EVALUATION OF INNOVATIVE SOIL REMEDIATION TECHNOLOGIES AT CAMP EDWARDS, MASSACHUSETTS

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1. ABSTRACT

Live fire training activity results in the deposition of spent munitions, propellants, and explosives in impact area soils at the Camp Edwards Training Area on the Massachusetts Military Reservation (MMR). Resulting contaminants of concern, including included hexahydro-1,3,5-trinitro-1,3,5-triazine (RDX) and octahydro-1,3,5,7-tetranitro-1,3,5,7-tetrazocine (HMX), are found in particulate form and are heterogeneously dispersed in the soil. An Innovative Technology Evaluation Program (ITE) was initiated by the Army National Guard in March 2000 to investigate the potential for remediation of the explosives-contaminated soil.

Soil remediation technologies chosen for the ITE to address this problem included: soil washing, low temperature thermal destruction (LTTD), composting, solid phase bioremediation, bioslurry, chemical oxidation, and chemical reduction. Soil washing was previously implemented as a field demonstration for remediation of explosives-impacted soils. Because innovative technologies may be implemented as a secondary treatment after soil washing, studies were therefore performed for all technologies using washed soil. Composting, bioslurry, solid phase bioremediation, and LTTD studies were also performed on untreated soils.

Results indicated that all technologies are likely to be effective on washed soils. LTTD and bioslurry were successful on untreated soil, with the exception of LTTD's inability to degrade HMX at low temperatures. One of two solid phase bioremediation studies was on untreated soil. Composting and the second solid phase bioremediation study experienced difficulties in degrading RDX and HMX in the untreated soils, likely due to the presence of particulate explosives.

The final reports included cost estimates for field-scale remediation at Camp Edwards. A comparison of the costs indicates that if soil washing would cost approximately $75 per ton to reduce the volume of 10,000 tons of soil requiring further remediation by 75%. Treatment of 10,000 tons of soil using a combination of soil washing and secondary treatment would cost between $75 and $135 per ton.

2. INTRODUCTION

Approximately 14,000-acres of the Massachusetts Military Reservation (MMR) constitute the Camp Edwards Training Ranges and Impact Area. Target practice and other range training operations have historically occurred at Camp Edwards. Such activity resulted in wide dispersion of low concentrations of spent munitions, propellants, explosives, and heavy metals in particulate form at Camp Edwards. In support of a series of Rapid Response Actions (RRA) implemented to protect groundwater at Camp Edwards, the National Guard Bureau (NGB) instituted the ITE program to study technologies that might meet the requirements for remediating soil and groundwater at the site. For the purpose of the soils studies, successful innovative technologies were defined as those technologies that can meet USEPA requirements to address remediation of the identified areas of concern.

In developing recommendations for ITE studies, the NGB assembled an ITE review team, including NGB, the Army Corps of Engineers (ACE), the Army Environmental Center (AEC), and AMEC Earth and Environmental, Inc. (AMEC) as the supervising contractor. The team developed selection criteria by which to assess potential remediation technologies and to select technologies for participation in the treatability studies. The major criteria included:

- Experience with treatment of soils,
- Experience with explosives,
- Level of clean-up achieved, and
- Time frame to complete clean up.

Soil cleanup goals established for the treatability studies included:

RDX	120 μg/kg	Lead	300 mg/kg
HMX	250 μg/kg	Dieldrin	246 μg/kg
TNT	250 μg/kg		

The team incorporated experience with a soil washing technology already demonstrated on the site by Brice Environmental Services Corporation (Brice) as part of a RRA. In soil washing, the fraction of the soil containing the contaminants of concern can be isolated and segregated from the remaining clean soil. Because this process may be implemented at Camp Edwards, it was determined that separate studies would be performed on washed soil and untreated soil from the site. The technologies chosen for the study were:

1) Chemical Oxidation - Brice, subcontracting to University of Nebraska-Lincoln (UNL),
2) Chemical Reduction - Brice / UNL,
3) Thermal Desorption/Destruction (LTTD) - TerraTherm Inc., subcontracting to Kiber Environmental Services (Kiber),
4) Bioslurry - Envirogen, Inc.,
5) Composting - BSI Environmental, Inc. (BSI), subcontracting to Woods End Laboratory (WEL), and
6) Solid Phase Bioremediation - Grace Canada, Inc. (Grace).

3. LABORATORY TREATABILITY STUDIES

Brice/UNL tested three remedial alternatives on washed soils only, as part of an overall treatment design to include soil washing as the first treatment step. One study was designed to simulate the reductive treatment of soil after the soil washing process by adding 5% zerovalent iron (ZVI) (mass:mass) in the form of iron filings, acetic acid, and aluminum sulfate solution to washed soils in a mixture maintained at 60% solids and maintaining conditions for 5 days. A second study was designed to simulate reductive treatment during the soil washing process , in a slurry of approximately 7% solids. In the third study, Fenton's Reagent (1% to 4% hydrogen peroxide with ferrous sulfate as a catalyst) was added to a 7% solids slurry to simulate oxidization of contaminants during the soil washing process.

TerraTherm tested a proprietary LTTD process on both washed and unwashed soil, which involves slowly heating soil to between 200° and 300°C, and holding for a minimum of 24 hours at the elevated temperature.

Envirogen tested a bioslurry process on unwashed soil. Molasses was added to a slurry of 25% soil and 75% water at a ratio of 0.3% (mass:mass). Two studies were performed during the study period of 35 days, one where slurry was constantly stirred at a low speed, and one where the slurry was intermittently stirred.

BSI tested composting technology on both the washed and unwashed soils. Twelve reactors were maintained for the study. Each reactor contained approximately 30% soil and 70% organic matter, including various forms of locally available manure, cranberry mash, and wood chips. The washed soil reactors were maintained for 12 days and those for the unwashed soils were maintained for 45 days.

Grace performed treatability studies on both washed and unwashed soil. Two separate treatments of the proprietary DARAMEND® treatment were tested on both types of soil. In addition, powdered iron was added to the soil to control the redox potential and calcium oxide was added to adjust the pH. An initial 2% application of DARAMEND® was added to the soil, as well as 0.2% powdered iron. Weekly amendments of 0.5% DARAMEND® and 0.2% powdered iron were then added to the soil during the 50-day test period.

4. RESULTS AND CONCLUSIONS OF LABORATORY SCALE STUDIES

Several findings were observed during the course of the studies. First, the heterogeneous distribution of the explosives residues of RDX and HMX at this site resulted in soil concentrations ranging up to five orders of magnitude difference within duplicate samples. This heterogeneous distribution affected conclusions drawn after review of the analytical results. Second, the explosive contaminants RDX and HMX do not adsorb onto the sandy soil grains at Camp Edwards. After soil washing, a significant proportion of explosive contaminants was co-located with the process water and organic matter. Therefore the initial soils available for the study contained lower concentrations of explosives than expected. However, this finding may further support the use of soil washing as a treatment process in that the vast majority of the explosive contaminants may be removed from the mineral soil particles and isolated into the organic matter and process water. Third, in previous studies, 95 – 99% of fresh RDX has been shown to be extracted using 18-hour sonication in acetonitrile, but only 85 – 90% of weathered RDX was extracted using the same technique. This may have implications for the time required for dissolution of weathered RDX into water.

Washed soils. In general, all studies on washed soils showed reductions of RDX and HMX, there being no detectable or low concentrations in the initial samples. The original concentration of RDX in samples sent to subcontractors was fairly low, averaging 590±30 μg/kg, and initial concentrations in soil as received by the subcontractors was approximately 160 μg/kg. Because the laboratory detection limit was 120 μg/kg, it is difficult to conclude that the technologies achieved a reduction in RDX, even though the final results were all below the detection limit.

Brice/UNL responded to this challenge by increasing concentrations of RDX and HMX in the slurries. The soil was spiked by adding decanted water from the initial buckets of received soil, then drying the resulting slurry to increase average RDX concentrations to 310 μg/kg. Figures 1 and 2 show results for the chemical oxidation and reduction studies, both of which were performed using the spiked soil. Chemical oxidation did not reduce explosives concentrations below soil cleanup goals. Therefore no further study of this process was made. Chemical reduction was shown to be effective in reducing the spiked RDX concentrations to below soil cleanup goals. Results suggest that the iron plus aluminum sulfate treatment in a post-soil washing treatment regime was the most effective and yielded results below soil cleanup goals for explosive compounds.

Untreated soils. The studies on unwashed soils showed varying success in reducing RDX concentrations. Figures 3, 4, 5, and 6 display results for LTTD, bioslurry, solid phase bioremediation, and composting. The following summarizes the results.

- LTTD was effective in degrading explosive compounds in soil below soil cleanup goals when temperatures greater than 250°C were applied.

- Bioslurry was effective in degrading explosive compounds to concentrations below the soil cleanup in the intermittently stirred reactors, but not in the constantly stirred reactors.

- Composting was partially successful in degrading explosive compounds in soil. The most successful compost mixes were those using hen and dairy manure, which yielded non-detectable results for HMX at the end of the study period. The final data suggested that HMX concentrations achieve soil cleanup goals; however, RDX was not degraded to concentrations below soil cleanup goals.

- Solid phase bioremediation using DARAMEND® was effective in degrading explosive compounds below soil cleanup goals in one of two similar unwashed soil tests.

As noted previously, the heterogeneous and particulate nature of explosives in soils had implications on data evaluation and comparison of laboratory studies. The average concentration can be greatly influenced by the existence of particulates, especially in smaller data sets, and is not necessarily representative of overall contamination of the soil. For example, if the average concentration alone is used as a measure of success, composting and solid phase bioremediation do not successfully degrade RDX. Therefore, the median concentration is also provided in the figures to give a balanced view of the effectiveness of the technology in treating explosives-contaminated soil. The median concentration can be considered to be a measure of the overall success of the technology. However, the technology must be able to treat explosives in all forms including the particulate form, and therefore it is important to see the impact of the particulates on the outcomes of the studies. For this reason, both average and median degradation curves are shown.

It should be noted that subcontractors were requested to focus on reduction and/or destruction of explosive contaminants. Other contaminants were described but not emphasized, including metals and pesticides. Chemical reduction and LTTD were found to be reasonably likely to achieve the RRA soil cleanup goals for dieldrin. LTTD was also found to achieve these goals for the remaining organic COCs. Metals were not treated by any technology tested.

5. DISCUSSION OF FIELD-SCALE DEMONSTRATION DESIGNS

Soil Washing Approximately 1,250 tons of soils that were excavated as part of RRA activities were processed by a soil washing plant in a field demonstration conducted during Fall 2000. Several post-processing stockpiles were produced as a result of the soil washing: (1) soil particles retained on a #140-mesh sieve (0.10 mm), (2) soil particles passing #140-mesh, (3) organic matter and vegetation debris, (4) particulate metals, and (5) rocks greater than 4 inches in diameter. After optimization of the system, approximately 75% of the washed soil met cleanup goals, mostly soil retained on a #140-mesh sieve and some soil passing #140-mesh. Effectiveness may be improved by increasing the residence time of the fine soil in the slurry phase to dissolve as much of the explosive contaminants as possible. If such improvements were made, soil washing might be considered as a stand-alone treatment technology, with between 75% and 90% of the treated soil available for reuse and the remainder transported for off-site landfill.

Chemical Reduction Washed soil would be placed in windrows, adding 5% ZVI, aluminum sulfate, acetic acid, and water to obtain a 35% to 40% (mass:mass) soil mass. The soil would be covered with plastic, which would be removed every seven to ten days for sampling and water application. Additional mixing of the soil would not be performed. Brice/UNL recommended that the field-scale implementation be conducted for thirty days rather than the five days used in the laboratory studies to accommodate any impacts from explosives in particulate form.

LTTD Soil would be staged in a three-sided concrete container. Heating rods would be placed throughout the soil and heated to the extent necessary to destroy contaminants. Vapors would be extracted through the heating rods so that volatilized contaminants would be captured and submitted to secondary treatment, likely granular activated carbon. LTTD would likely be implemented as an ex-situ treatment of the soil due to concerns with in situ soil heating in the presence of Unexploded Ordnance (UXO). UXO clearance would need to be completed prior to implementing this design. Preliminary discussions with the Explosives Safety Board of the Department of Defense indicate that ex situ thermal treatment of cleared soils would be possible due to the low concentrations of explosives in the soils.

Bioslurry An ex situ bioslurry treatment system would entail mixing one 55-gallon drum of molasses per 135 tons mixing tank containing a slurry of approximately 30% soil and 70% water, with possible addition of sodium hydroxide to keep pH at near-neutral levels. Envirogen noted that the tanks do not need to be closed, based on previous experience at Joliet Army Ammunition Plant (JAAP) and Iowa Army Ammunition Plant (IAAP). The process water would retrieved by passing the treated slurry through a belt filter press and recycled back into the plant process after the slurry. Operations would be optimal during the growing season, when the weather is above freezing. This process would function as secondary treatment following soil washing due to the high cost of treatment of the soil.

Composting An ex-situ system would use windrows containing 450 tons soil and 1,000 tons amendments. BSI indicated that the required timeframe would be based on the remedial goals set for the site. Periodic samples would be collected to determine the extent to which remediation had occurred. Because high concentrations of explosives were detected in final samples of untreated soils, a field-scale demonstration for composting may best be considered as part of a treatment train after soil washing. Operations would be optimal during the growing season, when the weather is above freezing.

Solid Phase Bioremediation The field scale design could involve in-situ treating of approximately 10,000 tons of soil to a depth of two feet with DARAMEND® and powdered iron. However, high concentrations of explosives were detected in untreated soils, including the final sampling event at Day 50. Therefore, a field-scale demonstration for solid phase bioremediation may best be considered as part of a treatment train after soil washing. Operations would be optimal during the growing season, when the weather is above freezing.

Preliminary cost estimates for treatment of soils were requested from each of the subcontractors except TerraTherm, which was deferred based on initial agreements regarding use of the thermal technology on unwashed soils only. In forming comparisons of the cost estimates, adjustments were made to ensure equivalency of implementation tasks among the technologies. The cost estimates included tasks for site preparation, mobilization, facilities construction, processing and testing, demobilization, site restoration, material disposal, report preparation, regulatory requirements, and project management/administration.

A comparison of these preliminary cost estimates for varying soil volumes is shown in Figure 7. Although the cost estimates for the technologies are based on previous experience in the field, no demonstrations except soil washing have been performed to date at Camp Edwards. Therefore these cost estimates are not intended to show the predicted costs of remediation for the site but rather for comparison purposes only. Of note is that treatment costs are uniformly high for volumes below 5,000 tons for all technologies. Because many of the technologies have significant fixed capital costs, treatment costs on a per ton basis are significantly lower for increased volumes of soil requiring treatment. In addition, costs are relatively constant among the technologies for volumes over 10,000 tons, ranging from $75 to $135 per ton.

Future field-scale demonstration work could include inquiry into the following:

1. Reuse of treated soil on the site, specifically:
   a) the impact of biological amendments in introducing invasive species to the area, or
   b) the impact of biological or chemical amendments on the growth of native species in competition with invasive species.

2. Field-scale demonstration of the soil washing process, refined as described above for optimization.

3. Field-scale demonstrations of the successful studies, including chemical reduction or biodegradation as a secondary treatment following soil washing.

4. Field-scale demonstrations of thermal desorption/destruction on untreated soil, depending on projected field demonstration costs.

5. Volumes at which soil washing may not be required to be cost effective, such as for solid phase bioremediation.

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FIGURES

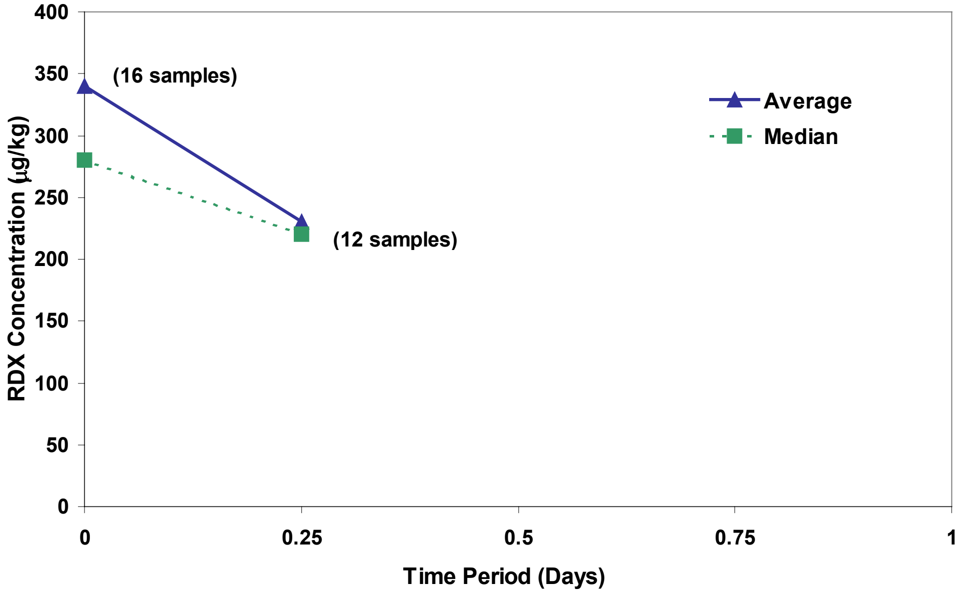

Figure 1. Chemical oxidation results, washed soils - Brice/UNL

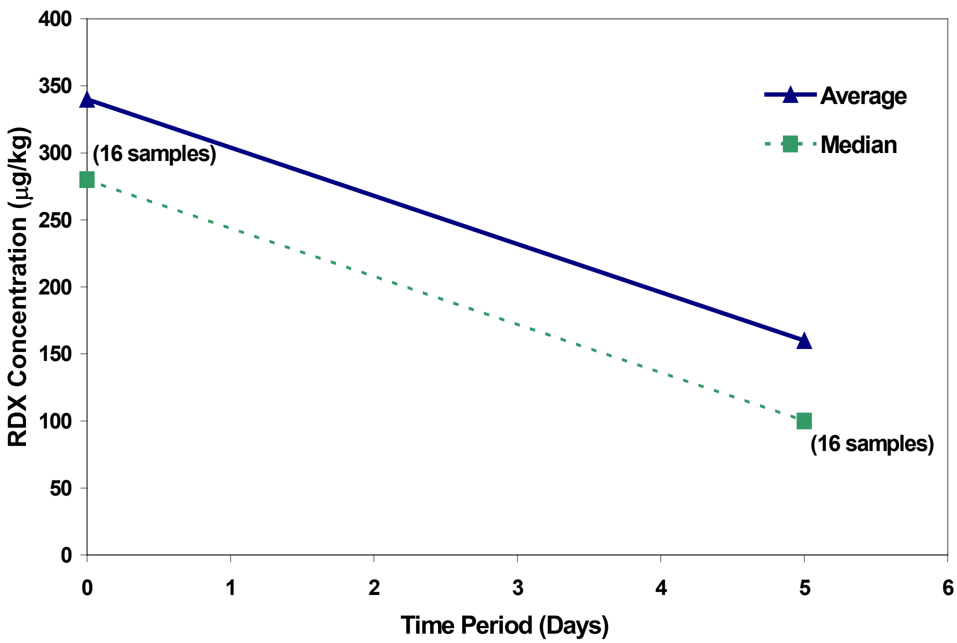

Figure 2. Chemical reduction results washed soils - Brice/UNL

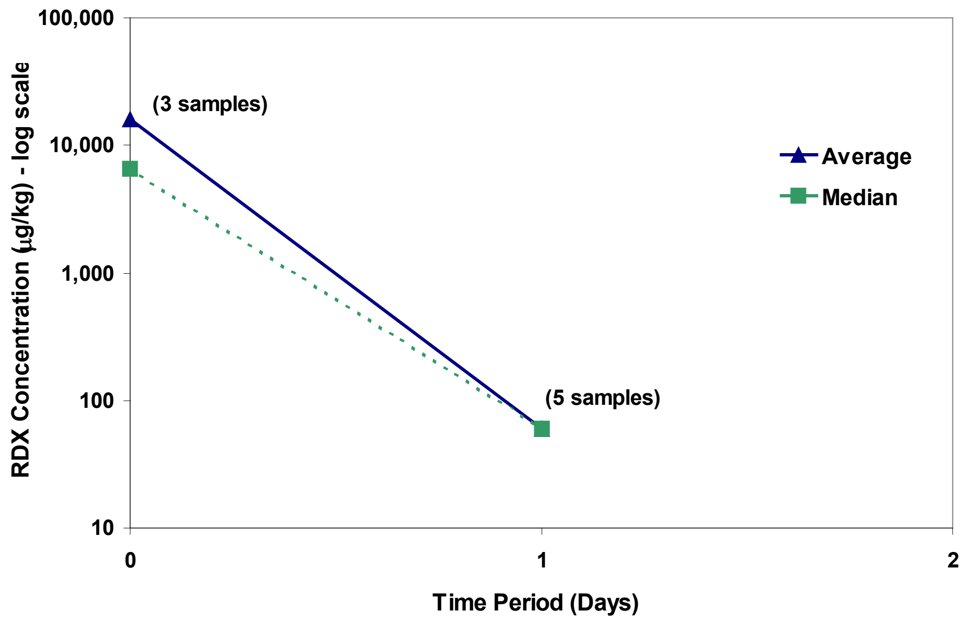

Figure 3. Low temperature thermal destruction, untreated (unwashed) soils - TerraTherm

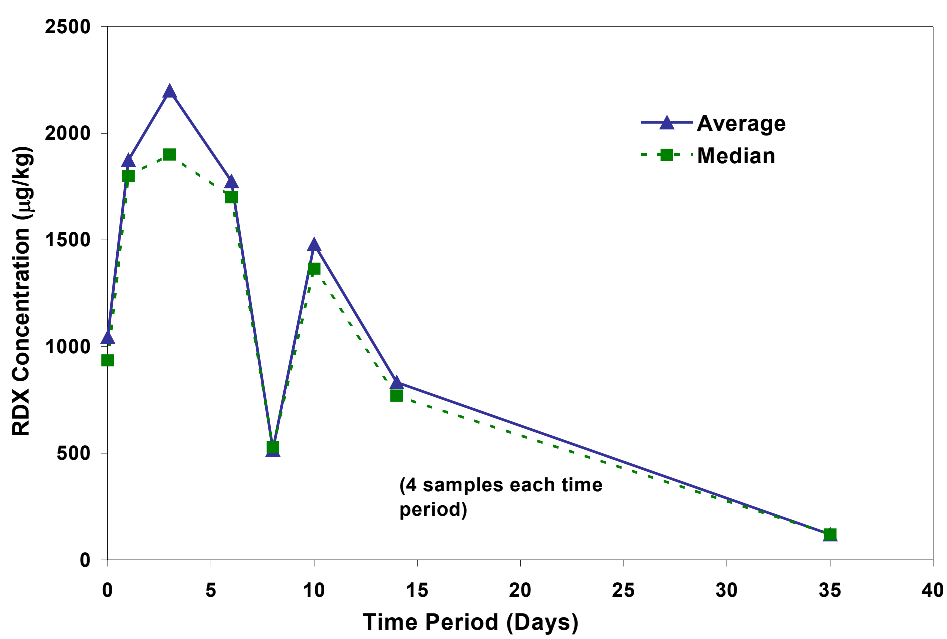

Figure 4. Bioslurry results, intermittent stirring, unwashed (untreated) soils - Envirogen

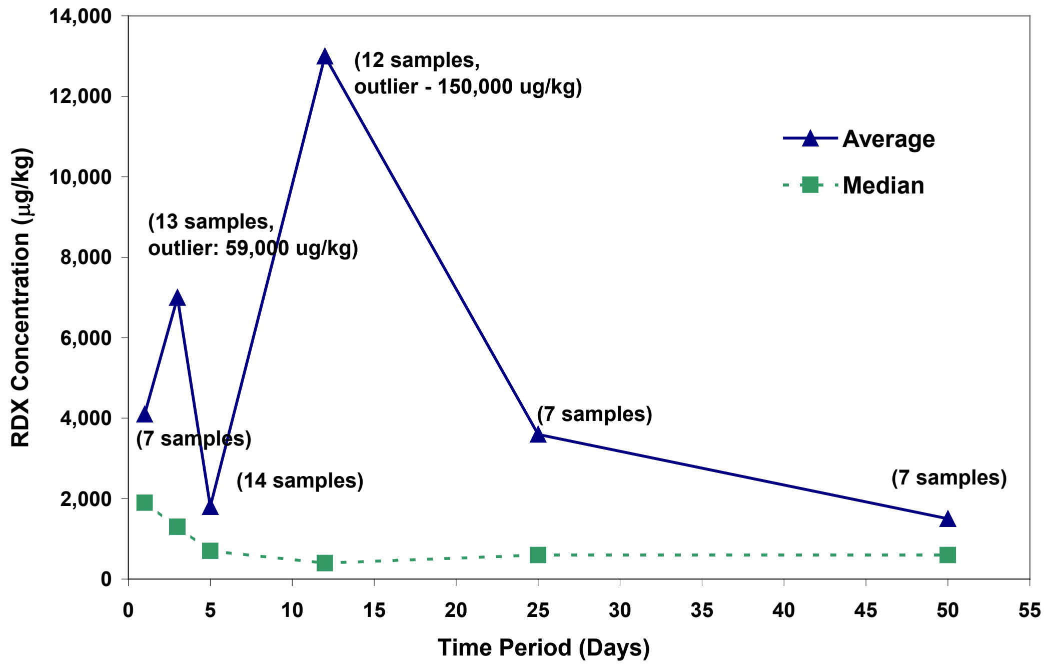

Figure 5. Composting results, untreated (unwashed) soils- BSI

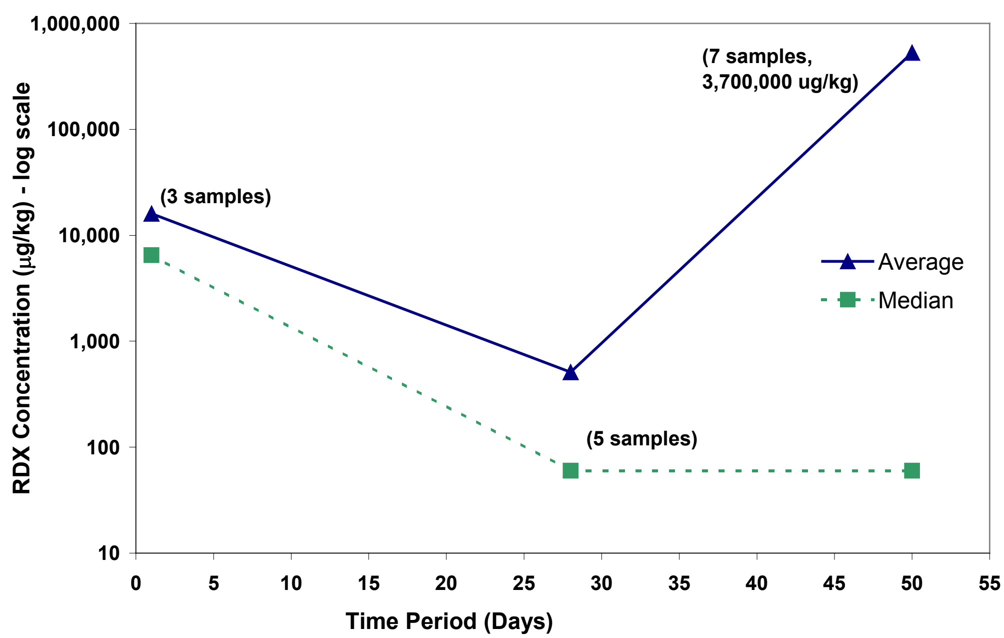

Figure 6. Solid phase bioremediation results, untreated (unwashed) soils - Grace Canada

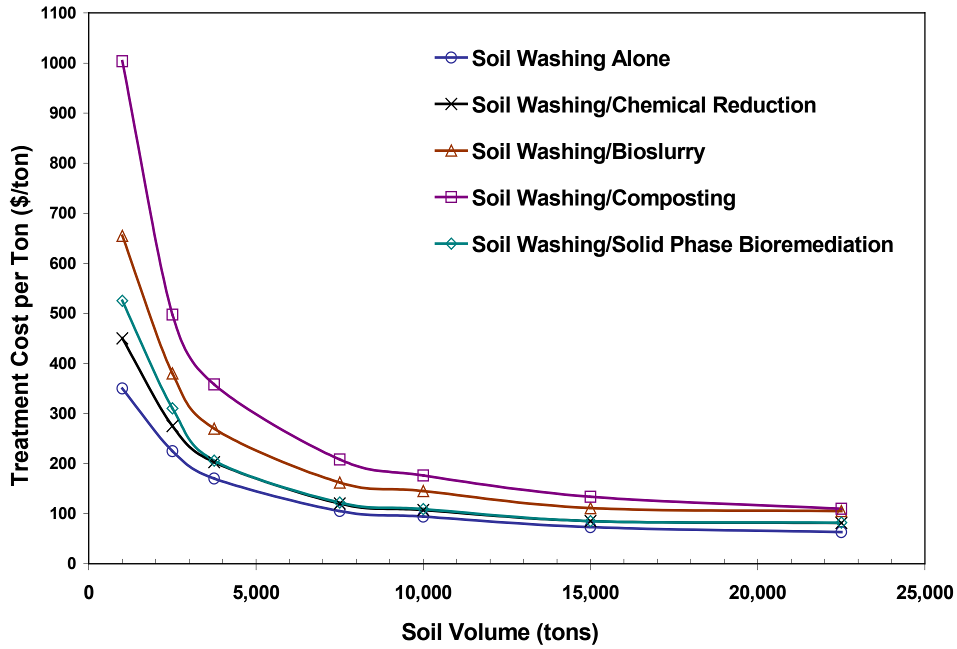

Figure 7. Comparison of estimated costs for soil treatment with soil volume