ELSEVIER Journal of Hazardous Materials 61 (1998) 31–36

JOURNAL OF HAZARDOUS MATERIALS

The use of mapping techniques in an ecological risk assessment of sites contaminated with chemical warfare agents

T.A. Miller [a,*], A. Yaghoobian [a], B.J. Stuckert [a], J.S. Goudey [b], J.M. McAndless [c]

[a] *Golder Associates, 500-4260 Still Creek Dr., Burnaby, BC, Canada*
[b] *HydroQual Laboratories, #3-6125 12th St. SE, Calgary, AB, Canada*
[c] *Defence Research Establishment Suffield, Box 4000, Medicine Hat, AB, Canada*

Abstract

The Defence Research Establishment Suffield (DRES) Experimental Proving Ground (EPG) at Canadian Forces Base (CFB) Suffield was established in 1941 and has been used for a variety of purposes including the testing, storage and disposal of chemical warfare agents (CWA). Following World War II, Canada's production stocks of CWA, primarily mustard, were shipped to DRES for safe storage and eventual disposal. Programs to dispose of CWA have been successfully completed; however, areas of residual soil contamination remained. Golder Associates was retained to evaluate the ecological risks associated with these areas of residual contamination and recommend remediation or mitigative measures to deal with unacceptable contaminant concentrations. The EPG, occupying 517 km^2 represents one of the last remaining large areas of natural short grass prairie and has been recognized under the Prairie Conservation Action Plan drawn up by World Wildlife Fund Canada. The selected sites under investigation ranged from several hundred square metres to 1 km^2. The approach to the ecological assessment included a detailed geophysical investigation, soil sampling and a soil toxicity testing program coupled with traditional ecological risk assessment techniques for higher trophic levels. The toxicity testing program included plants, soil bacteria, and a soil invertebrate. Results of individual tests were scored. A weighting factor was assigned to each test according to test responsiveness and perceived importance, with a greater weighting factor assigned to the tests conducted using native species. The individual test scores were multiplied by the weighting factor and summed to give a total score. Background samples were tested using the same test battery to establish a baseline

* Corresponding author.

PII S0304-3894(98)00104-6

response. Toxicity testing results were graded, colour-coded and mapped to facilitate identification of areas warranting remediation. The results of this investigation suggest that less than 1% of the EPG represented a significant ecological risk.

Keywords: Toxicity; Ecological risk; Chemical warfare agents; Mustard; Residual soil contamination

1. Introduction

Golder Associates (Golder) was contracted by Defence Research Establishment Suffield (DRES) to conduct an ecological risk assessment and develop remediation options for selected sites on the Experimental Proving Ground (EPG) at CFB Suffield. The DRES EPG occupies approximately 517 km^2 of CFB Suffield and has been used for a variety of purposes, the most relevant to the present project being the testing, storage and disposal of CWA and related materials. This project was undertaken to investigate the significance of potentially contaminated sites and to develop site-specific remediation plans, if warranted.

2. Methods

The methodology developed for the assessment was to use screening tools coupled with a battery of soil toxicity tests to assess the risks/impacts at each site and the nature and extent of remedial work warranted. The installation of groundwater wells was considered to be unnecessary for the successful completion of the assessment. Previous hydrogeological investigations on the EPG suggested that contaminants in soil would take approximately 300 years to migrate to the regional aquifer and about 4000 years to migrate to the EPG boundary.

Geophysical surveys were used to screen for potential subsurface hazards and chemical sources. Geophysical mapping surveys were carried out using electromagnetic (EM), magnetic and ground penetrating radar (GPR) techniques. The EM surveys were conducted using a Geonics EM31 frequency-domain conductivity meter. Magnetic surveys were carried out using an ENVIMAG gradiometer and GPR surveys were carried out using a Pulse-EKKO 100 digital acquisition radar system with 100 MHz antennas.

Indicator analytical tests were used to screen for chemicals at deleterious concentrations. Based on historical information, earlier reports and information from DRES, the main contaminant of concern was mustard and breakdown products. Additional potential contaminants included lewisite, nerve agent degradation products and various metals. Indicator analytical tests included sulphur for mustard, arsenic for lewisite, phosphorous for nerve agent, metals scans and pH. Detailed analytical testing, particularly for CWA, was reserved for selected samples suspected of being contaminated based on the results of the indicator testing, toxicity testing, site history and olfaction (for mustard).

Each soil sample was subjected to a battery of six toxicity tests. Tests and test species were selected based on their inferred relevance to the site, to cover the major trophic

Table 1

Test	Toxicity endpoint	Aqueous extract	Methanol extract	Soil
Bacterial luminescence (Microtox)	acute	✓	✓	
Total heterotrophic bacteria	–			✓
Fungal counts	–			✓
Root elongation	chronic	✓	✓	
Seedling emergence	chronic			✓
Algal growth inhibition	chronic	✓	✓	
Nematode survival	acute	✓	✓	
Soil respiration	chronic			✓

levels in a soil environment, a range of acute and chronic endpoints, and a mix of population and ecosystem endpoints. The test battery, which included species that occur on the EPG is outlined below (Table 1).

Each test was assigned a relative weight that reflected the test relevance, sensitivity and reliability. Test results for each sample from a site were then scored and compared to results for background or ‘reference’ samples.

3. Results and discussion

Geophysical investigation techniques were used on three sites on the EPG. At the Gate 4 Dump, EM31 and magnetic techniques were used to investigate trenches where CWA, various laboratory wastes and munitions were disposed (Fig. 1). Both the inphase and apparent conductivity response from the EM31, and the total magnetic field data were used to identify a number of metallic anomalies both inside and outside the areas of the disposal trenches. In addition, several areas of high apparent soil conductivity were mapped by the EM31. The success of the technique for mapping these areas was apparently augmented by a recent rainfall. The EM31 conductivity highs were associated with areas of high subsurface sulphur concentrations and samples exhibited a strong toxic response in the bioassays. GPR data were collected over one of the larger mapped metallic anomalies, identified as an area of subsurface tear gas (chloroacetophenone) contamination during the sampling phase. At another site, μSeismic with tomographic imaging and GPR were used with success to obtain the spatial coordinates of ordnance containing CWA that were disposed of in a concrete block.

Sulphur was found in high concentrations at several sites on the EPG. Samples exhibiting a strong toxic response and having the characteristic mustard odour were submitted for more detailed analyses focusing on mustard and breakdown products. Mustard was not detected in any samples. Thiodiglycol and 1,4-dithiane were detected in low concentrations. In most cases, a low soil pH (pH 3–5), resulting from the biodegradation of sulphur-containing compounds, was the only factor that could consistently explain a strong toxic response observed for a number of soil samples.

The results from the test battery were condensed to a total score for each sample. Background samples were also tested to provide a reference of the normal range of response that could be expected for this test battery on uncontaminated samples. The scores for background samples ranged from 1 to 1.85. Samples having a score of more

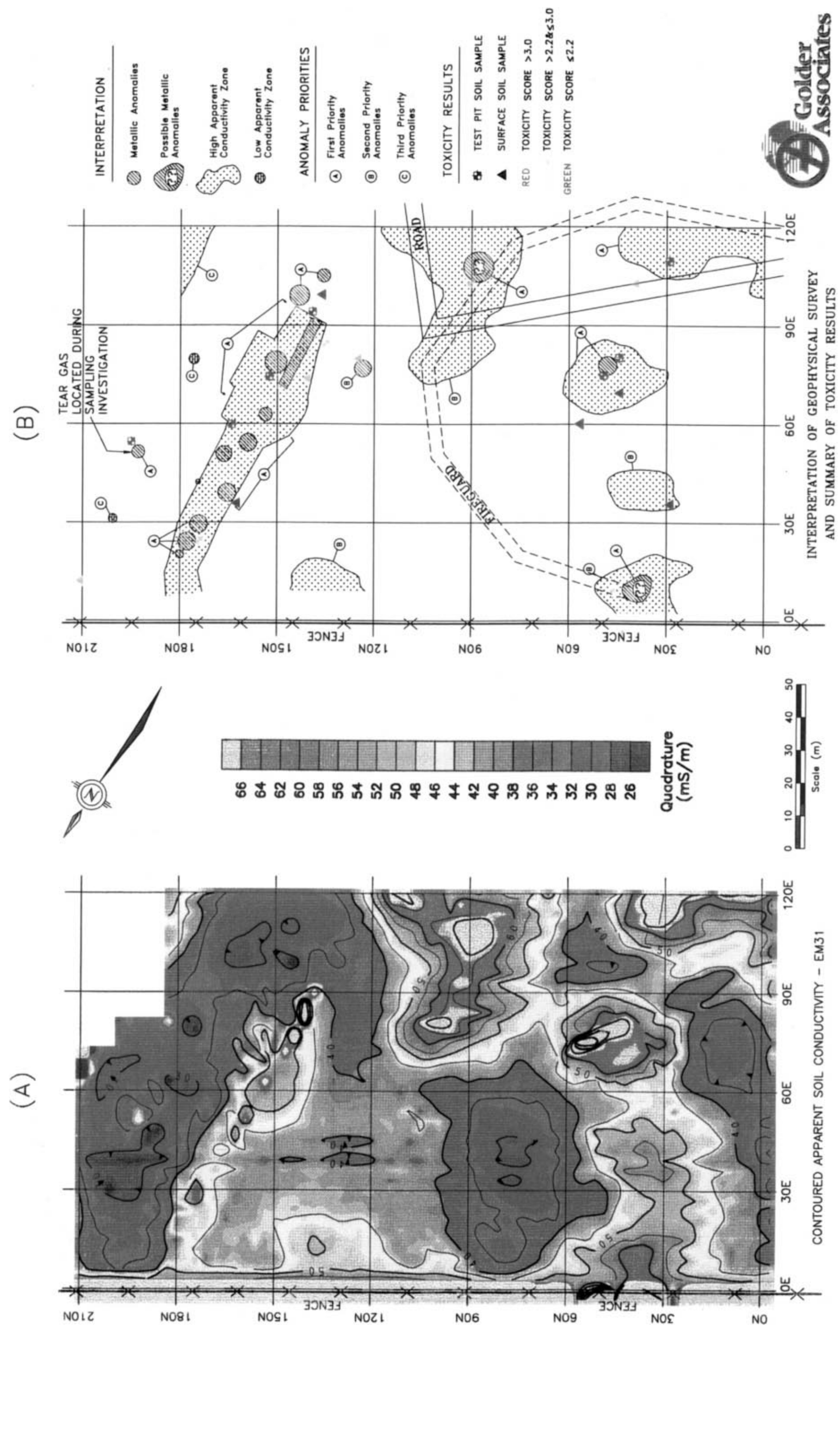
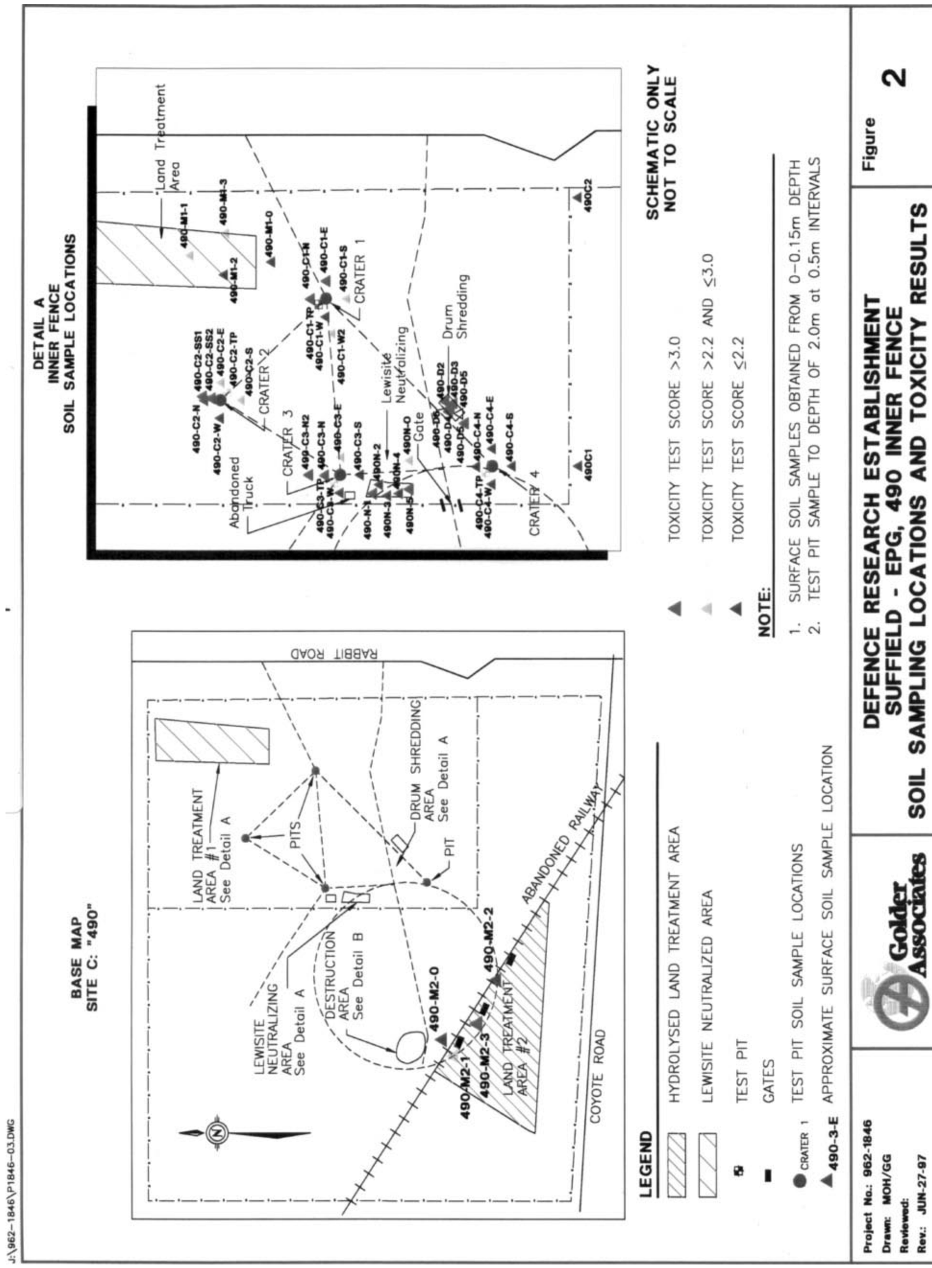

(A)
CONTOURED APPARENT SOIL CONDUCTIVITY – EM31
Quadrature (mS/m)
66
64
62
60
58
56
54
52
50
48
46
44
42
40
38
36
34
32
30
28
26
Scale (m)
(B)
TEAR GAS LOCATED DURING SAMPLING INVESTIGATION
ROAD
FIREGUARD
FENCE
INTERPRETATION OF GEOPHYSICAL SURVEY AND SUMMARY OF TOXICITY RESULTS
INTERPRETATION
Metallic Anomalies
Possible Metallic Anomalies
High Apparent Conductivity Zone
Low Apparent Conductivity Zone
ANOMALY PRIORITIES
First Priority Anomalies
Second Priority Anomalies
Third Priority Anomalies
TOXICITY RESULTS
TEST PIT SOIL SAMPLE
SURFACE SOIL SAMPLE
RED TOXICITY SCORE >3.0
TOXICITY SCORE >2.2&≤3.0
GREEN TOXICITY SCORE ≤2.2
Golder Associates
0N
30N
60N
90N
120N
150N
180N
210N
0E
30E
60E
90E
120E

Fig. 1.



DEFENCE RESEARCH ESTABLISHMENT
SUFFIELD - EPG, 490 INNER FENCE
SOIL SAMPLING LOCATIONS AND TOXICITY RESULTS
Figure 2
Golder Associates
Project No.: 962-1846
Drawn: MOH/GG
Reviewed:
Rev.: JUN-27-97
J:\962-1846\P1846-03.DWG
BASE MAP
SITE C: "490"
DETAIL A
INNER FENCE
SOIL SAMPLE LOCATIONS
SCHEMATIC ONLY
NOT TO SCALE
LEGEND
HYDROLYSED LAND TREATMENT AREA
LEWISITE NEUTRALIZED AREA
TEST PIT
GATES
CRATER 1 TEST PIT SOIL SAMPLE LOCATIONS
490-3-E APPROXIMATE SURFACE SOIL SAMPLE LOCATION
TOXICITY TEST SCORE >3.0
TOXICITY TEST SCORE >2.2 AND ≤3.0
TOXICITY TEST SCORE ≤2.2
NOTE:
1. SURFACE SOIL SAMPLES OBTAINED FROM 0–0.15m DEPTH
2. TEST PIT SAMPLE TO DEPTH OF 2.0m at 0.5m INTERVALS
RABBIT ROAD
COYOTE ROAD
ABANDONED RAILWAY
LAND TREATMENT AREA #1 See Detail A
LAND TREATMENT AREA #2
LEWISITE NEUTRALIZING AREA See Detail A
DESTRUCTION AREA See Detail B
DRUM SHREDDING AREA See Detail A
PITS
PIT
490-M2-0
490-M2-1
490-M2-2
490-M2-3
Land Treatment Area
Abandoned Truck
Lewisite Neutralizing
Drum Shredding
Gate
CRATER 1
CRATER 2
CRATER 3
CRATER 4
490C1
490C2

Fig. 2.

than 20% greater than background were considered to be potentially hazardous to soil-dependent receptors. Therefore, samples having a toxicity score of less than or equal to 2.2 were considered to be no different from background samples and were colour-coded green. Samples having a score of >2.2 and less than or equal to 3.0 were considered to be mildly toxic and were colour-coded yellow. Samples having a score of greater than 3.0 were considered to have a strong toxic response and were colour-coded red.

Toxicity test results for soil samples collected from the 490 Inner Fence Area are presented in Fig. 2. Results for surficial soil samples collected from blast craters used to store mustard-contaminated barrels ranged from no significant toxicity to a strong toxic response. Samples from areas where mustard was detected 5 to 6 years previously, showed a very strong response, while no significant toxicity was observed for the samples collected from the one blast crater that was used to store empty petroleum barrels. In the area where mustard-contaminated drums were shredded prior to incineration in 1991 and residual contamination was suspected, a strong toxic response was observed for all soil samples. Areas where hydrolyzed mustard was landfarmed generally showed mild or no toxicity. One sample from the landfarming area that had a strong toxic response was associated with a low soil pH (5.6). Generally, there was a positive correlation between geophysical anomalies, high concentrations of metals and sulphur and high scores from toxicity tests.

4. Recommendations for remediation

Practical recommendations for remediation of areas showing a toxic response were provided. In the former drum-shredding and lewisite neutralization areas, it was recommended that contaminated soils be excavated to a depth of 0.5 m or greater, based on toxicity tests, re-graded with clean, native soil, contoured and seeded with native grassland species. Contaminated soil from these two areas could be placed in the blast craters to a minimum depth of 2 m below ground surface (bgs). Recommended remediation of the blast craters included excavation of the contaminated soils around the perimeter of the craters and placement of the contaminated soil at the base of the crater to a depth of 2 m bgs. Clean fill was recommended to top up the craters 2 m bgs to ground surface. It was further recommended that the site of the former craters be contoured and compacted with native soil and seeded with native grassland species. The estimated cost of remediation for this site was CAN$170 000.

5. Conclusions

The results of this investigation suggest that geophysical techniques can be successfully applied to identify former trenches and subsurface hazards prior to an intrusive site investigation. In addition, geophysical investigations provide additional safety for the sampling crew and reduce the occurrence of accidental exposure during the site investigation. The battery of toxicity tests that use indigenous species grounded in standard test protocols, can be used as a relatively inexpensive tool to both assess the site in terms of ecological risks, and confirm closure following remediation.