less than for the control bay, indicating the hydroxide ion was completely neutralized before the leachate from the bay could impact the groundwater. The surface water samplers, placed in the direct surface water flow path from each bay, ranged from 4.86 to 7.79 for water from the treated bay. The pH for the surface water collected from the control Bay 2 surface water samplers #3 and #4 ranged from 5.41 to 6.64. The off-site #3 surface soil pH averaged 7.43, approximately 1 standard unit (SU) above the control bay. Therefore, there was no evidence of impact from the lime outside the treated area.

**Table 3. Pore water pH from the suction lysimeters**

Bay	Lysimeter ID	Pore Water pH	
		Average <sup>1</sup>	Std Dev
4	1	6.85	0.29
	2	6.87	0.68
	3	6.98	0.50
	4	6.93	0.40
	5	6.59	0.26
2	6	7.05	0.58
	7	7.07	0.60
	8	7.10	0.66
	9	6.85	0.26
	10	7.02	0.46

<sup>1</sup> Average sample size ranged from 4 to 9 due to available sample for analysis

- d. Evaluate ease of use. Identify problems, if any, with amendment and maintenance of the lime amended impact area. Determine the mixing efficiency required and estimate the frequency of lime re-application. Identify factors other than range use that may affect the maintenance frequency.**

*Results:* The application of the lime can be accomplished easily within a few hours with the proper tools and equipment. Several techniques were used to apply the lime in the bays. These varied from simply opening bags on the range by hand and raking to give a uniform color distribution (**Figure 6**) to using a drop seed spreader (**Figure 7**). A hydroseeder was used after the final lime application in order to evaluate the effect of consecutive liming and watering on dust control. The lime was applied to the test range; it was then raked, and then watered (**Figure 8**). In order to mix the lime into the HGR soil to the required depth several techniques were evaluated, including a garden rotor tiller, a small disc (**Figure 9**), a cultivator, and a rake (**Figure 10**).



**Figure 6. Applying  $\text{Ca}(\text{OH})_2$  by hand**



**Figure 7. Applying  $\text{Ca}(\text{OH})_2$  with a drop spreader**



**Figure 8. A hydro-seeder was used after the final lime application to evaluate its effectiveness for dust control**



**Figure 9. Using a disc to mix the lime into the Fort Jackson HGR soil to a depth of approximately 6 in**



**Figure 10. Using a cultivator and rake to mix the lime into the Fort Jackson HGR soil to a depth of approximately 6 in**

The cost of the lime applied to Throwing Bay 4 was approximately \$400 per application. It was determined that for the soil, climate, and range use conditions at the Fort Jackson HGR, the bay would have to be limed on a quarterly basis to maintain the pH above 10.5. Factors that may affect frequency of lime addition are:

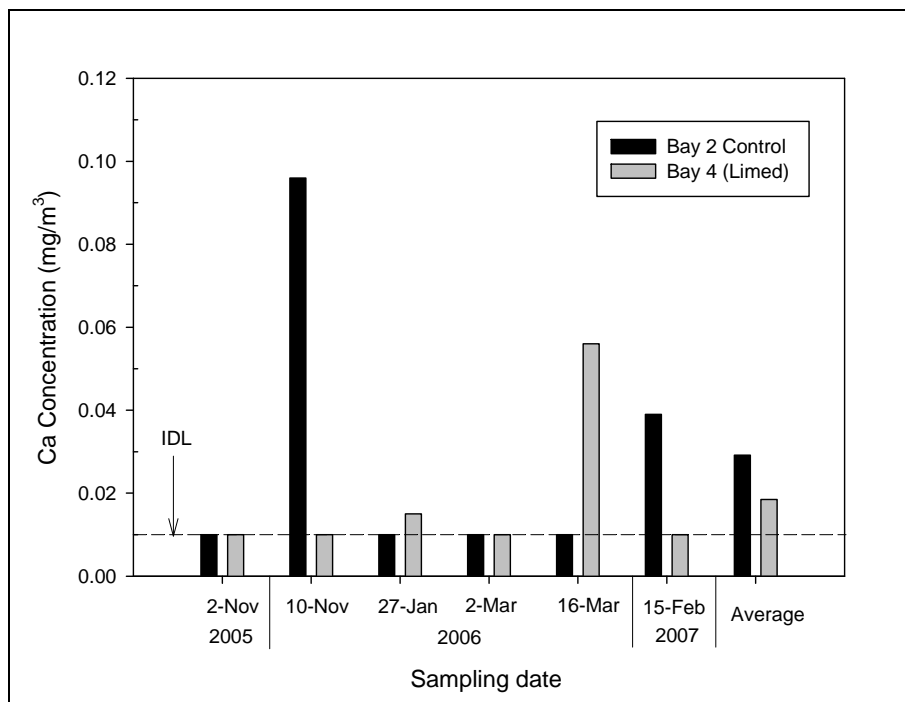
- The buffering capacity of the soil being treated
- Weather conditions on the range
- The frequency and type of range maintenance operations.

In general, for alkaline hydrolysis to perform effectively the soil pH must be elevated above 10.5. If the natural buffering capacity of the soil being treated is very high, then the initial application rate of the lime will also be high. However, a high buffering capacity may also result in a lower re-application rate. A soil with low natural buffering capacity will require very little lime to reach the target pH but may need frequent re-applications of the lime to maintain that pH. Weather also effects the alkaline hydrolysis reaction as there must be sufficient soil moisture content (or precipitation) for the RDX and hydroxide to react. One advantage to dry conditions is that RDX will not become mobile in the surface water or groundwater and be transported off-range. This is especially useful if the soil has a low buffering capacity as the combination of low buffering capacity and low precipitation will mean fewer lime applications to maintain the target soil pH. The use of lime could be limited to the rainy seasons when munitions transport is a greater concern and there will be sufficient soil moisture for the alkaline hydrolysis reaction. In a rainy climate, the application rate of lime may be more frequent than quarterly due to the dilution and buffering effects associated with the precipitation.

Range management also affects the lime technology. The normal addition of topsoil to the range to fill in divots or re-grade berms dilutes the lime and possibly gives the soil additional buffering capacity. The result is that the soil pH does not achieve the alkaline reactive zone for successful hydrolysis of the explosives or stabilization of the metals. Additional liming should be considered along with the normal range maintenance events or the lime could be mixed into the soil before it is added to the range.

**e. Evaluate the human health risks, including occupational risks associated with technology installation, range use, and range maintenance.**

*Results:* The air monitoring results (**Figure 11**) indicated that the Ca (used as a tracer for the hydroxide) levels in the air samples from the limed bay were similar to, if not the same as, the Ca levels in the air samples from the control bay. Application of the lime in the HGR bays requires only Level D personal protective equipment (PPE), modified by the addition of a particulate respiratory mask and, possibly, the substitution of goggles as protective eyewear. Range maintenance will require only Level D protection as the lime is incorporated into the soil at that point.



**Figure 11. Comparison of Ca concentrations in air (mg/m<sup>3</sup>) from treated and untreated bays during the field demonstration study (IDL=instrument detection limit)**

- f. **Determine transport characteristics by using Ca from the dissolution of lime as a tracer in pore water, surface water, soils, and air monitoring samples. Fort Jackson HGR soil has a naturally occurring low Ca concentration.**

*Results:* Results from the preliminary soil analysis and from the soil cores, extracted pre- and post-liming, indicate that Ca is normally present in Fort Jackson soil at low concentrations. The Ca concentration in the post-liming core was elevated in the surface 12 in of the soil. There was significant reduction in the Ca concentration, to background levels, in the samples taken at 12 to 18-in below ground surface (bgs) and below. This supports the pH data that indicates soil pH returns to background/neutral around 24 in bgs.

A comparison of the presence of the tracer Ca in the test media is summarized in **Table 4** for the different areas of the Fort Jackson, Remagen HGR during the field demonstration.

**Table 4. A summary of the occurrence of Ca in the different media of the Fort Jackson HGR during the field demonstration**

Average Ca concentration (mg/kg or mg/L) from each site and media <sup>a</sup>		
Site/media	Bay 2	Bay 4
Bay soil	60.26 ± 31.98	7745.90 ± 5218.02
Off-site soil #1	58.91 ± 54.10	NA
Off-site soil #2	55.13 ± 31.78	NA
Off-site soil #3	NA	2394.94 ± 2169.99
Lysimeter leachate	3.68 ± 2.77	2.54 ± 2.69
Surface water	1.56 ± 0.72	9.75 ± 13.01
<sup>a</sup> See text and appendix (Larson et al., 2007b, 2007c) for sample number used to determine each average. Minimum was three replicates for each sampling event.		
NA=not applicable		

Together, the field demonstration results indicate that, used on a regular basis, quarterly or biannual lime addition can be an effective treatment for munitions constituents on ranges, and this method does not appear to pose adverse side effects to the surrounding environment if applied properly and monitored on a regular basis.

## 2.4 Advantages and Limitations of the Technology

### 2.4.1 Advantages

The application of lime is an attractive technique for the destruction of energetic compounds because it treats at the source before the munitions constituents can migrate to surface water or groundwater. The simple addition of lime to soil at HGRs, with some mixing into the soil and occasional re-applications, can minimize the environmental impact of explosive compounds that are deposited on the range. In addition, the lime (hydroxide – OH<sup>-</sup>) can bind with soluble metals and stabilize them within the range soil matrix. Significant cost savings can be realized by preventing future contamination and remediation. Lime application is potentially a low-cost range management technology that stabilizes metals and transforms explosives in the source zone.

The advantages of the lime technology are:

- Low operating costs
- Low capital costs
- Explosives source zone mass reduction
- Eliminate munitions constituents (explosives and metals) mobility
- Eliminate or reduce soil and groundwater remediation following range closure
- Reduce liability
- Enhance public perception.

### 2.4.2 Limitations

Some issues of concern and technical risks associated with the technology include:

#### 2.4.2.1 Hydroxide Impacts

One potential issue of concern is the solubilization of hydroxide and transport of hydroxide off the range in storm water. High hydroxide concentrations can result in phytotoxic effects. Ca(OH)<sub>2</sub> solubility is low and stops when a pH of approximately 12.5 is reached. Specific soil types have varying reactive capacity for neutralization of hydroxide (Davis et al., 2006).

Treatability studies and the field demonstration results indicate that there will be minimal contact time between the pore water and/or surface water and the lime. The limited contact time allows the natural buffering capacity of the soil to neutralize the pore water before it reaches the groundwater. The surface water runoff is also buffered by the soil before it enters local bodies of water. After initial topical application of the lime to the range soil, the soil was disced to a depth of 6 in to further reduce off-site migration due to surface water transport (Larson et al., 2007a; 2007b; 2007c).

#### 2.4.2.2 Elevated pH

Elevation of the impact area pH to 12.5 might pose a risk of increased solubility of some heavy metals. The amphoteric solubility properties of some metals show increased solubility at both



high and low pH. Existing grenade soils were evaluated with regard to increases in metals leachability on  $\text{Ca}(\text{OH})_2$  amendment, release of heavy metals, hydroxide concentrations (pH) in leachate water, and surface water from simulated HGRs.

With the addition of lime and the decrease in TSS in the lysimeter studies indicates the potential to reduce soluble and particulate transport of contaminants (Larson et al., 2007a). Currently there is no range management technology that addresses the metals stabilization and explosives reduction. The current range management practices are to periodically fill in the hand grenade impact craters and place additional soil (as needed) on the range impact area. Treatability studies indicate that the addition of  $\text{Ca}(\text{OH})_2$  to the range soil matrix will stabilize and potentially reduce metals from leaving the range while reducing the explosives concentrations in the source zone and from leaving the range (Larson et al. 2007a).

#### **2.4.2.3 Airborne Dust Monitoring**

As with any HGR, the dust generated from the grenade detonation is a potential inhalation hazard that is dependent on the wind direction and speed. The results from air monitoring of active training during the field demonstration, using Ca as an indicator for lime, suggests that the Ca concentration in the unlimed bay was similar to that of the limed bay (Larson et al., 2007b; 2007c). Since the addition of lime to the soil was not expected to cause any increases in the suspension of other constituents at the site, no other analysis was performed on the air samples.

## **3 Considerations for Use at Your Range**

### **3.1 Range Use**

The geographic location, chemical and physical soil conditions, and range activity at site specific HGRs will be used by range managers to determine if lime application is appropriate. This document provides range managers with a guide to successfully determine the lime dose requirements and techniques in applying  $\text{Ca}(\text{OH})_2$  effectively to their HGR. Range managers need to take into consideration the specific conditions at their range when applying this technology.

### **3.2 Characterizing the Range**

There are several things to consider when characterizing the test site such as (this list is not all inclusive but provides a guide for range managers when considering the use of this technology):

#### *3.2.1 Range History*

Where is the range located?

How long has it been in operation?

Are there any regulatory issues/concerns that may affect the installation?

Are there any regulatory issues/concerns that may affect the range use?

#### *3.2.2 Range Characteristics*

Is the range near any streams, estuaries, lakes, or rivers?

How high is the water table in the area of the range?

What is the soil type (alkaline or acidic; clay, sand, or loam)?

What is the natural buffering capacity of the soil?

What is the local drinking water source?

What is the depth to the local groundwater?

What is the pH of the groundwater?

Does the pore water (leachate) feed into that source?

What is the local watershed for runoff water and to where does the runoff flow?

Does the HGR surface water flow off the range?

#### *3.2.3 Hand Grenade Range Operations*

How many bays does the range have?

What types of grenades are used at the range?

How often is the range used (once a year, once a quarter, or once a week)?

What time of year is the range used?

What are the Explosive Ordnance Disposal (EOD) procedures at the range?

What are the capabilities of range personnel (tiller, disc, spreader, soldier manpower)?

#### *3.2.4 Range Climate Conditions*

What is the average annual and monthly rainfall?

What is the average monthly temperature?

With little rainfall, is there the capability to apply water to the soil after lime application?

### **3.3 Implementation Issues**

#### *3.3.1 Environmental Checklist*

This in situ lime technology does not involve the use of any toxic or hazardous chemicals. The only chemical used is  $\text{Ca}(\text{OH})_2$ , which is not regulated for the addition to soil. Consult the appropriate Material Safety Data Sheet (MSDS) for the lime used or considered for use at the range.

#### *3.3.2 Other Regulatory Issues*

If migration potential is present and threatens nearby open water or groundwater resources, then Clean Water Act and/or Safe Drinking Water Act regulations may be of concern to ongoing range operations. Munitions constituent migration potential should be investigated prior to implementing any management strategy.

Concerns associated with the use of the lime amendments on HGRs include the potential for runoff with elevated pH. The elevated pH may be detrimental to biota or surface water quality, and consideration of such risks should be addressed prior to implementation of any range management strategy.

#### *3.3.3 End-User Issues*

The primary end user for this innovative in situ technology will be active hand grenade training ranges and the range managers. The technology will transform explosives and stabilize metals at the source zone before they can migrate to surface water or groundwater. The lime amendment management technology may be capable of being applied to other active range areas where explosives constituents are being deposited in the shallow soil layer; however, further development is required to identify effective application methods that can be safely implemented

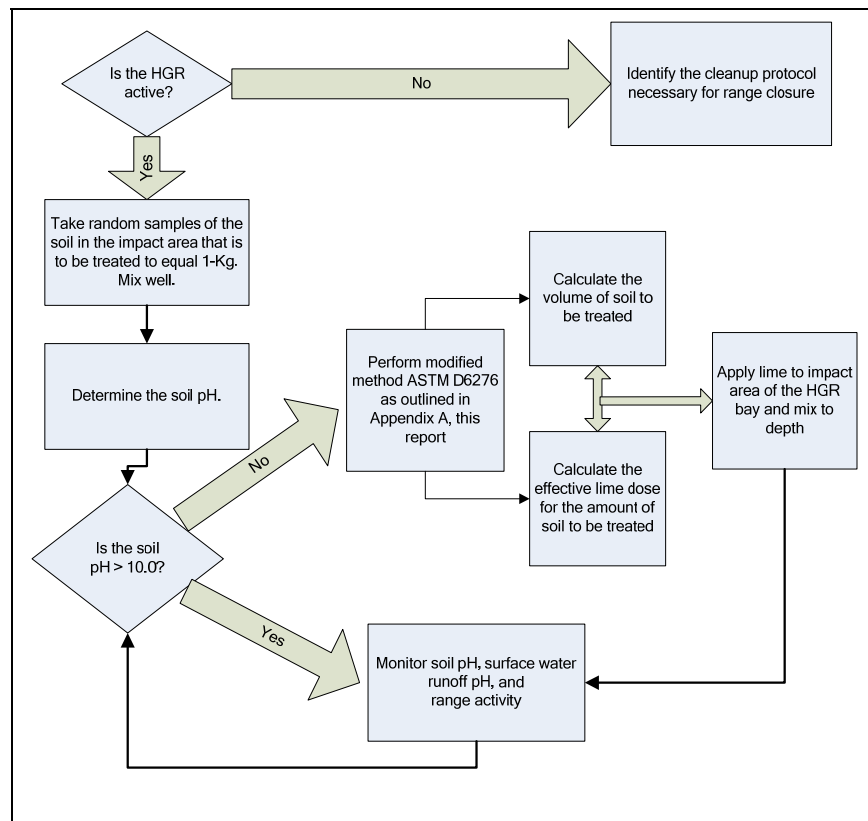
in these areas. Range managers and users should obtain and read the MSDS for the  $\text{Ca(OH)}_2$  used at the specific range prior to purchase and use on the range.

This management technology transforms explosives and stabilizes metals within the range impact area, thus reducing the munitions constituents leaving the range. Currently the incentive for participating in this technology is to use a low cost, low maintenance range technology that will control contaminant migration at the source zone, mitigate future cleanup costs, and prevent potential environmental issues.

## 4 Applying Lime to the HGR

After the range manager and appropriate personnel have determined that the application of  $\text{Ca}(\text{OH})_2$  to the HGR is an appropriate technology to use, then the amount of lime needed for application and the re-application rate can be determined. A flowchart of the steps involved and the decisions to be made is shown in **Figure 12**.

Initial lime application rate is based on soil chemistry at the site and how deep the lime will be cultivated into the soil. The reactive zone must achieve a  $\text{pH} > 10.5$ , and 6 in bgs is our recommended depth. Based on treatability studies and the field demonstration, the amount of lime needed to apply to the HGR can vary from a fraction of a percent to up to several percentage points. The procedure outlined in **Section 4.1** of this report can be used to directly test each soil to be treated and avoid costly soil characterization analysis. Statistical analysis of data collected from numerous soils indicated no direct correlation between any single soil parameter and the amount of lime needed to raise the soil pH to the levels necessary for alkaline hydrolysis transformation of explosives. **Appendix A** lists some HGR soils where the percentage of lime was determined for an end soil pH of 11.5. Not all installations were tested and the **Appendix A** values should only be used as a guide. It is recommended that range managers follow the steps detailed in this document to validate their lime dose and application rate.



**Figure 12. Flow diagram used for grenade range management using lime**

## 4.1 Lime Dose Determination

This method of determining lime dosage does not depend on soil characteristics, but measures the lime dosage requirement directly. In this way, all soil characteristics are taken into account and no additional soil characterization studies are necessary. Another advantage to this method is that the equipment required for this test is readily available in most laboratories.

### 4.1.1 Materials

Stir plates - 8	50-mL glass beakers - 8
Stir bars to fit a 50-mL beaker - 8	Balance with an accuracy to 3 decimal places
Weighing paper and spatulas	pH meter and electrode
pH buffers - 4 and 10	20-mL pipettes and pipettor
Soil to be tested (approximately 200 g, dried and large debris and rocks removed)	
Water (tap or rainwater)	

### 4.1.2 Method

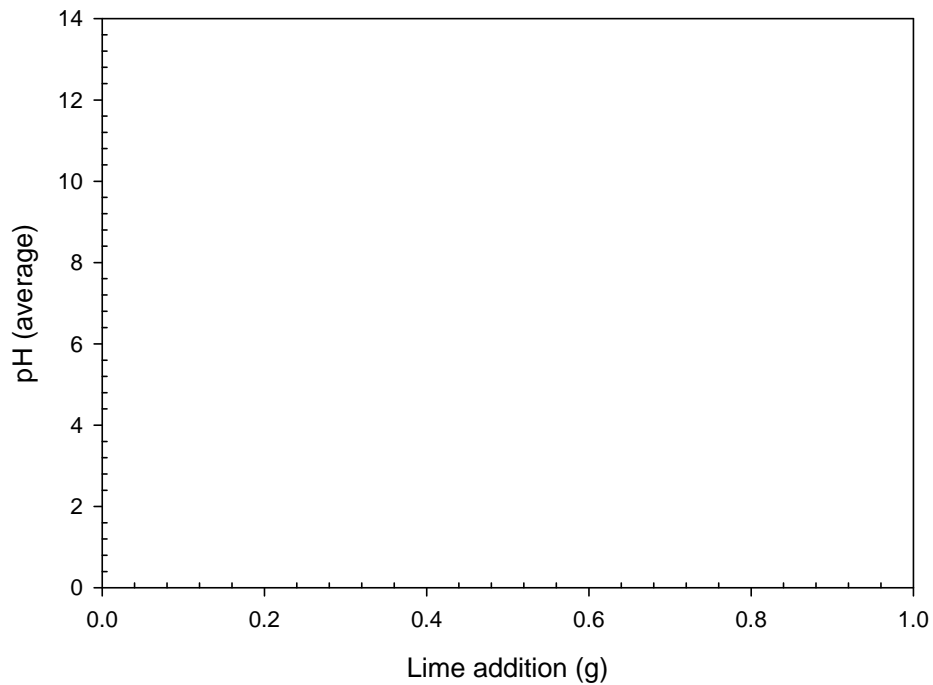
1. Add stir bars to the beakers and label the beakers according to the lime content to be added, listed in **Table 5**. There will be one beaker with no lime added, the pH control.
2. Calibrate the pH meter using a two-point calibration of pH 4 and 10.
3. Weigh out 20 g of the test soil for each beaker.
4. Weigh out the appropriate lime dose for each beaker (**Table 5**) and add it to the soil.
5. Add 20 mL water to each beaker and start the slurry gently mixing.
6. Mix the slurry for 30 minutes.
7. Take the pH of each slurry, beginning with the lime control, which will establish the initial soil pH. Average the log pH achieved at each level of lime addition. Create a table of lime dose and pH (using the template shown in **Table 6**).
8. Plot the data on a graph with the amount of lime addition to the soil slurry on the X-axis and the resulting average pH on the Y-axis (**Figure 13**).
9. A line drawn horizontally from your desired pH (ex. pH 11.5) to the line formed from the experimental data and then dropped to the X-axis will provide an estimate of the amount of lime (per 20 g of soil) that is needed to bring the soil to the desired pH. This value is used in the calculation to determine tons of lime to be added to the soil for either a plowed-in treatment or a top-dressing treatment.

**Table 5. Procedure for lime addition to each experimental beaker**

Beaker	Lime (% soil weight)	Lime (g)
1	0.00	0.00
2	0.05	0.01
3	0.10	0.02
4	0.50	0.10
5	1.00	0.20
6	2.00	0.40
7	3.00	0.60
8	5.00	1.00

**Table 6. Soil slurry pH determined from each lime addition after mixing for 30 minutes**

Beaker	Lime (%)	Lime (g)	Soil pH						Avg pH	Avg log pH
			Rep 1		Rep 2		Rep 3			
			pH	logpH	pH	logpH	pH	logpH		
1	0.00	0.00								
2	0.05	0.01								
3	0.10	0.02								
4	0.50	0.10								
5	1.00	0.20								
6	2.00	0.40								
7	3.00	0.60								
8	5.00	1.00								



**Figure 13. Graph of lime addition versus average pH**



### 4.1.3 Calculation of lime addition to achieve the required pH

#### 4.1.3.1 12-in application depth

Uses – cleared, active, or inactive land

Mode of application – surface application, then plow to depth

Convert from grams of lime per 20 g of soil to tons of lime per acre-ft.

$$(X \text{ g lime}/20 \text{ g soil}) * (1846.21) = Y \text{ tons lime/acre-ft}$$

#### 4.1.3.2 6-in application depth

Uses – cleared, active or inactive land

Mode of application – surface application then plow to depth

Convert from grams of lime per 20 grams of soil to tons of lime per acre-6-in.

$$(X \text{ g lime}/20 \text{ g soil}) * (153.8508) * 6 = Y \text{ tons lime/acre-6-in}$$

#### 4.1.3.3 Surface application (3-in depth of lime)

Uses – land uncleared and in use

Mode of application – spray on or airdrop a top dressing

Convert from grams of lime per 20 grams of soil to tons of lime per acre-3-inch.

$$(X \text{ g lime}/20 \text{ g soil}) * (153.8508) * 3 = Y \text{ tons lime/ acre-3-in}$$

$$Y \text{ tons lime} * 2,000 = Z \text{ pounds lime/acre}$$

Calculate the area of the range that is to be treated, for example 100 ft x 100 ft = 10,000 ft<sup>2</sup>. Since 1 acre = 43,560 ft<sup>2</sup>, the area to be treated is 10,000/43,560 = 0.23 acre.

The application is designed to be applied in 50 pound bags of Ca(OH)<sub>2</sub> within a specified area on the range. In order to determine the number of bags to purchase, first, divide the total pounds of lime required (Z, calculated above) by 50. This gives the number of bags to apply on a 1-acre area to the depth selected. Second, multiply by the total acreage to be treated, in our example 0.23 acres, which equals 11.5 bags of lime. The entire 12 bags of lime can be applied and mixed into the soil without negative effects on the alkaline hydrolysis reaction.

## 4.2 Lime Application

In order to work on the HGR impact area, the range must first be cleared of all unexploded ordinances (UXOs) and other low-order grenade materials. This should be done according to the local, range-specific operating procedures. Once the range has been cleared for personnel to

work on the impact area, there are several techniques that can be used to apply lime to the range. Using the calculations below, determine the number of bags of lime needed for the treated area. The lime can be applied by simply opening the bags and raking the lime out into the soil, providing a mixing depth of approximately 3 in (depth of the rake tines). If the equipment is available, a drop spreader and disc can be used to apply and mix the lime into the soil to a depth of 6 in as shown in **Figures 14 through 17**.



**Figure 14. Staging bags of lime to apply to the treated HGR bay**



**Figure 15. Dumping  $\text{Ca(OH)}_2$  into drop spreader** (notice the use of long sleeves, masks, and gloves when handling the lime)



**Figure 16. Using an ATV and the drop spreader to apply the lime to top of the HGR soil**



**Figure 17. Using an ATV and a disc to mix the lime and HGR soil to a depth of approximately 6 in**

Under optimal reaction conditions the soil must be damp, but over 30% soil moisture does not contribute to the reaction. If the HGR site is in drought or the site climate is naturally dry, water

may be added to soil following addition and mixing of the lime. **Figure 18** illustrates the use of a hydroseeder to add water to the treated area of the HGR bay. The hydroseeder also serves to control dust from both the application of the lime and the explosion of the hand grenades.



**Figure 18. A hydro seeder was used after the final lime application to evaluate its effectiveness for dust control**

### **4.3 Lime Dose Re-Application Rate**

After the lime has been applied, it will be necessary to check to soil pH and stormwater runoff pH monthly until you determine the necessary lime application rate for your site-specific range. The pH of both soil and runoff water can be tested in the field using pH paper. These values should be recorded on the charts provided in **Appendix B**.

The soil in the reactive area should be equal to or greater than pH 10.5. When the pH falls below this value, the area should be scheduled for reliming. The runoff water from the reactive area should remain below pH 9.5. If it is consistently above this value, recalculate the amount of lime added to the reactive area or check to be sure the lime is mixed thoroughly into the soil.

After determining the lime application rate, a schedule can be established and adjusted, based on the range use and weather conditions. Again, this will be site-specific based on the weather, soil conditions, and range use.

## 5 Cost Assessment

### 5.1 Cost Reporting

A complete cost analysis has been conducted in support of this project following the Federal Remediation Technologies Roundtable (FRTR) *Guide to Documenting and Managing Cost and Performance Information for remediation Projects* (FRTR, 2007). The complete analysis and technology cost comparison has been reported in the Environmental Security Technology Certification Program (ESTCP) Cost and Performance Report for ER-0216 (Larson et al., 2007d).

### 5.2 Cost Analysis

Ex situ remediation technologies are costly and could far exceed the funding available for normal range management operations. Currently, it is very expensive to conduct detailed characterization and remedial investigation activities. The application of this range management technology using  $\text{Ca}(\text{OH})_2$  supersedes the need for intensive characterization and results in relatively short-term degradation of explosives (RDX, TNT, and associated compounds) (Brooks et al., 2003; Hansen et al., 2003; Davis et al., 2006, 2007a, 2007b) and the stabilization of heavy metals (such as Zn, Cd, Cr, and Cu) in the soil (Larson et al., 2007a).

The cost of lime treatment at the Fort Jackson HGR for one year was approximately \$1,600. This cost is solely associated with the cost of purchasing the  $\text{Ca}(\text{OH})_2$  on a quarterly basis. The complete cost analysis report details the cost of using the lime management technology at an extremely active HGR like Fort Jackson and also allows estimation of the cost for a less active HGR that may be used only once a year (Larson et al., 2007d).

## 6 Supplies

Not everything on this list will be required, but all are recommended. Some equipment will be available from other activities on the range, and activities can be coordinated with regular range maintenance operations.

### 6.1 Lime Dose Determination

Stir plates - 8	50-mL glass beakers - 8
Stir bars to fit a 50-mL beaker - 8	Balance with an accuracy to 3 decimal places
Weighing paper and spatulas	pH meter and electrode
pH buffers - 4 and 10	20-mL pipettes and pipettor
Soil to be tested (approximately 200 g, dried, large debris and rocks removed)	
Water (tap or rainwater)	

### 6.2 Lime Application

Ca(OH)<sub>2</sub>

Drop spreader - to apply lime to HGR

Disc - to mix lime into approximately 6 in of soil

ATV - to pull drop spreader and disc

Rake and shovel - to apply and mix lime manually

pH strip paper, the results of which need to be confirmed in the lab with a pH probe

### 6.3 Monitoring

An electronic soil pH probe and standardizing buffers for pH 4, pH 7, and pH 10.

It is recommended that the results from field use of pH strip paper be confirmed with laboratory pH testing of the soil. This is particularly important for soil with a low buffering capacity in which the pH can change quickly.

### 6.4 Personal Protective Equipment (PPE)

Tyvek coveralls

Gloves - to avoid direct skin contact with lime

Dust masks - to avoid inhalation hazard associated with lime dust generation during application

Goggles

## **6.5 Additional Supplies**

MSDS - for lime application and use

Tape measure - to measure total HGR treated area and lime bag placement area

Water for washing hands and face after lime application

Water Tanker - to apply water to range after lime application if soil moisture is needed

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## Appendix A: Hydrated Lime Required to Elevate Soil pH at Specific DoD Sites

**Table 7** lists soils from various DoD sites, the soil type, initial pH, and lime dose required to elevate the soil to pH 11.5. This table should be used only as a guide by range managers, since the soil conditions may have changed since these were determined.

**Table 7. Examples of soil types and lime dose required to achieve pH 11.5**

Site	Predominant soil type <sup>a</sup>	Initial soil pH	Lime dose to achieve pH 11.5 <sup>b</sup>
WES reference soil, MS	Loess	8.67	4.15
Ft. Drum, NY	Clay silt	6.75	18.46
Ft. Knox, KY	Silty loam	5.12	9.23
Ft. Jackson, SC	Silty sand	5.48	4.62
Ft. Lewis, WA	Silty sand	4.96	20.77
Ft. Polk, LA	Silty sand	6.15	1.85
Iowa Army Ammunition Plant, IA	Silty clay	8.10	18.46
Volunteer Army Ammunition Plant, TN	Silty loam	8.14	3.92
Nebraska Ordnance Plant	Loamy sand	5.70	6.92
Yakima Training Center, WA	Silty loam	7.20	3.51
Camp Guernsey, WY	Shallow sandy loam	7.43	1.15
Redstone Arsenal, AL	Silty clay, loam	7.42	5.31
Camp Edwards, MA	Loamy, coarse sand	4.90	0.55
Ft. Hood, TX	Cobbly, silty clay	4.90	1.62
US Military Academy, NY	Gravelly loam	7.70	1.92
<sup>a</sup> Soil Survey Staff, Natural Resources Conservation Service, United States Department of Agriculture. Web Soil Survey. Available online at <a href="http://websoilsurvey.nrcs.usda.gov/">http://websoilsurvey.nrcs.usda.gov/</a> accessed November 29, 2007			
<sup>b</sup> lime dose expressed as tons of lime/acre-3-in			

**Appendix B: Tracking Sheets for Long-Term Monitoring of pH in Soil and Surface Water**

**Table 8. Soil pH tracking sheet** (Use monthly tracking as needed, after a pattern is observed quarterly, or other tracking may be sufficient)

pH Monitoring of Treated Soil												
Site:												
Lime requirement::												
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Notes: (such as dates of range maintenance, unusual weather conditions, etc.)												

**Table 9. Surface water runoff pH tracking sheet** (Use monthly tracking as needed, after a pattern is observed quarterly, or other tracking may be sufficient)

pH Monitoring of Surface Water Runoff												
Site:												
Lime requirement::												
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Notes: (such as dates of range maintenance, unusual weather conditions, etc.)												