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**STUDY OF THE IMPACTS OF OB/OD ACTIVITY ON SOILS AND
GROUNDWATER AT THE DESTRUCTION AREA IN CFAD DUNDURN**

By

**G. Ampleman, S. Thiboutot, A. Gagnon and A. Marois, DREV
R. Martel and R. Lefebvre, INRS-Géoressources**

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ABSTRACT

Since open burning/open detonation (OB/OD) in the United States has been proven to be a polluting activity thereby representing a possible threat to human health and to the environment, it was decided to evaluate the impact of this activity on the environment at the largest OB/OD site in Canada, located at the Canadian Forces Ammunition Depot, CFAD Dundurn, Saskatchewan. A thorough investigation was initiated by collecting soils on the site followed by the drilling of boreholes and installation of many observation wells to analyse groundwater contamination by explosives. After four years of studying and performing analyses of soils and groundwater, it appeared that the impact of the open destruction activity on the environment is minimal. Furthermore, because of the site's location, the velocity and the direction of the groundwater flow, there were no adverse effects on human health or ecological receptors. Therefore, it was concluded in this study that the open detonation of obsolete ammunition can be pursued at CFAD Dundurn using the same techniques while implementing a monitoring program of groundwater quality. On the other hand, the open burning activity was not evaluated on this site but study made on other sites showed that open burning is not as clean as open detonation since the temperature of the combustion is not as elevated.

RÉSUMÉ

Étant donné qu'il a été démontré aux États-Unis que les activités de brûlage/détonation à aire ouverte peuvent être polluantes et représentent donc un danger pour la santé humaine et pour l'environnement, on a pris la décision d'évaluer l'impact de cette activité sur le plus gros site de brûlage/détonation extérieur du Canada situé au dépôt de munitions des forces canadiennes, DMFC Dundurn, Saskatchewan. Une étude poussée a été initiée en échantillonnant les sols sur le site suivie par le forage et l'installation de puits d'observation pour analyser l'eau souterraine quant à la contamination par les explosifs. Après quatre années d'études et d'analyses des sols et de l'eau souterraine, il est apparu que l'impact de la détonation extérieure sur l'environnement est minime. De plus, dû à la localisation du site, à la vitesse et la direction de la nappe phréatique, il n'y a pas d'effets nocifs pour la santé humaine et pour les récepteurs écologiques. En conséquence, il a été conclu dans cette étude que la destruction de matériels désuets par détonation extérieure peut être poursuivie sur le site du dépôt de munitions des forces canadiennes à Dundurn en utilisant les mêmes techniques, tout en instaurant un programme de surveillance de la qualité de l'eau souterraine. D'un autre côté, l'activité de brûlage extérieure n'a pas été évaluée sur ce site mais, une étude faite sur d'autres sites a démontré que le brûlage extérieur n'est pas un procédé aussi propre que la détonation extérieure dû au fait que la température de combustion est moins élevée.

TABLE OF CONTENTS

ABSTRACT/RÉSUMÉ	i
EXECUTIVE SUMMARY.....	v
NOMENCLATURE	vii
1.0 INTRODUCTION.....	1
2.0 THEORY	3
2.1 Soil Sampling	4
2.2 Subsurface and Groundwater Sampling.....	4
2.3 Sample Analysis	5
2.4 Lysimeters Installation.....	6
2.5 Air Impact.....	6
2.6 Site Risk Assessment.....	7
3.0 EXPERIMENTAL.....	8
3.1 Samples and Contractors	8
3.2 High Pressure Liquid Chromatography	8
3.3 Soil Sampling	9
3.4 Observation Well Installation and Groundwater Sampling.....	12
4.0 RESULTS AND DISCUSSION	16
4.1 Soils Analyses	16
4.2 Groundwater Analyses.....	19
4.3 Lysimeters Study.....	21
4.4 Groundwater Flow	22
4.5 Site Risk Assessment.....	24
5.0 CONCLUSION	26
6.0 FUTUR WORKS AND RECOMMENDATIONS.....	27
7.0 ACKNOWLEDGEMENTS	29
8.0 REFERENCES.....	30

TABLES I to II

FIGURES 1 to 10

EXECUTIVE SUMMARY

It is a goal of the Department of National Defence (DND) to implement environmentally-benign defence activities. This involves evaluating all defence activities to ensure that they have no adverse impact on the surrounding environment. It is within this context, and also within the context of base closures and demilitarization, that the Defence Research Establishment Valcartier (DREV) initiated a R&D program five years ago to study the environmental impact of energetic materials that are found in the DND ammunition stockpile. Another aspect of the DREV R&D program is the development of practical and economical remediation technologies for the cleaning of explosives-contaminated sites. Both programs on soil characterization and soil remediation will position the Department of National Defence in a state of readiness for any future potential contamination problems. The remediation aspect will not be discussed in the present report but will be covered in future documents.

Many activities of the Canadian Forces such as firing, demolition and destruction of obsolete ammunition by open burning and open detonation may lead to the dispersion of energetic compounds in the environment. In Canada, limited effort has been spent to examine this particular environmental threat. Energetic compounds are just now being recognised as environmental contaminants as compared to other contaminants such as petroleum or solvents. Energetic compounds are unique due to their highly specific physical, chemical and toxicological properties.

Open burning/open detonation (OB/OD) activity is now forbidden in some parts of the United States and is tightly regulated by US EPA because it is seen as a polluting activity. It was decided to evaluate the environmental impact of this activity at the largest DND OB/OD site which is located at Canadian Forces Ammunition Depot, CFAD Dundurn, Saskatchewan. A thorough investigation was initiated by collecting soil on the site and was followed by the drilling of boreholes and installation of many observation wells to analyse groundwater for explosives contamination. After four years of studying and performing analyses of soils and groundwater, it appears that the impact of the open destruction activity on the environment is minimal. Furthermore, because of the site's location and the velocity and the direction of the groundwater flow, there is no adverse effects on human health or ecological receptors. Therefore, it was concluded in this study that the open destruction of obsolete ammunition can continue at CFAD Dundurn using the same techniques. However, a monitoring program of groundwater quality should be implemented. On the other hand, study from other sites showed that open burning is not as clean as open detonation since the temperature of the combustion is not as elevated.

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vii

NOMENCLATURE

ASTM	American Standard Method
CCME	Canadian Council of Ministers of the Environment
CF	Canadian Forces
CFAD	Canadian Forces Ammunition Depot
CH	Chlorinated Hydrocarbon
D ₅₀	Mean Grain Diameter
DDH	D'Aragon, Desbiens et Halde
DMFC	Dépôt de munitions des forces canadiennes
DND	Department of National Defence
DREV	Defence Research Establishment Valcartier
EIA	Enzyme Immunoassay
GC	Gas Chromatography
HMX	Cyclo 1,3,5,7-tetramethylene-2,4,6,8 tetranitramine
HDPE	High Density Polyethylene
HPLC	High Pressure Liquid Chromatography
INRS	Institut national de recherche scientifique
K _d	Distribution Coefficient
MAVC	Monocyclic Aromatic Volatile Compound
OB/OD	Open Burning/Open Detonation
ODEX	Overburden Drilling Excentric System
PAH	Polycyclic Aromatic Hydrocarbon
PTFE	Polytetrafluoroethylene
PVC	Polyvinyl Chloride
QA/QC	Quality Assurance/Quality Control
R _f	Retardation Factor
RDX	Cyclo-1,3,5-trimethylene-2,4,6-trinitramine
R&D	Research and Development
SPE	Solid Phase Extraction
Tetryl	2,4,6-Trinitro-phenylmethylnitramine
TNT	Trinitrotoluene
US EPA	United States Environmental Protection Agency
WES	Waterways Experiment Station

1.0 INTRODUCTION

It is a world-wide goal to identify and develop economical and effective methods to eliminate undesirable contaminants from soils and groundwater. This task is more complicated when the contaminants are energetic materials because of their crystalline properties and their energetic characteristics. Energetic materials are the main components of gun powders, explosives warheads and solid rocket propellants and could therefore be found in war zones, training ranges or on industrial production sites. The new international context with the end of the Cold War resulted in the closing of many military bases and a growing awareness in environmental issues. It is within this context that the Canadian Research and Development Branch has directed some of its resources to assess the environmental risks associated with explosive compounds.

Many Canadian Forces sites such as impact areas, training ranges, demolition and open burning/open detonation (OB/OD) ranges which are used to destroy the out-of specification materials are highly suspected to be contaminated by energetic substances as described in the literature (Refs. 1-6). To evaluate the contamination of DND sites, sampling and characterization of various ranges was performed in the last four years. All standard sampling, analysis and data management techniques should be applied (Refs. 7,8) when characterizing explosives contaminated sites. One of the most important site to be sampled by DREV was the Canadian Forces Ammunition Depot, CFAD Dundurn located in Saskatchewan. Since the destruction area of CFAD Dundurn is the largest open burning/open detonation site in Canada and, considering that OB/OD is forbidden in some states of the United States because it is seen as a polluting activity, it was decided to investigate the impacts of the OB/OD activity on the environment and on the human health at the destruction area in CFAD Dundurn.

CFAD Dundurn is located 30 km south of Saskatoon, Saskatchewan and the OB/OD site is situated on the Dundurn base, 3.5 km to the northwest of the Dundurn camp. The topography is typical of an eolian environment where surficial sediments are eolian plain and eolian dune sands underlain by fluviolacustrine sediments (Ref. 9). Two classes of grain-size are observed and consisted in a poorly sorted sand corresponding to a very fine sand and a second class composed of a well

sorted fine sand which corresponds to layered sand deposits. The Bearpaw rock formation that underlain the same deposits is defined as a grey, noncalcareous silt and clay (Ref. 10).

Energetic materials have been open burned and open or underground detonated at that site for more than 25 years. In recent years, energetic materials including obsolete or deteriorated ammunition and anti-personnel mines have been destroyed at a rate of about 100 Tons/year. As part of this study, a first preliminary assessment of the contamination by explosives was done in November 1994, doing a surface soil characterization of the destruction site and collecting water samples from two water wells. Then, a thorough study was performed in November 1995 to determine if subsurface soils and groundwater were contaminated by explosives. Sixteen (16) observation wells were then installed at 8 different locations most of them directly in the destruction area. Seventy-two (72) soil samples and 31 groundwater samples were also taken to investigate the site. To better determine the groundwater flow direction and also the extent of a possible contamination plume in groundwater, a third visit was done in December 1996 and 14 additional wells were drilled in 10 different locations outside the destruction area to ascertain the groundwater flow direction and quality. Moreover, 6 lysimeters were installed in two distinct locations in the destruction area to understand the explosive fate in the environment. In May 97, INRS-Géoressources returned to complete tracer tests at the two lysimeters and finally DREV measured the groundwater table levels in observation wells in September 1997.

This report describes all the work carried out between November 1994 and September 1997 and the results obtained so far within the study of the OB/OD activity at CFAD Dundurn. This study was performed under the WU 2nc21, Characterization of DND Sites Contaminated with Energetic Materials and was sponsored by a task coming from Directorate General Environment (DGE) through the Directorate of Ammunition Program Management (DAPM). Part of this work was done in collaboration with INRS-Géoressources.

2.0 THEORY

Explosives such as TNT, RDX and HMX are crystalline compounds having low vapour pressure and low water solubility. Their crystalline properties result in heterogeneous dispersion in the soil matrix leading to a difficult characterization. Conventional sampling procedures were modified to take this behaviour into account. Explosives behave differently from each other, depending on their water solubility and structure. TNT is more soluble in water than RDX, which in turn is more soluble than HMX. Also, TNT dissolves more rapidly than RDX and HMX, which is the slowest to dissolve. TNT is a nitroaromatic while RDX and HMX are nitramines. TNT has a great tendency to degrade by photolysis while RDX and HMX do not. In addition to their differences in solubility, TNT itself can degrade into 21 metabolites, which possess their own solubility and toxicity. As an example, the aminodinitrotoluenes resulting from the photolysis or biodegradation of TNT are much more soluble than the parent compound but can covalently bound to humic acid. Therefore, these metabolites are stabilised by the formation of an amide with organic content of the soil. Moreover, adsorption mechanisms with soils containing clays are stronger with TNT and its metabolites than for RDX and HMX, which adsorb very poorly to clays minerals and some other organic matter (Refs. 11-14).

Therefore, a soil contaminated by these three explosives would lead to a complex situation and as a result, RDX will leach out faster than TNT, which will itself leach out faster than HMX. RDX being more soluble than HMX and less soluble than TNT moves faster because it does not adsorb on soils. TNT being the most soluble of the three compounds should leach first but as already mentioned, it adsorbs strongly to clay minerals or degrades into metabolites more soluble than TNT which bind covalently to the clay particles. This process of adsorption/desorption slows down the speed of migration of TNT into soils. HMX being almost insoluble in water has a great tendency to stay at the soil surface (Ref. 15). Considering that the destruction area at CFAD Dundurn is composed mainly of sandy soils, the sorption/desorption process is quite different than in clay type soils meaning that the relative fate of the various explosives and metabolites will also be different.

2.1 Soil Sampling

At the beginning of this study, it was thought that an open detonation did not lead to a complete reaction and that a little fraction of the explosives was sprayed out directly on the ground. For this reason, the entire surface at the destruction area of CFAD Dundurn was sampled to assess the contamination. As already mentioned, explosives are crystalline compounds which, when dispersed in the soils, lead to a large spatial heterogeneity. Conventional sampling procedure is not efficient with explosives and if a grid is chosen as a pattern for sampling, compositing the samples is essential to evaluate and understand the contamination at the site. Such a grid was applied at CFAD Dundurn to assess the contamination by explosives at the destruction area and will be described later. Some studies were done to understand the spatial heterogeneity and propose new ways of soil sampling (Refs. 16-22). In fact, now, a wheel pattern is applied to characterize efficiently and rapidly a site contaminated by explosives (Ref. 23).

2.2 Subsurface and Groundwater Sampling

The explosives can be slowly dissolved by rain or melted snow, migrate toward the unsaturated zone and reach the groundwater table leading to the formation of a plume in groundwater. In order to understand the size and the direction of the contamination plume and also to evaluate the impact on the environment, drilling boreholes and installing observation wells is essential to collect the groundwater samples. The services of a drilling firm specialised in contaminated site assessment is required to install wells at different depths and to establish the contaminant profile. Depth of drilling is related to the depth of the groundwater table at the sites.

The local stratigraphy of the site is determined by first examining existing drilling data usually available from the provincial ministry of environment. From existing boreholes, the thickness of unconsolidated material can be estimated. Proposed boreholes and monitoring wells are located, taking into account the geology, the topography of the site and the presumed groundwater flow direction. Hydrogeologists should be involved at this step to evaluate the groundwater flow direction and the likely extent of the contaminant plume. Drilling depth is defined on-site, depending on

observations made from the first drilling. During the drilling, the split spoon could be opened to allow the sampling of soils. Once the groundwater is reached, the observation wells could be installed according to specific procedures (Ref. 24) and be covered by protective well casings as illustrated in Fig.1.

Sampling the groundwater of a potentially contaminated site is the best way to monitor the environmental impact. This is particularly true for explosives, since they are not volatile. CF ranges are often very large areas for which a systematic gridding and soil characterization can result in large costs. Thus, sampling groundwater can minimise the associated sampling and analytical costs by directly understanding the impact of the contaminant on the environment. If contamination is not detected on-site in groundwater, down and up gradient of the site, it means that the potential contaminant does not leach from the site, or does not reach groundwater table and does not represent a threat to the environment. If contamination is found in groundwater, a more detailed sampling program must be undertaken for soil and groundwater to ascertain the situation and characterize the plume in groundwater. A detailed protocol for sampling explosive contaminated groundwater was developed as part of a natural attenuation study conducted in the United States by WES scientists (Ref. 25). The groundwater samples could be stabilized by adding sodium bisulphate (Ref. 26).

2.3 Sample Analysis

There are two field-screening methods commercially available to analyse the presence of explosives in soil and water samples. These are the D-Tech enzyme immunoassay (EIA) method used for both RDX and TNT and the EnSys colorimetric test kit used for TNT, RDX and HMX which are both commercially available from the same company (Ref. 27). These two methods were developed in 1990-95 (Refs. 28-33) and were compared and evaluated (Refs. 23, 34). The D-tech field method was used in the Dundurn study as a yes/no answer about the presence of explosives in soil and water samples and proved to be very helpful as a decision tool for the location and number of wells to be installed. When positive answers were obtained from the D-tech, samples were shipped to a laboratory to be more precisely analysed by the US EPA SW846 HPLC method 8330 which is the method to analyse quantitatively the explosives concentration in soils and water (Refs. 35-36).

2.4 Lysimeters Installation

To better understand the migration processes and biodegradation pathways of energetic materials within the unsaturated zone, lysimeters were installed at variable depths, at 2 different locations in the destruction area CFAD Dundurn. All the lysimeters were placed in the unsaturated zone between 1 and 5 m depth above the water table. The selected lysimeter is made of porous Teflon because it is stable and inert in contact with energetic material. Lysimeters are 44.5 cm long, have an outside diameter of 48 mm and can contain 200 ml of water. When the lysimeters are placed under vacuum, they can suck water which is in the soils surrounding the porous cup and, since the lysimeters are placed at different depths, it gives a profile of explosives concentration in the water of the soils. They also give information on the biodegradation pathway occurring during the migration of explosives towards the unsaturated zone since metabolite formation can be observed. These lysimeters have to be sampled many times in the year during the spring at snow melt and at fall to give the understanding on how explosives migrate during water infiltration. To better evaluate the velocity of explosives migration, a tracer test with potassium bromide (KBr) is done. Spraying a fine layer of potassium bromide on the ground and measuring its concentration in the suction lysimeters during water infiltration yields the time of travel of water in the unsaturated zone. A laboratory evaluation of retardation factors of different explosives in soil lead to the estimation of dissolved explosives travel time in the unsaturated zone of the studied site.

2.5 Air Impact

The impact on the atmosphere of ammunition destroyed by OB/OD will not be covered in this report. Even if experiments conducted in a closed vessel demonstrated that gaseous emissions were almost completely composed of non toxic gases (Refs.37-39), an R&D effort is underway at DREV to sample gases in real open detonation situations and to assess the air impact of such activities. Recent investigations and discussions with U.S. scientists tend to indicate that even if the detonation of ammunition in OD operations does not lead to toxic emissions, it may lead to the spreading of heavy metals in the atmosphere and the deposition of these contaminants on the ground in areas

surrounding the OD ranges. These assumptions are not supported by any sampling data and further research is needed.

2.6 Site Risk Assessment

In order to take appropriate action when contamination is encountered, one should have guidelines to decide what is clean and what is not. For explosives, there is no human health risk or ecotoxicological criteria already accepted by legislation that can be applied to the explosives contamination. For soil, Daniel and Knezovich published some human health risk generic criteria for TNT, RDX and HMX (Ref. 40). These criteria were below the ppm level meaning that these compounds are really toxic. For the water, guidelines for TNT and RDX in drinking water were also published by the US EPA and were below the ppb level for RDX and 2 ppb for TNT (Ref. 41). Recently, Lorraine Rouisse Inc. calculated human health risk generic criteria for RDX, HMX and TNT in soils and water. Land uses such as agricultural, residential, commercial and industrial were considered in the calculations. Five different models were evaluated and compared. All the calculations ended with criteria at the ppb and ppm levels for water and soils respectively (Refs. 42-43).

Since generic criteria take into account all the possible scenarios of ingestion, inhalation, dermal contact, etc., the more sophisticated is the model, the more severe are the criteria, their values are often too conservative to be applied on real military sites where the environment is not comparable with standard environment since it is often located far from potential receptors. In this context, the United States and also Canada have taken the approach of a site-by-site evaluation. This approach is more appropriate to DND needs and is more consistent with the reality encountered on military sites. A site risk assessment is therefore more appropriate and more relevant to the situation but is more expensive since it has to be done at each site. Nevertheless, this approach was taken to evaluate the risks of the open detonation activity at the destruction area at CFAD Dundurn.

3.0 EXPERIMENTAL

3.1 Samples and contractors

All solvents were purchased from Fisher Scientifique Co. The D-tech test kits for TNT and RDX detection were purchased from Diagnostix Inc. Drilling and observation well installations were achieved by Golder Associates Ltd. under the supervision of INRS-Géoressources and DREV scientists. INRS-Géoressources was responsible for the hydrogeology study of the site, for the determination of the groundwater flow velocity and direction, for the grain-size distribution, composition of soils, etc. In collaboration with DREV, INRS- Géoressources sampled soils and groundwater, installed and developed observation wells, determined hydraulic conductivity and measured groundwater levels in each well.

Soils analyses were done by DREV and also by contractors such as Analex Inc. and Zénon Laboratoires Environnementaux Inc. Analex Inc. performed most of the surface characterization including heavy metals, polycyclic aromatic hydrocarbons (PAHs), monocyclic aromatic volatile compounds (MAVCs), phenolic compounds, chlorinated hydrocarbons (CHs) and explosives using the US EPA SW846 HPLC method 8330. The selection of parameters was based on previous studies (Refs. 1-3). Zénon Laboratoires Environnementaux Inc. performed some soils and water analyses coming respectively from boreholes and observation wells as quality control. They also analysed the same parameters than Analex Inc. (heavy metals, PAHs, explosives etc.). The site risk assessment was performed by D'Aragon, Desbiens et Halde Associés Ltée (DDH).

3.2 High Pressure Liquid Chromatography

The US EPA SW846 HPLC method 8330 is the method accepted for explosives analysis in soils and groundwater. This method was thoroughly described in Ref. 23 and was performed by DREV to analyse the soils and groundwater collected at the destruction area at CFAD Dundurn. There are many ways of extracting the explosives prior their analyses by HPLC such as sonication, salting-out, etc. (described in Ref. 23). For the Dundurn study, the sonication extraction was applied to the soil

samples while the salting-out and solid phase extraction (SPE) procedure was applied to the water samples using the HPLC method 8330 for the analyses. DREV used for the analyses an HPLC model HP-1090 chromatograph from Hewlett-Packard equipped with a diode array detector Hewlett-Packard DAD HP-1100.

3.3 Soil Sampling

Soils were collected during the surface characterization in September 1994 and during the drilling of boreholes in November 1995 and December 1996. At the first visit in September 1994, the destruction area was sampled with a 30 m² grid doing compositing at each intersection of the grid (Fig. 2). All these points were named according to their geodesic locations. Moreover, some of the points were sampled at the surface and also at 30 cm deep and named "S" for surface and "P" for one foot deep. Four additional excavations were made using a mechanical shovel in the most often used part of the range to assess the contamination at depths varying from one to five meters. Composite samples were built from 15 sub samples collected in the mechanical shovel in each excavation at each of the 5 meters depth and were named MS1- 1M to 5M, MS2, MS3 and MS4- 1M to 5M. It was also decided to sample the area east of the site where the gaseous plume usually falls on the ground after a detonation. This was carried out to evaluate the contamination caused by the deposition of the ashes. After discussion with the personnel, six samples were taken at distances of 20 and 40 meters from the east boundary separated by 30 meters and were named PF1 to PF3 -20 and 40 M (see Fig. 2). Since the surface is 200 m by 110 m, a lot of samples were obtained and heavy metals, PAHs, MAVCs and CHs were analysed by Analox Inc. while DREV used the HPLC method to analyse explosives in all these samples. These results could be recovered from Table I.

A general procedure would consist of collecting a minimum of 500 g of soil for each point of the grid by mixing different sub-samples to obtain a composite sample. Amber glass should be used in order to prevent the photodegradation of light sensitive TNT and TNT derivatives. However, polyethylene bags might be used since this material is resistant to the absorption of explosives when used in conjunction with relatively dry soil samples. The bags must be immediately stored in ice coolers in the dark. Use of polyethylene bag decreases the space needed for storing samples, reduces

shipping costs and has lower risks associated with sample transportation. Samples must be kept at low temperature from time of collection until the analytical work is completed.

Following that preliminary characterization of the site, a second visit was performed in November 1995 to determine the contamination by explosives of subsurface soils and groundwater. This visit was also oriented towards the determination of the groundwater flow direction and velocity. Sixteen (16) wells were then installed at 8 different locations named P1 to P8, most of them directly in the destruction area. Vibrasonic method or hollow stem auger with split spoon is recommended for soil sampling. Preferably, boreholes will have to be drilled without the use of drilling fluid. If the vibrasonic method is selected for sampling, any ODEX type-drilling method can be used for drilling boreholes. For each borehole, a well log should identify all geologic material drilled. Initial borehole diameter in unconsolidated material should be sufficient to allow the installation of two-inch monitoring wells.

All soil samples were collected during borehole drilling with a truck mounted BRATT 22 auger rig equipped with hollow or solid stem augers. For our study, the hollow stem auger was chosen and used in conjunction with a 2-inch split spoon sampler. After each 5 feet interval, the sampler was retrieved from the augers and opened to allow soil sampling and a continuous record of soil conditions. The record of all the boreholes and the soils conditions are found in Refs. 44 and 45. Two classes of grain-size were observed and consisted in a poorly sorted sand with a mean grain diameter (d_{50}) which varies between 40 μm to 70 μm corresponding to a very fine sand and a second class composed of a well sorted fine sand (d_{50} between 100 μm and 150 μm) which corresponds to layered sand deposits. The proportion of silt-size material in sand varies from 1% to 10 %. The sand is iron stained above the water table, which indicates an oxidizing environment. Layers of fine coal fragments were noticed in the sand between 6 and 7 m depth (around elevation 495 and 494 m). The underlying unoxidized till formation and the underlying cretaceous rock formation were not drilled. All drilling and sampling equipment were washed in warm water, and decontaminated with acetone and rinsed with water to reduce the potential for cross contamination. These samples were analyzed on-site with D-tech test kits and contaminated samples were sent to DREV for HPLC analyses. In doing so, a three-dimensional map may be constructed and a better understanding and visualisation

of the contaminated zone is obtained.

To better determine the groundwater flow direction and also the extent of a possible plume, a third visit was done in December 1996 and, fourteen additional wells were drilled and installed in nine different locations outside the destruction area to ascertain the groundwater situation and were named P9 to P17 (Fig. 3). Soils samples were collected in four (4) out of fourteen (14) drilled boreholes. The same hollow stem auger system was used in conjunction with a 2-inch split spoon sampler for boreholes P12a, P14b, P15a and P4a. Soils were only taken close to the surface (0 to 3 m) during drilling of the new well P4a to replace the former well P4a that was silted up and destroyed during OB/OD operations on site. No soil sample was taken in the other deep boreholes because they were located outside of the OB/OD site in an area not susceptible to contamination as already known by the preliminary soil and groundwater characterization study (Ref. 44). Borehole logs from Golder Associates Ltd. were included and described the geology of the sampled soils (Refs. 44,45). The soils consisted of fine to medium grained brown sand and iron stained above the water table. Fine coal fragments and thin brown organic zones were noted within the sand.

During the same visit, nine soil samples were also collected from a solid stem auger in nine shallow boreholes 0.9 m deep located around well P-3 and P-4 (S-3A to S-3D and S-4A to S-4E). For an easier identification of these samples in the report, we named them Series S. These samples were collected because anti-personnel mines had been detonated earlier leaving dark residues on the ground. It was thought that these residues were composed of PAH, CH and heavy metals. Therefore, it was decided to investigate that particular area of the range.

Moreover, six lysimeters were installed in two distinct locations in the destruction area to understand the explosives fate in the environment. Twenty two soil samples were taken continuously from solid stem auger in six shallow boreholes (1 to 5 m deep) dedicated to the installation of two lysimeter nests consisting of three lysimeters per nest (L3a through L3c and L4a through L4c) (Fig. 4). For an easier identification of these samples in the report we named them Series L. The installation was made according to the Timco Manufacturing Inc. instruction manual. The schematic of these installations is presented in the boreholes logs in Ref. 45. The drilling and sampling

equipment were cleaned using the same procedure described earlier to reduce cross-contamination between samples and boreholes.

Finally, nine composite soil samples were taken at the surface by DREV scientists because of the intensive destruction of the anti-personnel mines in the previous months. The first four samples were taken around wells P3, P4, P5, and P15 by surface sampling with a shovel from 2.5 to 15 cm depth. Composite samples were built with twenty sub-samples taken in a circle of about 4.6 m diameter around wells. Those samples are identified as Composite: composite P3, composite P4, composite P5, and composite P15. The five other composite samples were taken in craters created by detonation of landmines. Composite sample locations are presented in Fig. 5. These were sampled after removing the snow on the ground with the help of a small loader (Bobcat). This operation removed about 2.5 to 15 cm of top soil and soil sampling was made in this soil pushed aside and in the new exposed soil surface. On the map, samples identification is function of their location: 50mwP3 means 50 meters west of P3, 50msP4 means 50 meters south of P4, 50mswP4 means 50 meters southwest of P4, 50mnwP5 means 50 meters northwest of P5 and 10mwP4 means 10 meters west of P4. All the results of the soil analyses are described in Table I. The locations of all the soil samples will be seen in different figures representing the site (Figs. 2, 5, 7 and 8).

3.4 Observation Well Installation and Groundwater Sampling

Each borehole should be equipped with a monitoring well. Well components (well tubing, joints, well screen, filter pack, expanding cement, cement/bentonite mixture or bentonite seal, protecting casing etc...), their dimension, and well installation guideline must be in conformity with requirements presented in the document "Guide d'échantillonnage à des fins d'analyses environnementales", cahier *Échantillonnage des eaux souterraines* (ISBN 2-89443-006-X), published by Le Griffon d'argile, or prescribed by the ASTM-D5092-90 procedure. Well installation and drilling methods are also described in the Canadian Council of Ministers of the Environment CCME report "*Manuel d'évaluation de la subsurface des lieux contaminés*" and also in the Natural Attenuation Protocol published by Pennington of the Waterways Experiment Station (WES) (Refs. 24, 25). No other seal material than those required by the guideline or by the ASTM norm should

be used in the space between the permanent well tubing and the borehole walls. Well permanent tubing and well screen were made of 1.5 meter long polyvinyl chloride PVC 8-slot well screen attached to the same 51 mm diameter PVC tubing extending to the surface. An appropriate grain-size filter pack was placed surrounding the well screen. A bentonite chip seal and a bentonite grout were placed above the filter pack to about one meter below ground surface where a concrete plug was installed. Each well elevation was established from the top of the PVC permanent tubing. A report describing boreholes locations, depth of drilling, local geological stratigraphy (drilling log), identification of the drilling method and the specifications related to well installation was written and can be found in Refs. 44-45.

A protective well casing with locks should be installed on each well. This will protect the observation wells from vandalism, outside contamination and also from mechanical shock which could permanently damage the well. Usually, well casings are installed over the well tubing and extent two to three feet above ground and six feet under ground. When installing a well casing over observation wells which are located in the range and could be subjected to impact by explosions, it is recommended that the protective well casings be surface mounted. These well casings should be installed into expending concrete to provide the necessary protection. These types of wells were installed at the destruction area of CFAD Dundurn and are represented in Fig. 1.

In this study, observation wells were installed in seventeen different locations with a 203 mm diameter hollow stem flight auger during two visits in November 1995 and December 1996. In December 1996, a new well was drilled to replace the well P4a which had become unusable. Between November 1995 and December 1996, during open detonation operations, wells P4a and P3b were destroyed at ground surface and completely silted up. No flush mount metal-casing protectors had been installed immediately after the drilling program in November 1995. Wells P3a (about 1 m of sand) and P5b (about 0.5 m of sand) were slightly silted up but were still usable. They were cleaned by pumping out the sand and groundwater by air lifting and with a submersible pump. A new PVC tubing was installed above ground on P3a and P5a in December 1996. Metal casing protectors were installed on every wells in December 1996, except for P-7 and P-8 that were fitted with an above ground steel casing in spring 1997 as illustrated in Fig. 1.

For drilling sites, each well is identified with the letter 'a' or 'b' indicating respectively the deep wells (1995 study: approximately 13 m depth; 1996 study: approximately 16 m depth) and the shallow wells (1995 study: approximately 9 m depth; 1996 study: approximately 12 m depth). Sites with only one well (P-9, P-10, P-11, P-16 and P-17) have an observation well installed at approximately 12 m depth.

For the groundwater sampling, a detailed protocol for sampling explosive contaminated groundwater was developed as part of a natural attenuation study conducted in the United States by WES scientists (Ref. 25). This protocol suggests purging the well until stabilisation of specific parameters. These parameters include temperature, conductivity, pH, turbidity, redox potential and dissolved oxygen levels. Measurements are taken at each successive half-well volume. When three of the parameters are in agreement within approximately 10% of the three consecutive measurements, sufficient water has been purged from the well in order to collect a representative groundwater sample. The result of these tests should be noted in the sampling logbook. Should these parameters not reach agreement, no more than five well volumes shall be purged. If the equipment needed for monitoring the above parameters is available, the protocol should be followed. In the case where the monitoring of parameters would increase the cost of sampling or if the monitoring equipment is not available, then, purging the well of three well volumes before sampling is recommended. In most cases, a purging time of thirty minutes is sufficient to achieve this purging volume.

The purging of wells is necessary since water within the casing of a well is stagnant, degassed, may react with the screen or casing material and is in an oxidative environment due to air contact at the water surface. It is therefore necessary to purge a sufficient volume of water from the well to ensure that the sample will be composed only of representative formation groundwater. Purging may be accomplished with a submersible pump, a low-flow pump or a bailer. The choice of bailer or pump will be based on the depth of the water table, volume to be purged and permeability of the aquifer. The water retrieved from the well should be kept in appropriate containers until the analysis reveals the absence or presence of explosive contaminants. Uncontaminated water can be disposed directly

on the site while contaminated groundwater must be treated by passing through an activated charcoal filter before disposal.

Immediately upon completion of purging, samples should be collected for analysis using either a polytetrafluoroethylene (PTFE) (TEFLON)-coated bailer on a PTFE-coated stainless steel cable or the output of the PTFE well tubing when using a Waterra pumping system. A minimum volume of 2 liters of water should be collected in each well and poured in two amber glass containers. Groundwater samples will be collected from the least contaminated wells first to minimise cross-contamination. When a bailer is used for sampling, the bailer should be decontaminated by rinsing three times with acetone and three times with distilled water between each well sampling. It is highly recommended to install a dedicated PTFE tubing using a Waterra pump in each well thus avoiding the step of decontamination and minimising cross contamination. A high density polyethylene HDPE tubing could also be dedicated to each well since this type of tubing is relatively cheap and inert.

Samples suspected to be contaminated by TNT or TNT metabolites should be stabilised by adding sodium bisulphate (1.5 g/l) since it has been demonstrated that acidification to a pH of 2 with this compound is efficient to stabilise water containing nitroaromatics (Ref. 26). Depending on the pre-concentration method used, a sufficient volume of water must be collected in order to obtain the needed number of replicates and to insure quality assurance/quality control (QA/QC) by a separate laboratory. The salting-out procedure of the US EPA SW846 HPLC method 8330 requires 770 ml per sample while the solid phase extraction procedure requires 500 ml per sample.

All wells were then purged with a submersible pump (Redi-Flo2 from Grundfos) until the water was clear. It took usually between 30 minutes and one hour to purge one well. A sampling system was dedicated at each well. It was a high-density polyethylene (HDPE) tubing with a Debrin foot valve using an electric pump for sampling (Hydrolift II from Waterra). Shallow wells had dedicated 1.58 cm diameter tubing and deep wells were equipped with dedicated 2.54 cm diameter tubing. To obtain a representative groundwater sample, a volume of groundwater corresponding to 3 times the volume of water inside the PVC tubing of the well and the sand filter around the screen was removed from the observation wells before sampling. Groundwater samples were taken from

all wells and analyzed by D-tech or US EPA HPLC method 8330. When water samples had to be shipped to external laboratory or to DREV, they were stabilized with sodium bisulphate according to Ref. 23.

All the water analyses were done to evaluate groundwater contamination. The groundwater depth was measured with a water level detector using an alarm probe. Water table elevations were then mapped and illustrated in Figs. 3 and 6. Downward slug tests were also performed in each observation well to evaluate the hydraulic conductivity of the aquifer. Data were collected with the help of a pressure transducer and a data logger (Steven's 420 level logger) (Refs. 44,45). The data were interpreted using the Hvorslev (1951) method included in the software Aquifer Test version 2.5 (Waterloo Hydrogeologic Software) (Ref. 46).

4.0 RESULTS AND DISCUSSION

The objective of this study was to assess the environmental impact of the open detonation activity at the destruction area at CFAD Dundurn. To achieve this objective, soils and groundwater were sampled and analyzed to determine the concentrations of explosives and other potential contaminant on the site. The groundwater flow direction and velocity were also determined to evaluate if a plume of contaminants was developed and represented a threat to the environment. Lysimeters were also installed to understand the fate of explosives in soils. Finally a site risk assessment based on all the data available was done to evaluate the health risks associated with the open detonation of energetic materials at the destruction area.

4.1 Soil Analyses

As described in the experimental part, many soils samples were taken at different phases of the study. To better understand the results of the soil analyses, these were all compiled in Table I. This table contains the results for the explosives, heavy metals and organic compounds analyses of all the soils collected during the study. The first part of the table contains the results of the soils analyses done for the surface characterization in September 1994. Figure 2 illustrates the sampling

grid used for this characterization study. All the heavy metals and the organic compounds analyses were carried out by Analox Inc., their report was incorporated in the DDH final report (Ref. 47). HAPs, MAVCs and CHs were also analysed since open burning often results in the formation of these compounds (Ref. 48). In HPLC Method 8330, RDX, TNT and HMX are extracted with acetonitrile and estimation of these organic compounds concentrations and identification of their metabolites are made with a detection limit varying from 0.2 to 1.0 mg/kg (ppm) when using a diode array detector.

If one examines the first 86 samples of Table I for the surface characterization, no contamination is observed neither by heavy metals nor by PAHs, MAVCs or CHs since no value higher than the residential CCME criteria was observed or since the compounds were simply not detected. Explosives contamination was observed in 8 out of 22 samples from the mechanical shovelled excavations. These contaminated samples contained mainly RDX and TNT at levels as high as 35.5 and 13.0 ppm respectively and were found in MS3 and MS4 which are close to the most intensively used area of the site. All the samples collected in MS4 at all depths were contaminated by explosives and could be the result of a vertical cross-contamination. In general, no contamination by explosives is observed at the surface of the destruction area of CFAD Dundurn.

Following the surface characterization, it was decided to evaluate the contamination by explosives of the subsurface and groundwater since contamination was found below the surface, between 1 and 5 m depth at two locations (M3 and M4) and because of the sandy nature of the site. Sampling the subsurface soils was done according to the procedure explained in the experimental part. RDX and TNT concentrations in soils were determined in the field on every soil samples (except for P-8, with one sample out of two) with the D-tech on-site method and on one sample out of two in the laboratory by the HPLC method (US EPA SW-846 Method 8330). All results of TNT, RDX and HMX analyses by HPLC in soil samples are included in Table I. All results of TNT, RDX and HMX analysed by both D-tech and HPLC in soil samples could be retrieved in Refs. 44 and 45. HMX concentrations in soil as well as TNT concentrations in groundwater were determined only in the laboratory by the HPLC technique (US EPA SW-846 Method 8330).

Figures 7 and 8 present RDX and TNT concentration profiles in soil of the 1995 drilling program and in borehole P-15. As shown in Fig. 7, no significant RDX concentration was detected in soil samples, including the two small samples at P-15 collected between 22 and 22.5 feet and from 26.5 to 27 feet in high organic matter layers. Only 1.3 ppm was detected at P-4 between 40 and 45 feet in December 1995, which corresponds to the location of observation, well P4a. RDX was detected at the beginning in groundwater but dissipated with time (see the following section on groundwater characterization). If the concentration of 1.3 ppm of RDX in soil of P4a is not related to analytical or sampling problems, the soil can be considered contaminated. However, soils at 12 m (40 feet) depth do not have significant risk to human health and wildlife because there is no contact with these receptors. Also, the volume of contaminated soil is very small. RDX was not detected in Composite samples (Fig. 5) nor in Series S, Series L, top soil of P4a and P15a because soil is considered contaminated at extremely low concentrations (see Table I).

In December 1995, TNT was detected at depth (deeper than 9 m) in some soil samples of P-1, P-2, P-3 and P-4. TNT concentrations were low and the highest concentration was found in P4 at 1 ppm. The sampling program of December 1996 did not detect TNT in the new borehole P-15 (Fig. 8). Composite surface samples (9) were analyzed with the US EPA method 8330 since TNT was detected with the D-Tech method. A concentration of 0.7 ppm was detected in Composite P-5, top soil of P4a (0-1.5 m) and 50 msP4 (Fig. 5). The composite sample P-5 was also contaminated with 2.9 ppm of tetryl that was associated with landmines destruction. Tetryl was also found in one sample of Series S (S4e at 39 ppm) (Table I).

Explosives, polycyclic aromatic hydrocarbons (PAHs) and heavy metals in soil samples of Series L and S, in all Composite soil samples and in top soil of boreholes P4a (0-3 m) and P15a (0-1 m) were analyzed by Zénon Laboratoires Environnementaux Inc. with standard laboratory analytical methods. The heavy metals Ag, Hg, Mo, Pb and Sn were not detected in most samples and the other analyzed heavy metals (Ba, Cd Cr, Co, Cu, Ni, Zn) were detected in soil samples at background levels or close to background levels (Table I). Concentrations of copper that are not an environmental problem and that are above background level were found in a soil sample of lysimeter at site P-3 (between 6 and 10 feet deep) and in the soil sample S4d. PAHs were not detected in the soils of

Series L and Series S (Table I). Very low concentrations of PAHs were detected in eight (8) of the twelve (12) Composite samples (Table I). These concentrations are below acceptable land use level for residential development and can be considered insignificant. All the results of the soil analyses indicate that explosives, heavy metals or organic compounds exist at very low concentration and represent a minimum impact to human health or to the environment. It was surprising though that lead concentrations were low considering the amount of anti personnel mines destroyed in one event. This could indicate that heavy metals are sprayed out in the atmosphere during the detonation and fall on the ground outside the site. This will have to be evaluated more precisely in the near future.

4.2 Groundwater Analyses

RDX, TNT and dissolved heavy metals were analyzed in groundwater samples of the December 1996 sampling campaign. RDX and TNT in groundwater were analyzed by DREV with the D-Tech method and also by US EPA HPLC method 8330. Dissolved heavy metals (Ag, Ba, Cd, Cr, Co, Cu, Sn, Hg, Mo, Ni, Pb, and Zn) were analyzed by Zénon Laboratoires Environnementaux Inc. (Table II). For RDX analyses with the D-Tech method, only groundwater sample from well P3a was positive (25-45 ppb) (see Ref. 45). Samples from wells P3a, P3b and P4a were also analyzed with the US EPA 8330 method and RDX was detected in P3b at 159 ppb and P4b at 3.4 ppb (Fig. 9). These results are consistent with the 1995 and other 1996 groundwater sampling programs. Figure 9 indicates that RDX concentrations in groundwater "persist" at wells P3b and P4b with an average concentration of 110 ppb and 4 ppb respectively. This concentration is well above the EPA published guideline of 0.3 ppb for RDX in groundwater (Ref. 49). RDX concentration may also persist at well P3a but RDX was under detection limit for the December 1996 sampling program. This observation may be an indication of RDX dissipation in groundwater. TNT was not detected in the new observation wells (P9-P17). Analytical results of TNT in groundwater in the burning area show that TNT is still not detected at P-4 and at P-3a sites (Fig. 10) and TNT is not detected from Sept 1996 at the P-3b site indicating a dissipation process. This hypothesis of dissipation is consistent with the fact that original concentrations are low and do not persist but decrease with time.

In fact, most of the low concentrations of TNT, RDX and HMX detected in wells P1 to P7 during the first sampling program in 1995 dissipated with time and were under detection limit one year later at the end of 1996 (Table II). This behavior can be explained by vertical cross contamination of the soil (from top to the bottom) during drilling operations. Cross contamination between drilling sites is more easily controlled than vertical contamination at one site and was avoided by using the decontamination procedure of the equipment. In fact, a very small quantity of soil containing traces of TNT, RDX or HMX is sufficient to contaminate groundwater and detect them at the ppb level. These compounds are slowly dissolved in groundwater and they are detected for a period of time according to the mass of the compounds around the well screen. The duration of detection in groundwater depends also on effective solubility of compounds in groundwater (aqueous solubility of: RDX:28.9 mg/L, TNT:110 mg/L and HMX:1.21 mg/L) and their potential biodegradation at the groundwater temperature (approximately 10° C). Another groundwater sampling program could be done to confirm that dissipation of the introduced energetic material by vertical cross-contamination occurred in groundwater.

RDX and HMX were detected in groundwater at the first sampling program at P7 wells. More extensive sampling was required to verify if there was groundwater contamination up gradient of the OB/OD site or if cross-contamination occurred during well installation. Table II shows that RDX and HMX were not detected in three subsequent sampling programs. These results confirm that there is no contamination up gradient of the OB/OD range and that cross-contamination occurred during well installation. During the preliminary study, high concentrations of RDX in groundwater were found in well P3b (77.9 ppb in November 1995 and 120.8 ppb in April 1996). To assess the extent of a possible down-gradient groundwater contamination by RDX or TNT, eight (8) observation wells were installed downstream of wells P3. Four different sites were drilled (wells P12, P13, P14 and P15 of Fig. 6) at two different depths (about 12 m and 16 m deep). Groundwater of the new drilled sites was analyzed for RDX and TNT content by the D-tech technique and none of these energetic materials was detected. These results are not surprising since the new observation wells installed gave a better definition of groundwater flow which is in the east-west direction instead of being in the south-east/north-west direction as it was thought in 1995. So, the main groundwater flow direction from P-3 was not northwest but west and no groundwater plume of TNT or RDX

could be drawn. Groundwater contamination by RDX is only limited at shallow depth around the P-3 and P-4 sites, which are the most used areas of the range for the OB/OD activity. For TNT, by examining Fig. 10, it is evident that the original concentrations are decreasing to a point at which TNT is no longer detected in any of the wells.

4.3 Lysimeters Study

The suction lysimeters were installed to better understand RDX and TNT migration processes and biodegradation pathways within the unsaturated zone. As mentioned in the experimental part, 6 lysimeters were installed in December 1996, at variable depths, at 2 different locations near wells P3a and P4a in the burning area, respectively L3a, L3b, L3c and L4a, L4b, L4c (Fig. 4). Lysimeters were put under vacuum on May 4, 1997, and sampled on May 5. Only 2 samples were collected: L4a (about 50 ml) and L4c (about 150 ml). Lysimeters L4b and the three lysimeters of site L3 (a,b and c) were dry or unable to keep the vacuum and no sample was collected. The lack of precipitation in the previous weeks and leaking installations (joint, tubing, fittings, etc.) were responsible for this unsuccessful sampling. The two collected samples were put in a cooler and brought to DREV on May 7. Because of the too small volume of sample, DREV was unable to perform a chemical analysis. However, INRS was able to perform a bromide analysis with ionic chromatograph on water sample L4a (bottle L4c was broken during transportation) for a bromide background estimation of 0.1 mg/L.

On May 5, 1997, a tracer test with bromide (KBr) was started at site L3 and L4 in order to evaluate the travel time of water in the unsaturated zone (from the surface to water table). A fine layer of bromide solution (L3: 2063.3 g of KBr in 7.6 L of water; L4: 2841.2 g of KBr in 7.6 L of water) was spread on the soil surface in a radius of 8 m around lysimeters L3c and L4c. After each abundant precipitation in the fall and during the following snow melt in the spring, samples were supposed to be taken according to the sampling protocol presented in Appendix 5 (Ref. 45). A CFAD Dundurn member was trained to make the sampling but unfortunately the lysimeters were unusable and no sample was collected. We can make the hypothesis that these instruments are too fragile and susceptible to break under field conditions with the high vibrations created by open detonations. The

capillary contact between porous cup and silica floor was probably broken by vibrations generated by open detonation. It is not recommended to install Teflon lysimeters that are more susceptible to have vacuum leaks at joints than the PVC or stainless steel lysimeters. Therefore, because of operational problems, this objective of the study was not met.

4.4 Groundwater Flow

One of the objectives of the study was to define groundwater flow direction and velocity. Figs. 3 and 6 show the elevation of the water table and the general directions of groundwater flow based on measurements made in December 1996 and September 1997. Groundwater levels in wells are compiled in Table 1 of the INRS final Report (Ref. 45). These results generally confirm the groundwater flow direction defined by the preliminary study carried in November/December 1995. However, INRS identified a shift in groundwater flow direction at the west end of the burning area. The main groundwater flow direction is now observed to be generally from east to west and somewhat towards the northwest in the burning area (Fig. 6). The horizontal hydraulic gradient (the slope of water table) in December 1996 and September 1997 is the same (0.0005 m/m) as the one obtained earlier (Ref. 44). December 1996 and May 1997 water level data suggest no vertical gradient in the saturated zone. This implies that ground water flows horizontally in the upper part of the aquifer.

The water table elevation variations over the observed months (November/December 1995, December 1996, May 1997 and September 1997) is very small and is in the order of 12 to 16 cm. This suggests that recharge of the aquifer by precipitation (snow melt and rain) is low (Ref. 45). However, the observations are sparse over a few years and should be extended over a complete year if a better estimation of the recharge is needed. We suggest the installation of a data logger in one well for a year and a half to better estimate groundwater recharge. Recharge evaluation will indicate the amount of water that percolates vertically through the OB/OD site.

As mentioned in the experimental part, the hydraulic conductivity was evaluated using downward slug tests, which were interpreted using the Hvorslev (1951) method. The values

measured during the first visit varied by one order of magnitude i.e. from 1.7×10^{-5} to 1.0×10^{-4} m/s which is usual in stratified sediments (Ref. 44). The geometric mean hydraulic conductivity (5.0×10^{-5} m/s) was typical of a fine sand (Ref. 49). The mean hydraulic conductivity of the sand was also evaluated from the 10% passing grain diameter (d_{10}) obtained from the grain-size curve (Hazen relation in Freeze and Cherry Ref. 49). The estimated average permeability (2.5×10^{-5} m/s) from grain-size curves agrees with the mean hydraulic conductivity estimated from slug tests (Ref. 44). Because there is no low permeability sediment layers on top of the sand unit, the aquifer is unconfined and is vulnerable to groundwater contamination from the soil surface. The water table at the site is located between 5 and 7 m depth which corresponds to an elevation close to 505 m. The horizontal hydraulic gradient (the slope of the water table) is 0.0005 m/m and groundwater flows from east to west (Figs. 3 and 6). Assuming a porosity of 0.3 for the sand, groundwater flow was estimated with an average velocity of 2.6 m/year.

Since most of the wells were aligned to follow potential contamination in soil and groundwater from the burning area in 1996, it was recommended to drill nine more sites to confirm groundwater flow directions on a larger area. Since the hydraulic gradient was so small, it could shift with seasons and the groundwater flow direction needed to be established more firmly. This was confirmed at the second visit of the site. More wells were drilled and the geometric mean of the hydraulic conductivity values obtained for these wells (4.6×10^{-5} m/s) was typical of a fine sand and was in the same order of magnitude as the one evaluated in the 1996 hydrogeological study (5.0×10^{-5} m/s). Still assuming a porosity of 0.3 and a horizontal hydraulic gradient of 0.0005 m/m, the groundwater velocity can be estimated now at 2.5 m per year. This means that if groundwater flows at the same velocity between the burning area and the closest discharge area (Indian Lake), it would take more than 2000 years for water flowing through the OB/OD area, to reach this point located 5.7 km west of the site.

Based on liquid-solid distribution coefficient (K_d) available in the literature (Refs. 50, 51), it is possible to estimate the retardation factor (R_f) of the dissolved energetic material in groundwater (Ref. 52). Because in the literature the distribution coefficients have widespread values and are site specific, the calculation of the retardation factor is a first approximation of actual values that would

be found in the aquifer at Dundurn. The calculations were made with a porosity of 0.3 and a density of solids of 2.65 g/cm^3 . The results of retardation factor calculation show that the dissolved energetic material in groundwater will travel slower than groundwater itself (Ref. 45). For RDX, TNT and HMX respectively, the velocity of the dissolved phase will be 25, 180 and 40 times slower than groundwater. For a groundwater velocity of 2.5 m/y, the dissolved RDX, TNT and HMX will travel respectively at 0.1 m/y, 0.01 m/y and 0.06 m/y. These data were taken into account to realize the site risk assessment of the destruction area.

4.5 Site Risk Assessment

The main objective of this site risk assessment was to establish the potential risks associated with exposure to energetic materials and other related compounds and determine at which level the site has to be decontaminated to protect the human health and the environment. All the data available for the contamination by explosives at the site were considered for this study, including the way of detonating the obsolete materials, handling materials, breathing in the bunker etc... Since the surface characterization did not show contamination by explosives, the subsurface and the groundwater analyses demonstrated minimal concentrations which in the case of TNT were dissipating over time, it was concluded that the impact from explosives was minimal or negligible at the site. Moreover, considering the groundwater flow velocity and direction, contaminants coming from the destruction area would take a minimum of 2000 years to reach the first receptor and this does not take into account the retardation factors which would lead to longer times.

Global risks calculations involving compounds such as: benzo(a)pyrene, RDX, TNT etc. indicate that risk criteria for cancer effects identified in this study are largely met for off site residents and on site workers using the US EPA criterion of 10^{-4} . The same applies for Alberta and Québec criteria of 10^{-5} and 10^{-4} respectively. However, in some jurisdictions (such as Ontario and British Columbia and, according to Canadian Council of Ministers of the Environment (CCME) soil quality criteria) a risk criterion of 10^{-6} for cancer effects would be slightly exceeded when benzo(a)pyrene and RDX are combined for the dermal contact pathway for on site workers. Considering all the factors used in the calculations (models, reference values and other data), the results presented in the

risk analysis are most likely an overestimate of the "real" risk encountered at the destruction area CFAD Dundurn. Non-cancer effects criteria of the US EPA and other Canadian jurisdictions are largely met for the on site workers and for the off site population. U.S. Army studies have shown that air quality is not significantly affected by a detonation (Refs. 37-38). Nevertheless, this potential source will be studied by DREV before any definitive conclusion is reached on this issue. DREV will also investigate the surrounding of the site to assess the contamination by explosives.

The drinking water does not represent a problem since the nearest drinking wells is located 5 km away from the destruction area and this area is not impacted by the OB/OD activities. So, the groundwater pathway was not considered in the assessment for on and off site receptors. Another important aspect for the protection of the workers is the health and safety procedure already in place at the destruction area. This includes personal protection for dermal contact such as gloves, a ten-minute wait in the bunker after detonation to limit inhalation of potential toxic fumes, wearing masks and so on. It is recommended that this procedure be maintained to protect human health. In fact, the workers at the destruction area undergo medical examinations twice a year, including a biological monitoring using blood tests.

The site is not considered to have a significant impact on ecological receptors based on the type of activities going on at the site and the fact that vegetation is not present in the main destruction zone, limiting ingestion of potentially contaminated food. Finally, impacts associated with overpressure, missiles, thermal radiation fluxes or noise are described as negligible or mitigated by measures such as a concrete bunker to protect the workers during the detonation.

All the data collected during the characterization of the surface, the subsurface, the groundwater and the site risk assessment indicate that the impact of explosives on the environment related to the open detonation of obsolete materials at the destruction area of CFAD Dundurn is minimal or negligible. Moreover, study of the hydrogeology of the site and the groundwater flow indicated that the threat to human health is negligible since it would take more than 2000 years to reach the first receptors. The ecological impact is also minimal since there is no vegetation at the destruction area so, no contaminated food is available for the ecological receptors. The workers are

also protected by a health and safety procedure. Usually, a site risk assessment leads to a specific criteria for the site decontamination which takes into account all the risks related with this level of contaminant that should be reached to protect the human health and the environment. At Dundurn, this criterion was not calculated since the impact of explosives on human health and the environment was minimal.

5.0 CONCLUSION

The objective of this study was to assess the impact of the open detonation activity on the environment and on human health at CFAD Dundurn. Since the Dundurn destruction area is the largest open detonation site in this country, it represents the worst case scenario and could serve as a model to evaluate the other OB/OD sites in Canada.

The first characterization demonstrated that the soil contamination at the surface of the destruction area was negligible except the soils collected in the excavations made by mechanical shovel where RDX and TNT were found at 0.5-35.5 ppm concentrations. These concentrations are not representative of the surface and subsurface and should be considered as isolate cases. The second and third characterization demonstrated that the subsurface is almost clean of explosives with a few exceptions. It was also observed that the quality of groundwater was good. It is low contaminated in RDX except at P3b, which is located directly in the most used zone of the site. TNT concentrations were found at the beginning of the drillings but decreased with time to become not detectable a year later. This could be explained by vertical contamination during the drillings of boreholes. Therefore, it can be concluded that the soils and groundwater are not contaminated by explosives or at least low contaminated.

The velocity and the direction of the groundwater flow were also determined. It moves at a velocity of 2.5 m/year in the north west direction. At this speed, contaminants, if present, would take more than 2000 years to reach the first receptor who is located 5.7 km away from the destruction area in this direction. One could therefore state that there is no threat neither to human health nor to the environment coming from a potential plume of contaminants out of the destruction area and

this is particularly true since there is no contaminant present at high concentrations in the groundwater of the destruction area. The fate of explosives was also evaluated by using lysimeters. These experiments failed since they were damaged during the open detonation activities or were simply not functional. The tracer test was abandoned because of malfunction of the equipment. In consequence, this objective of the study was not met.

The site risk assessment demonstrated that the open detonation activity is leading to negligible impacts for on and off site receptors. In fact, this study shown that cancer and non-cancer effects for human receptors are minimal and that, negligible impact is observed on ecological receptors. It is also recognised that there is no impact on the drinking wells and negligible impacts associated with overpressure, missiles, thermal radiation fluxes or noise. No occupational disease or accidents were reported and according to US scientists, the impact on air quality following a detonation is negligible. This last aspect is not clear to us and further works will be done to assess this situation. Another point of interest is the possible dispersion of the contaminants outside the destruction area; this will also be investigated. In conclusion, all the study is demonstrating that, according to the procedure used by the Canadian forces to detonate obsolete materials at the destruction area at CFAD Dundurn, the impact of this activity on human health and on the environment is minimal and can be pursued until further notice. It was demonstrated that the open detonation process is clean and do not lead to the accumulation of explosive residues neither on the soils nor in the groundwater.

6.0 FUTUR WORKS AND RECOMMENDATIONS

To complete this study, it is recommended to implement a groundwater monitoring program for energetic materials at wells P1 to P7 to verify if analytical results are similar to those already obtained. This program would verify if a low artificial groundwater contamination by energetic materials was generated by drilling during the installation of observation wells in the Fall of 1995 and that only groundwater in shallow wells P3b and P4b is contaminated with RDX. This location corresponds to the most used area in the range. From this sampling point there is no groundwater plume detected and no off site contamination detected.

Despite no evidence of off site contamination, it is recommended to make groundwater sampling every 2 years for the next ten years at wells P3b, P4b, P5b, P17, P6b for an environmental fate survey of energetic material in groundwater. Two wells (P6b, P-17) will be used as alert wells to detect any off-site migration of these potential contaminants.

To reduce the noise of the detonations, it was once proposed to use water bags. Preliminary evaluation of the Dundurn site shows dry conditions (very low water infiltration) and any water addition in the range may result in an increase in groundwater recharge and consequently in groundwater contamination. Therefore, it is recommended that the use of water bags for noise control during open detonation be avoided since it could have a negative impact on the groundwater quality. This could increase the potential migration of energetic material to the groundwater table and could contaminate groundwater.

To make an hydrologic mass balance and to follow annual groundwater level variation it is recommended to install a pressure probe and a data logger for at least one year in two observation wells (P1b and P6a). A down hole two-inch Troll (SP4000) data logger equipped with a pressure transducer (0 to 15 psi) is recommended for continuous water level measurements every day. This equipment requires no maintenance and is installed down hole, which makes it safe and well protected in detonation areas. In parallel, meteorological data are required to make water balance calculations at the site. This information will make possible the calculation of the average annual water flux through the unsaturated zone.

To protect the workers at the destruction area, a health and safety procedure is already in place. This includes personal protection for dermal contact by using gloves. To limit the exposure by inhalation of potential toxic fumes, a 10-minute wait in the bunker after a detonation is applied. We recommend that the procedure now in effect be maintained. We also recommend that measures to mitigate such as washing hands and face before eating, eating only in clean areas and restriction of smoking while working in the destruction area be applied to ensure that the potential risk to on site workers is kept at an acceptable level.

The air impact will be evaluated using drag tubes to sample gases after a detonation. These gases will be analysed by gas chromatography (GC). The analyses will reveal if toxic gases are present and if so, possibly evaluate the impact on air quality. The other aspect is the dispersion of heavy metals outside the destruction area. If one considers the amount of heavy metals that should have been retrieved on the site after the destruction of the anti-personnel mines, analyses done shortly after the detonation revealed no heavy metals on the site. This indicates that these contaminants were probably dispersed in the atmosphere and transported somewhere else by the wind. There are specialised programs or software that can be run to determine where the sphere of gases is deposited after a detonation. At this location, soils will be analysed to confirm the presence or absence of contaminants, explosives or heavy metals. It is highly probable that the contaminants when vaporised and dispersed by the detonation fall on the ground at respectable distances from the site and be present in the environment at concentrations not detectable. Further works will be done to assess this possibility.

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TABLE I
ANALYTICAL RESULTS FOR SOILS COLLECTED AT CFAD

Samples number	Date	Depth (cm)	Compounds (mg/kg)												
			Metals												
			Al	Ag	Ba	Cd	Cr	Co	Cu	Sn	Fe	Hg	Mo	Ni	Pb
CCME criteria															
Agriculture			-	20	750	3	750	40	150	-	-	0,8	5	150	375
Residential/Parkland			-	20	500	5	250	50	100	-	-	2	10	100	500
Commercial/Industrial			-	40	2 000	20	800	300	500	-	-	10	40	500	1 000
PF1-20M	Feb. 1995	0-10	8 550	-	-	-	-	-	20	-	9 950	-	-	7	<20
PF1-40M	Feb. 1995	0-10	9 550	-	-	-	-	-	42	-	10 700	-	-	8	20
PF2-20M	Feb. 1995	0-10	7 400	-	-	-	-	-	18	-	8 750	-	-	6	<20
PF2-40M	Feb. 1995	0-10	8 000	-	-	-	-	-	7	-	9 700	-	-	7	<20
PF3-20M	Feb. 1995	0-10	7 350	-	-	-	-	-	20	-	9 100	-	-	7	<20
PF3-40M	Feb. 1995	0-10	7 500	-	-	-	-	-	20	-	9 200	-	-	7	<20
89174711S	Feb. 1995	0-10	7 550	-	-	-	-	-	18	-	9 100	-	-	8	<20
89174711P	Feb. 1995	30	6 950	-	-	-	-	-	22	-	7 900	-	-	7	<20
89174708S	Feb. 1995	0-10	6 950	-	-	-	-	-	14	-	8 900	-	-	7	<20
89174705S	Feb. 1995	0-10	6 350	-	-	-	-	-	5	-	8 200	-	-	6	<20
89174705P	Feb. 1995	30	7 250	-	-	-	-	-	23	-	8 350	-	-	7	<20
89164702S	Feb. 1995	0-10	7 250	-	-	-	-	-	12	-	8 750	-	-	6	<20
89164700S	Feb. 1995	0-10	7 050	-	-	-	-	-	9	-	8 950	-	-	7	<20
89164700P	Feb. 1995	30	7 400	-	-	-	-	-	<5	-	9 150	-	-	7	<20
89144711S	Feb. 1995	0-10	7 450	-	-	-	-	-	12	-	8 650	-	-	7	<20
89144711P	Feb. 1995	30	7 800	-	-	-	-	-	27	-	9 300	-	-	7	<20
89144708S	Feb. 1995	0-10	7 600	-	-	-	-	-	6	-	9 850	-	-	7	<20
89144708P	Feb. 1995	30	7 650	-	-	-	-	-	<5	-	9 650	-	-	7	<20
89144705P-1	Feb. 1995	30	7 750	-	-	-	-	-	<5	-	9 650	-	-	7	<20
89144705P-2	Feb. 1995	30	7 700	-	-	-	-	-	10	-	9 800	-	-	7	<20
89134702S	Feb. 1995	0-10	7 700	-	-	-	-	-	12	-	9 400	-	-	7	<20
89134702P	Feb. 1995	30	7 700	-	-	-	-	-	7	-	9 650	-	-	7	<20
89134700S	Feb. 1995	0-10	7 300	-	-	-	-	-	21	-	9 200	-	-	8	<20
89134700P	Feb. 1995	30	7 800	-	-	-	-	-	5	-	9 800	-	-	8	<20
89114712S	Feb. 1995	0-10	7 700	-	-	-	-	-	6	-	9 350	-	-	8	<20
89114709S	Feb. 1995	0-10	7 400	-	-	-	-	-	6	-	9 450	-	-	7	<20
89114709P	Feb. 1995	30	7 650	-	-	-	-	-	5	-	9 650	-	-	7	<20
89114706S	Feb. 1995	0-10	7 500	-	-	-	-	-	5	-	9 250	-	-	7	<20
89114706P	Feb. 1995	30	7 850	-	-	-	-	-	7	-	9 450	-	-	7	<20
89104703S	Feb. 1995	0-10	7 725	-	-	-	-	-	7	-	9 525	-	-	7	<20
89104703P	Feb. 1995	30	7 150	-	-	-	-	-	5	-	8 550	-	-	6	<20

LECTED AT CFAD DUNDURN

Compounds (mg/kg)					Phenolic compounds (1)	Energetic materials					PAHs	MAVCs (3)(4)(5)	CHs (6)
Mo	Ni	Pb	Zn			HMX	RDX	Tetryl	TNT	Other (2)			
5	150	375	600			-	-	-	-	-			
10	100	500	500	(7)		-	-	-	-	-	(7)	(7)	(7)
40	500	1 000	1 500			-	-	-	-	-			
-	7	<20	140	-	-	<1	<1	<0.7	<0.3	<0.3	<0.1	<0.1	<0.1
-	8	20	63	-	-	<1	<1	<0.7	<0.3	<0.3	<0.1	0.4	<0.1
-	6	<20	89	-	-	<1	<1	<0.7	<0.3	<0.3	<0.1	0.2	<0.1
-	7	<20	27	-	-	<1	<1	<0.7	<0.3	<0.3	<0.1	0.2	<0.1
-	7	<20	32	-	-	<1	<1	<0.7	<0.3	<0.3	<0.1	<0.1	<0.1
-	7	<20	67	-	-	<1	<1	<0.7	<0.3	<0.3	<0.1	<0.1	<0.1
-	8	<20	44	-	-	<1	<1	<0.7	<0.3	<0.3	<0.1	<0.1	<0.1
-	7	<20	49	-	-	<1	<1	<0.7	<0.3	<0.3	<0.1	<0.1	<0.1
-	7	<20	72	-	-	<1	<1	<0.7	<0.3	<0.3	<0.1	<0.1	<0.1
-	6	<20	26	<0.1	<0.1	<1	<1	<0.7	<0.3	<0.3	<0.1	<0.1	<0.1
-	7	<20	38	<0.1	<0.1	<1	<1	<0.7	<0.3	<0.3	<0.1	<0.1	<0.1
-	6	<20	27	-	-	<1	<1	<0.7	<0.3	<0.3	<0.1	<0.1	<0.1
-	7	<20	26	-	-	<1	<1	<0.7	<0.3	<0.3	<0.1	<0.1	<0.1
-	7	<20	22	-	-	<1	<1	<0.7	<0.3	<0.3	<0.1	<0.1	<0.1
-	7	<20	28	-	-	<1	<1	<0.7	<0.3	<0.3	<0.1	<0.1	<0.1
-	7	<20	46	-	-	<1	<1	<0.7	<0.3	<0.3	<0.1	0.1	<0.1
-	7	<20	26	-	-	<1	<1	<0.7	<0.3	<0.3	<0.1	<0.1	<0.1
-	7	<20	23	-	-	<1	<1	<0.7	<0.3	<0.3	<0.1	<0.1	<0.1
-	7	<20	25	-	-	<1	<1	<0.7	<0.3	<0.3	<0.1	<0.1	<0.1
-	7	<20	35	-	-	<1	<1	<0.7	<0.3	<0.3	<0.1	<0.1	<0.1
-	7	<20	33	-	-	<1	<1	<0.7	<0.3	<0.3	<0.1	<0.1	<0.1
-	7	<20	28	-	-	<1	<1	<0.7	<0.3	<0.3	<0.1	<0.1	<0.1
-	8	<20	33	-	-	<1	<1	<0.7	<0.3	<0.3	<0.1	<0.1	<0.1
-	8	<20	25	-	-	<1	<1	<0.7	<0.3	<0.3	<0.1	<0.1	<0.1
-	8	<20	32	-	-	<1	<1	<0.7	<0.3	<0.3	<0.1	<0.1	<0.1
-	7	<20	69	-	-	<1	<1	<0.7	<0.3	<0.3	<0.1	<0.1	<0.1
-	7	<20	38	-	-	<1	<1	<0.7	<0.3	<0.3	<0.1	<0.1	<0.1
-	7	<20	38	<0.1	<0.1	<1	<1	<0.7	<0.3	<0.3	<0.1	<0.1	<0.1
-	7	<20	34	<0.1	<0.1	<1	<1	<0.7	<0.3	<0.3	<0.1	<0.1	<0.1
-	7	<20	29	-	-	<1	<1	<0.7	<0.3	<0.3	<0.1	<0.1	<0.1
-	6	<20	23	-	-	<1	<1	<0.7	<0.3	<0.3	<0.1	<0.1	<0.1

TABLE I
ANALYTICAL RESULTS FOR SOILS COLLECTED A

Samples number	Date	Depth (cm)	Comp											
			Metals											
			Al	Ag	Ba	Cd	Cr	Co	Cu	Sn	Fe	Hg	Mo	Ni
CCME criteria														
Agriculture			-	20	750	3	750	40	150	-	-	0,8	5	150
Residential/Parkland			-	20	500	5	250	50	100	-	-	2	10	100
Commercial/Industrial			-	40	2 000	20	800	300	500	-	-	10	40	500
89104701S	Feb. 1995	0-10	7 050	-	-	-	-	-	8	-	8 400	-	-	7
89084713P	Feb. 1995	30	7 900	-	-	-	-	-	<5	-	9 600	-	-	8
89084710S	Feb. 1995	0-10	6 950	-	-	-	-	-	6	-	8 450	-	-	7
89084710P	Feb. 1995	30	8 350	-	-	-	-	-	7	-	9 800	-	-	7
89084707P	Feb. 1995	30	8 100	-	-	-	-	-	<5	-	9 950	-	-	8
89074704S	Feb. 1995	0-10	7 850	-	-	-	-	-	<5	-	9 400	-	-	7
89074704P	Feb. 1995	30	7 900	-	-	-	-	-	<5	-	9 900	-	-	8
89074702P	Feb. 1995	30	7 350	-	-	-	-	-	<5	-	8 650	-	-	7
89054710P	Feb. 1995	30	7 700	-	-	-	-	-	<5	-	9 200	-	-	7
89054707S	Feb. 1995	0-10	8 000	-	-	-	-	-	<5	-	9 500	-	-	7
89054707P	Feb. 1995	30	8 150	-	-	-	-	-	5	-	9 650	-	-	8
89054708S	Feb. 1995	0-10	8 700	-	-	-	-	-	<5	-	10 600	-	-	8
89054708P	Feb. 1995	30	8 250	-	-	-	-	-	<5	-	9 900	-	-	8
89044704P	Feb. 1995	30	8 400	-	-	-	-	-	11	-	9 850	-	-	7
89044702S	Feb. 1995	0-10	7 800	-	-	-	-	-	12	-	8 900	-	-	7
88994712P	Feb. 1995	30	7 850	-	-	-	-	-	<5	-	9 050	-	-	7
88984706P	Feb. 1995	30	8 550	-	-	-	-	-	6	-	9 850	-	-	8
88974715S	Feb. 1995	0-10	7 950	-	-	-	-	-	<5	-	9 850	-	-	7
88974715P	Feb. 1995	30	7 550	-	-	-	-	-	<5	-	8 900	-	-	7
88974703S	Feb. 1995	0-10	8 050	-	-	-	-	-	<5	-	9 250	-	-	10
88974703P	Feb. 1995	30	8 250	-	-	-	-	-	<5	-	9 050	-	-	8
MS1-1M	Feb. 1995	100	7 950	-	-	-	-	-	<5	-	9 150	-	-	8
MS1-2M	Feb. 1995	200	8 050	-	-	-	-	-	10	-	9 300	-	-	8
MS1-3M	Feb. 1995	300	8 650	-	-	-	-	-	<5	-	9 700	-	-	9
MS1-4M	Feb. 1995	400	8 050	-	-	-	-	-	<5	-	10 000	-	-	8
MS1-5M	Feb. 1995	500	9 550	-	-	-	-	-	<5	-	10 500	-	-	11
MS2-1M	Feb. 1995	100	8 050	-	-	-	-	-	<5	-	8 950	-	-	7
MS2-2M	Feb. 1995	200	8 950	-	-	-	-	-	<5	-	9 450	-	-	8
MS2-2MD	Feb. 1995	200	9 750	-	-	-	-	-	<5	-	11 400	-	-	8
MS2-3M	Feb. 1995	300	9 700	-	-	-	-	-	<5	-	11 700	-	-	11
MS2-4M	Feb. 1995	400	9 300	-	-	-	-	-	<5	-	9 200	-	-	8
MS2-5M	Feb. 1995	500	9 050	-	-	-	-	-	<5	-	10 400	-	-	9

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TABLE I
OILS COLLECTED AT CFAD DUNDURN

Compounds (mg/kg)						Phenolic compounds (1)	Energetic materials					PAHs	MAVCs (3)(4)(5)	CHs (6)
Fe	Hg	Mo	Ni	Pb	Zn		HMX	RDX	Tetryl	TNT	Other (2)			
-	0.8	5	150	375	600	-	-	-	-	-	-	-	-	-
-	2	10	100	500	500	(7)	-	-	-	-	-	(7)	(7)	(7)
-	10	40	500	1 000	1 500	-	-	-	-	-	-	-	-	-
8 400	-	-	7	<20	32	-	<1	<1	<0.7	<0.3	<0.3	<0.1	<0.1	<0.1
9 600	-	-	8	<20	24	-	<1	<1	<0.7	<0.3	<0.3	<0.1	<0.1	<0.1
8 450	-	-	7	<20	28	-	<1	<1	<0.7	<0.3	<0.3	<0.1	<0.1	<0.1
9 800	-	-	7	<20	28	-	<1	<1	<0.7	<0.3	<0.3	<0.1	<0.1	<0.1
9 950	-	-	8	<20	32	-	<1	<1	<0.7	<0.3	<0.3	<0.1	<0.1	<0.1
9 400	-	-	7	<20	41	<0.1	<1	<1	<0.7	<0.3	<0.3	<0.1	<0.1	<0.1
9 900	-	-	8	<20	24	<0.1	<1	<1	<0.7	<0.3	<0.3	<0.1	<0.1	<0.1
8 650	-	-	7	<20	19	-	<1	<1	<0.7	<0.3	<0.3	<0.1	<0.1	<0.1
9 200	-	-	7	<20	25	-	<1	<1	<0.7	<0.3	<0.3	<0.1	<0.1	<0.1
9 500	-	-	7	<20	27	-	<1	<1	<0.7	<0.3	<0.3	<0.1	<0.1	<0.1
9 650	-	-	8	<20	29	-	<1	<1	<0.7	<0.3	<0.3	<0.1	<0.1	<0.1
10 600	-	-	8	<20	27	-	<1	<1	<0.7	<0.3	<0.3	<0.1	<0.1	<0.1
9 900	-	-	8	<20	23	-	<1	<1	<0.7	<0.3	<0.3	<0.1	<0.1	<0.1
9 850	-	-	7	<20	35	-	<1	<1	<0.7	<0.3	<0.3	<0.1	<0.1	<0.1
8 900	-	-	7	<20	27	-	<1	<1	<0.7	<0.3	<0.3	<0.1	<0.1	<0.1
9 050	-	-	7	<20	22	-	<1	<1	<0.7	<0.3	<0.3	<0.1	<0.1	<0.1
9 850	-	-	8	<20	26	-	<1	<1	<0.7	<0.3	<0.3	<0.1	<0.1	<0.1
9 850	-	-	7	<20	25	-	<1	<1	<0.7	<0.3	<0.3	<0.1	<0.1	<0.1
8 900	-	-	7	<20	23	-	<1	<1	<0.7	<0.3	<0.3	<0.1	<0.1	<0.1
9 250	-	-	10	<20	23	-	<1	<1	<0.7	<0.3	<0.3	<0.1	<0.1	<0.1
9 050	-	-	8	<20	22	-	<1	<1	<0.7	<0.3	<0.3	<0.1	<0.1	<0.1
9 150	-	-	8	<20	23	-	<1	<1	<0.7	<0.3	<0.3	<0.1	<0.1	<0.1
9 300	-	-	8	<20	30	-	<1	<1	<0.7	<0.3	<0.3	<0.1	<0.1	<0.1
9 700	-	-	9	<20	24	-	<1	<1	<0.7	<0.3	<0.3	<0.1	<0.1	<0.1
10 000	-	-	8	<20	24	<0.1	<1	<1	<0.7	<0.3	<0.3	<0.1	<0.1	<0.1
10 500	-	-	11	<20	24	-	<1	<1	<0.7	<0.3	<0.3	<0.1	<0.1	<0.1
8 950	-	-	7	<20	21	-	<1	<1	<0.7	<0.3	<0.3	<0.1	<0.1	<0.1
9 450	-	-	8	<20	29	-	<1	<1	<0.7	<0.3	<0.3	<0.1	<0.1	<0.1
11 400	-	-	8	<20	36	-	<1	<1	<0.7	<0.3	<0.3	<0.1	<0.1	<0.1
11 700	-	-	11	<20	27	-	<1	<1	<0.7	<0.3	<0.3	<0.1	<0.1	<0.1
9 200	-	-	8	<20	19	-	<1	<1	<0.7	<0.3	<0.3	<0.1	<0.1	<0.1
10 400	-	-	9	<20	24	<0.1	<1	<1	<0.7	<0.3	<0.3	<0.1	<0.1	<0.1

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TABLE I
ANALYTICAL RESULTS FOR SOILS COLLECTED AT CFA

Samples number	Date	Depth (cm)	Compounds (mg/kg)												
			Metals												
			Al	Ag	Ba	Cd	Cr	Co	Cu	Sn	Fe	Hg	Mo	Ni	Pb
CCME criteria															
Agriculture			-	20	750	3	750	40	150	-	-	0,8	5	150	375
Residential/Parkland			-	20	500	5	250	50	100	-	-	2	10	100	500
Commercial/Industrial			-	40	2 000	20	800	300	500	-	-	10	40	500	1 000
MS3-1M	Feb. 1995	100	7 600	-	-	-	-	-	5	-	9 450	-	-	7	<20
MS3-2M	Feb. 1995	200	9 200	-	-	-	-	-	36	-	10 000	-	-	18	<20
MS3-3M	Feb. 1995	300	8 800	-	-	-	-	-	8	-	9 250	-	-	8	<20
MS3-4M	Feb. 1995	400	9 250	-	-	-	-	-	<5	-	10 800	-	-	8	<20
MS3-4MD	Feb. 1995	400	8 450	-	-	-	-	-	<5	-	9 900	-	-	8	<20
MS3-5M	Feb. 1995	500	9 050	-	-	-	-	-	<5	-	11 100	-	-	9	<20
MS4-1M	Feb. 1995	100	8 050	-	-	-	-	-	54	-	9 550	-	-	8	<20
MS4-2M	Feb. 1995	200	8 100	-	-	-	-	-	39	-	9 600	-	-	8	<20
MS4-3M	Feb. 1995	300	8 550	-	-	-	-	-	48	-	10 000	-	-	8	<20
MS4-4M	Feb. 1995	400	8 900	-	-	-	-	-	7	-	10 600	-	-	9	<20
MS4-5M	Feb. 1995	500	8 800	-	-	-	-	-	5	-	11 300	-	-	8	<20
89044704-1ME	Feb. 1995	0-15	8 025	-	-	-	-	-	11	-	9 950	-	-	10	<20
89044704P-1MO	Feb. 1995	30	8 150	-	-	-	-	-	13	-	9 850	-	-	21	<20
Blank #1	Feb. 1995	0-30	7 550	-	-	-	-	-	<5	-	9 600	-	-	8	<20
Blank #2	Feb. 1995	0-30	7 300	-	-	-	-	-	5	-	9 450	-	-	7	<20
Blank #3	Feb. 1995	0-30	7 850	-	-	-	-	-	8	-	10 200	-	-	7	<20
Blank #5	Feb. 1995	0-30	8 000	-	-	-	-	-	<5	-	10 100	-	-	8	<20
90144711P (89...Dup.)	Feb. 1995	30	8 300	-	-	-	-	-	22	-	10 100	-	-	8	<20
90104703P (89...Dup.)	Feb. 1995	30	8 400	-	-	-	-	-	8	-	9 600	-	-	8	<20
90074702P (89...Dup.)	Feb. 1995	30	6 850	-	-	-	-	-	<5	-	8 700	-	-	8	<20
90054710P (89...Dup.)	Feb. 1995	30	7 700	-	-	-	-	-	<5	-	9 500	-	-	8	<20
90974715P (88...Dup.)	Feb. 1995	30	7 550	-	-	-	-	-	<5	-	9 400	-	-	7	<20
90044704P-1ME (89...)	Feb. 1995	30	7 700	-	-	-	-	-	11	-	9 375	-	-	8	<20
P1 10-15	Nov. 1995	305-460	-	-	-	-	-	-	-	-	-	-	-	-	-
P1 20-25	Nov. 1995	610-760	-	-	-	-	-	-	-	-	-	-	-	-	-
P1 30-35	Nov. 1995	915-1070	-	-	-	-	-	-	-	-	-	-	-	-	-
P1 45-50	Nov. 1995	1370-1525	-	-	-	-	-	-	-	-	-	-	-	-	-
P2 0-5	Nov. 1995	0-150	-	-	-	-	-	-	-	-	-	-	-	-	-
P2 10-15	Nov. 1995	305-460	-	-	-	-	-	-	-	-	-	-	-	-	-
P2 20-22.5	Nov. 1995	610-685	-	-	-	-	-	-	-	-	-	-	-	-	-
P2 22.5-25	Nov. 1995	685-760	-	-	-	-	-	-	-	-	-	-	-	-	-
P2 25-30	Nov. 1995	760-915	-	-	-	-	-	-	-	-	-	-	-	-	-

ATED AT CFAD DUNDURN

Compounds (mg/kg)												
Mo	Ni	Pb	Zn	Phenolic compounds (1)	Energetic materials					PAHs	MAVCs (3)(4)(5)	CHs (6)
					HMX	RDX	Tetryl	TNT	Other (2)			
5	150	375	600		-	-	-	-	-			
10	100	500	500	(7)	-	-	-	-	-	(7)	(7)	(7)
40	500	1 000	1 500		-	-	-	-	-			
-	7	<20	24	-	<1	<1	<0.7	<0.3	<0.3	<0.1	<0.1	<0.1
-	18	<20	43	-	<1	<1	<0.7	0.5	<0.3	<0.1	<0.1	<0.1
-	8	<20	23	<0.1	<1	<1	<0.7	<0.3	<0.3	<0.1	<0.1	<0.1
-	8	<20	21	-	<1	3.3	<0.7	<0.3	<0.3	<0.1	<0.1	<0.1
-	8	<20	24	-	<1	<1	<0.7	<0.3	<0.3	<0.1	<0.1	<0.1
-	9	<20	24	-	<1	0.7	<0.7	<0.3	<0.3	<0.1	<0.1	<0.1
-	8	<20	23	-	<1	8.6	<0.7	2.7	<0.3	<0.1	<0.1	<0.1
-	8	<20	27	<0.1	<1	7.4	<0.7	2.9	<0.3	<0.1	<0.1	<0.1
-	8	<20	55	-	<1	35.5	2.3	13.0	<0.3	<0.1	<0.1	<0.1
-	9	<20	53	-	<1	10.9	<0.7	3.8	<0.3	<0.1	<0.1	<0.1
-	8	<20	25	-	<1	16.4	<0.7	13.7	<0.3	<0.1	<0.1	<0.1
-	10	<20	31	-	<1	<1	<0.7	<0.3	<0.3	<0.1	<0.1	<0.1
-	21	<20	44	-	<1	<1	<0.7	<0.3	<0.3	<0.1	<0.1	<0.1
-	8	<20	21	-	<1	<1	<0.7	<0.3	<0.3	<0.1	<0.1	<0.1
-	7	<20	21	-	<1	<1	<0.7	<0.3	<0.3	<0.1	<0.1	<0.1
-	7	<20	24	-	<1	<1	<0.7	<0.3	<0.3	<0.1	<0.1	<0.1
-	8	<20	27	-	<1	<1	<0.7	<0.3	<0.3	<0.1	<0.1	<0.1
-	8	<20	42	-	<1	<1	<0.7	<0.3	<0.3	<0.1	<0.1	<0.1
-	8	<20	28	-	<1	<1	<0.7	<0.3	<0.3	<0.1	<0.1	<0.1
-	8	<20	20	-	<1	<1	<0.7	<0.3	<0.3	<0.1	<0.1	<0.1
-	8	<20	23	-	<1	<1	<0.7	<0.3	<0.3	<0.1	<0.1	<0.1
-	7	<20	20	-	<1	<1	<0.7	<0.3	<0.3	<0.1	<0.1	<0.1
-	8	<20	28	-	<1	<1	<0.7	<0.3	<0.3	<0.1	<0.1	<0.1
-	-	-	-	-	0.4	<1	-	<0.3	-	-	-	-
-	-	-	-	-	<1	<1	-	<0.3	-	-	-	-
-	-	-	-	-	<1	<1	-	0.3	-	-	-	-
-	-	-	-	-	<1	<1	-	0.2	-	-	-	-
-	-	-	-	-	<1	<1	-	<0.3	-	-	-	-
-	-	-	-	-	<1	<1	-	<0.3	-	-	-	-
-	-	-	-	-	<1	<1	-	<0.3	-	-	-	-
-	-	-	-	-	<1	<1	-	<0.3	-	-	-	-
-	-	-	-	-	<1	<1	-	<0.3	-	-	-	-
-	-	-	-	-	<1	<1	-	<0.3	-	-	-	-

TABLE I
ANALYTICAL RESULTS FOR SOILS COLLECTED A

Samples number	Date	Depth (cm)	Comp											
			Metals											
			Al	Ag	Ba	Cd	Cr	Co	Cu	Sn	Fe	Hg	Mo	N
CCME criteria														
Agriculture			-	20	750	3	750	40	150	-	-	0,8	5	15
Residential/Parkland			-	20	500	5	250	50	100	-	-	2	10	10
Commercial/Industrial			-	40	2 000	20	800	300	500	-	-	10	40	50
P2 35-40	Nov. 1995	1070-1220	-	-	-	-	-	-	-	-	-	-	-	-
P3 0-5	Nov. 1995	0-150	-	-	-	-	-	-	-	-	-	-	-	-
P3 10-15	Nov. 1995	305-460	-	-	-	-	-	-	-	-	-	-	-	-
P3 20-25	Nov. 1995	610-760	-	-	-	-	-	-	-	-	-	-	-	-
P3 30-35	Nov. 1995	915-1070	-	-	-	-	-	-	-	-	-	-	-	-
P3 40-45	Nov. 1995	1220-1370	-	-	-	-	-	-	-	-	-	-	-	-
P4 0-5	Nov. 1995	0-150	-	-	-	-	-	-	-	-	-	-	-	-
P4 10-15	Nov. 1995	305-460	-	-	-	-	-	-	-	-	-	-	-	-
P4 20-25	Nov. 1995	610-760	-	-	-	-	-	-	-	-	-	-	-	-
P4 30-35	Nov. 1995	915-1070	-	-	-	-	-	-	-	-	-	-	-	-
P4 40-45	Nov. 1995	1220-1370	-	-	-	-	-	-	-	-	-	-	-	-
P5 0-5	Nov. 1995	0-150	-	-	-	-	-	-	-	-	-	-	-	-
P5 10-15	Nov. 1995	305-460	-	-	-	-	-	-	-	-	-	-	-	-
P5 20-25	Nov. 1995	610-760	-	-	-	-	-	-	-	-	-	-	-	-
P5 30-35	Nov. 1995	915-1070	-	-	-	-	-	-	-	-	-	-	-	-
P5 40-45	Nov. 1995	1220-1370	-	-	-	-	-	-	-	-	-	-	-	-
P6 0-5	Nov. 1995	0-150	-	-	-	-	-	-	-	-	-	-	-	-
P6 10-15	Nov. 1995	305-460	-	-	-	-	-	-	-	-	-	-	-	-
P6 20-25	Nov. 1995	610-760	-	-	-	-	-	-	-	-	-	-	-	-
P6 30-35	Nov. 1995	915-1070	-	-	-	-	-	-	-	-	-	-	-	-
P7 0-5	Nov. 1995	0-150	-	-	-	-	-	-	-	-	-	-	-	-
P7 10-15	Nov. 1995	305-460	-	-	-	-	-	-	-	-	-	-	-	-
P7 20-25	Nov. 1995	610-760	-	-	-	-	-	-	-	-	-	-	-	-
P7 30-35	Nov. 1995	915-1070	-	-	-	-	-	-	-	-	-	-	-	-
P8 5-10	Nov. 1995	150-305	-	-	-	-	-	-	-	-	-	-	-	-
P8 25-30	Nov. 1995	760-915	-	-	-	-	-	-	-	-	-	-	-	-
L3A 05-07 & 07-11	Dec. 1996	150-335	-	<2	70	<1	8	3	15	<2	-	<0.02	<2	11
L3B 0-3	Dec. 1996	0-90	-	<2	66	<1	7	3	16	<2	-	<0.02	<2	11
L3B 6-9.6	Dec. 1996	180-290	-	<2	86	3	7	4	160	<2	-	<0.02	<2	16
L3C 0-3	Dec. 1996	0-90	-	<2	72	1	7	3	36	<2	-	<0.02	<2	11
L3C 0-3 Duplicate	Dec. 1996	0-90	-	-	-	-	-	-	-	-	-	<0.02	-	-
L3C 6-9	Dec. 1996	180-275	-	<2	95	<1	8	4	48	<2	-	<0.02	<2	14

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TABLE I
S COLLECTED AT CFAD DUNDURN

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2

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TABLE I
ANALYTICAL RESULTS FOR SOILS COLLECTED AT CFA

Samples number	Date	Depth (cm)	Compounds (												
			Metals												
			Al	Ag	Ba	Cd	Cr	Co	Cu	Sn	Fe	Hg	Mo	Ni	Pb
CCME criteria															
Agriculture			-	20	750	3	750	40	150	-	-	0.8	5	150	375
Residential/Parkland			-	20	500	5	250	50	100	-	-	2	10	100	500
Commercial/Industrial			-	40	2 000	20	800	300	500	-	-	10	40	500	1 000
L3C 15-16.9	Dec. 1996	460-510	-	<2	110	<1	7	4	15	<2	-	<0.02	<2	12	<25
L4A 0-3	Dec. 1996	0-90	-	<2	73	<1	10	4	29	<2	-	<0.02	<2	11	<25
L4B 0-3	Dec. 1996	0-90	-	<2	81	<1	10	4	29	<2	-	<0.02	<2	13	<25
L4B 3-4.5	Dec. 1996	90-135	-	<2	97	1	10	4	64	<2	-	<0.02	<2	12	<25
L4B 3-4.5 Duplicate	Dec. 1996	90-135	-	-	-	-	-	-	-	-	-	-	-	-	-
L4B 4.5-5.5	Dec. 1996	135-165	-	<2	69	<1	10	4	39	<2	-	<0.02	<2	13	<25
L4B 4.5-5.5 Duplicate	Dec. 1996	135-165	-	-	-	-	-	-	-	-	-	-	-	-	-
L4B 9-10.8	Dec. 1996	275-325	-	<2	110	<1	10	5	28	<2	-	<0.02	<2	14	<25
L4C 0-3	Dec. 1996	0-90	-	<2	79	<1	10	4	32	<2	-	<0.02	<2	12	<25
L4C 3.5-4.5	Dec. 1996	105-135	-	<2	90	<1	8	4	40	<2	-	<0.02	<2	11	<25
L4C 6-8.5	Dec. 1996	180-260	-	<2	90	<1	9	4	31	<2	-	<0.02	<2	13	<25
L4C 6-8.5 Duplicate	Dec. 1996	180-260	-	<2	84	<1	8	4	26	<2	-	<0.02	<2	12	<25
L4C 12-14	Dec. 1996	365-425	-	<2	130	<1	10	5	17	<2	-	<0.02	<2	15	<25
S3A	Dec. 1996	0-100	-	<2	76	1	12	4	42	<2	-	<0.02	<2	15	<25
S3A Duplicate	Dec. 1996	0-100	-	-	-	-	-	-	-	-	-	-	-	-	-
S3B	Dec. 1996	0-100	-	<2	72	<1	10	4	26	<2	-	<0.02	<2	11	<25
S3C	Dec. 1996	0-100	-	<2	81	<1	12	4	23	<2	-	<0.02	<2	13	<25
S3D	Dec. 1996	0-100	-	<2	80	<1	10	4	30	<2	-	<0.02	<2	13	<25
S4A	Dec. 1996	0-100	-	<2	79	<1	11	4	16	<2	-	<0.02	<2	12	<25
S4B	Dec. 1996	0-100	-	<2	76	1	14	4	43	<2	-	<0.02	<2	12	<25
S4B Duplicate	Dec. 1996	0-100	-	-	-	-	-	-	-	-	-	<0.02	-	-	-
S4C	Dec. 1996	0-100	-	<2	75	1	10	4	52	<2	-	<0.02	<2	12	<25
S4C Duplicate	Dec. 1996	0-100	-	-	-	-	-	-	-	-	-	-	-	-	-
S4D	Dec. 1996	0-100	-	<2	79	1	9	4	110	<2	-	<0.02	<2	13	<25
S4E	Dec. 1996	0-100	-	<2	80	<1	11	4	36	<2	-	<0.02	<2	13	<25
Composite P3	Dec. 1996	0-15	-	<2	75	1	8	4	32	2	-	<0.02	<2	13	30
Crater Comp. 50MW P3	Dec. 1996	0-30	-	<2	75	1	7	4	18	<2	-	<0.02	<2	12	<25
P4 0-5	Dec. 1996	0-150	-	<2	82	2	8	4	79	<2	-	<0.02	<2	14	<25
P4 5-10	Dec. 1996	150-305	-	<2	77	2	8	4	84	<2	-	<0.02	<2	13	<25
P4 10M West	Dec. 1996	0-30	-	<2	77	2	9	4	29	<2	-	<0.02	<2	14	<25
P4 10M West Duplicate	Dec. 1996	0-30	-	<2	78	2	10	4	49	<2	-	-	<2	14	<25
P4 50M Sud	Dec. 1996	0-30	-	<2	72	1	8	3	20	<2	-	<0.02	<2	12	<25

ECTED AT CFAD DUNDURN

Compounds (mg/kg)					Phenolic compounds (1)	Energetic materials					PAHs	MAVCs (3)(4)(5)	CHs (6)
				HMX		RDX	Tetryl	TNT	Other (2)				
Mo	Ni	Pb	Zn										
5	150	375	600		-	-	-	-	-				
10	100	500	500	(7)	-	-	-	-	-	(7)	(7)	(7)	
40	500	1 000	1 500		-	-	-	-	-				
2	<2	12	<25	28	-	<1	<1	<0.7	<0.3	<0.3	<0.1	-	-
2	<2	11	<25	32	-	<1	<1	<0.7	<0.3	<0.3	<0.1	-	-
2	<2	13	<25	34	-	<1	<1	<0.7	<0.3	<0.3	<0.1	-	-
2	<2	12	<25	70	-	<1	<1	<0.7	<0.3	<0.3	<0.1	-	-
	-	-	-	-	-	-	-	-	-	-	<0.1	-	-
2	<2	13	<25	34	-	<1	<1	<0.7	<0.3	<0.3	<0.1	-	-
	-	-	-	-	-	<1	<1	<0.7	<0.3	<0.3	-	-	-
2	<2	14	<25	33	-	<1	<1	<0.7	<0.3	<0.3	<0.1	-	-
2	<2	12	<25	34	-	<1	<1	<0.7	<0.3	<0.3	<0.1	-	-
2	<2	11	<25	52	-	<1	<1	<0.7	<0.3	<0.3	<0.1	-	-
2	<2	13	<25	32	-	<1	<1	<0.7	<0.3	<0.3	<0.1	-	-
2	<2	12	<25	30	-	-	-	-	-	-	-	-	-
2	<2	15	<25	33	-	<1	<1	<0.7	<0.3	<0.3	<0.1	-	-
2	<2	15	<25	46	-	<1	<1	<0.7	<0.3	<0.3	<0.1	-	-
	-	-	-	-	-	-	-	-	-	-	<0.1	-	-
2	<2	11	<25	31	-	<1	<1	<0.7	<0.3	<0.3	<0.1	-	-
2	<2	13	<25	32	-	<1	<1	<0.7	<0.3	<0.3	<0.1	-	-
2	<2	13	<25	38	-	<1	<1	<0.7	<0.3	<0.3	<0.1	-	-
2	<2	12	<25	30	-	<1	<1	<0.7	<0.3	<0.3	<0.1	-	-
2	<2	12	<25	43	-	<1	<1	<0.7	<0.3	<0.3	<0.1	-	-
2	-	-	-	-	-	-	-	-	-	-	-	-	-
2	<2	12	<25	51	-	<1	<1	<0.7	<0.3	<0.3	<0.1	-	-
	-	-	-	-	-	<1	<1	<0.7	<0.3	<0.3	-	-	-
2	<2	13	<25	80	-	<1	<1	<0.7	<0.3	<0.3	<0.1	-	-
2	<2	13	<25	83	-	<1	<1	39	<0.3	<0.3	<0.1	-	-
2	<2	13	30	60	-	<1	<1	<0.7	<0.3	<0.3	0.11	-	-
2	<2	12	<25	39	-	<1	<1	<0.7	<0.3	<0.3	0.39	-	-
2	<2	14	<25	120	-	<1	<1	<0.7	0.7	<0.3	<0.1	-	-
2	<2	13	<25	120	-	<1	<1	<0.7	<0.3	<0.3	<0.1	-	-
2	<2	14	<25	72	-	<1	<1	<0.7	<0.3	<0.3	2.03	-	-
	<2	14	<25	71	-	-	-	-	-	-	1.66	-	-
2	<2	12	<25	39	-	<1	<1	<0.7	0.7	<0.3	2.79	-	-

TABLE I
ANALYTICAL RESULTS FOR SOILS COLLECTED

Samples number	Date	Depth (cm)	Com											
			Metals											
			Al	Ag	Ba	Cd	Cr	Co	Cu	Sn	Fe	Hg	Mo	
CCME criteria														
Agriculture			-	20	750	3	750	40	150	-	-	0,8	5	1
Residential/Parkland			-	20	500	5	250	50	100	-	-	2	10	10
Commercial/Industrial			-	40	2 000	20	800	300	500	-	-	10	40	50
P4 50M SW	Dec. 1996	0-30	-	<2	76	1	10	4	32	<2	-	<0.02	<2	1
Composite P4	Dec. 1996	0-15	-	<2	74	2	7	4	23	<2	-	<0.02	<2	1
50M MNW P5	Dec. 1996	0-30	-	<2	82	1	9	4	25	<2	-	<0.02	<2	1
Composite P5	Dec. 1996	0-15	-	<2	80	1	9	4	32	<2	-	<0.02	<2	1
Composite P5 Duplicate	Dec. 1996	0-15	-	-	-	-	-	-	-	-	-	<0.02	-	
P15 0-5	Dec. 1996	0-150	-	<2	88	<1	9	4	26	<2	-	<0.02	<2	1
Composite P15	Dec. 1996	0-15	-	<2	70	2	8	3	21	<2	-	<0.02	<2	1

Legend

160

: concentration in excess of residential/parkland criterion (CCME)

-: no data available.

CHs: Chlorinated Hydrocarbons.

HMX: octahydro-1,3,5,7-tetranitro-1,3,5,7-tetrazocine.

MAVCs: Monocyclic Aromatic Volatile Compounds.

PAHs: Polycyclic Aromatic Hydrocarbons.

RDX: hexahydro-1,3,5-trinitro-1,3,5-triazine.

Tetryl: trinitrophenyl-n-methylnitramine.

TNT: 2,4,6-trinitrotoluene.

Notes

1: Usual detection limits for 2-methyl-4,6-dinitrophenol and 2,4-dinitrophenol: <2 et <5, respectively.

2: Covers 1,3,5-trinitrobenzene, 1,3-dinitrobenzene, nitrobenzene, 4-amino-2,6-dinitrobenzene, 2-amino-4,6-dinitrotoluene, 2,6-dinitrotoluene, 2,4-dinitrotoluene, 2-nitrotoluene, 4-nitrotoluene and 3-nitrotoluene.

3: Styrene is the detected compound in samples PF1-40M, PF2-20M and PF2-40M.

4: Benzene is the detected compound in sample 89144711P.

5: Usual detection limit for toluene et m+p-xylenes: <0.2.

6: Usual detection limit for dichloromethane and chloroform: <5 et <0.2, respectively.

7: No criteria established for compounds summation

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TABLE I
OILS COLLECTED AT CFAD DUNDURN

Compounds (mg/kg)						Phenolic compounds (1)	Energetic materials					PAHs	MAVCs (3)(4)(5)	CHs (6)
Fe	Hg	Mo	Ni	Pb	Zn		HMX	RDX	Tetryl	TNT	Other (2)			
-	0.8	5	150	375	600	-	-	-	-	-	-	-	-	-
-	2	10	100	500	500	(7)	-	-	-	-	-	(7)	(7)	(7)
-	10	40	500	1 000	1 500	-	-	-	-	-	-	-	-	-
-	<0.02	<2	14	<25	65	-	<1	<1	<0.7	<0.3	<0.3	2.48	-	-
-	<0.02	<2	12	<25	68	-	<1	<1	<0.7	<0.3	<0.3	0.28	-	-
-	<0.02	<2	13	<25	69	-	<1	<1	<0.7	<0.3	<0.3	0.28	-	-
-	<0.02	<2	13	<25	360	-	<1	<1	<0.7	<0.3	0.4	<0.1	-	-
-	<0.02	-	-	-	-	-	<1	<1	2.9	0.7	<0.3	-	-	-
-	<0.02	<2	14	<25	36	-	<1	<1	<0.7	<0.3	<0.3	<0.1	-	-
-	<0.02	<2	12	<25	48	-	<1	<1	<0.7	<0.3	<0.3	2.15	-	-

nitrotoluene,

2

TABLE II
ANALYTICAL RESULTS FOR GROUNDWATER COLLECTED AT CFAD DUNDURN

Samples number	Date	COMPOUNDS (ug/l)														Energetic materials		
		Ag	Ba	Cd	Cr	Co	Cu	Sn	Hg	Mo	Ni	Pb	Zn	HMX	RDX	TNT		
CCME criteria																		
Freshwater Aquatic Life		0.1	-	0.2-1.8	2-20	-	2-4	-	0.1	-	25-150	1-7	30	-	-	-	-	
Irrigation		-	-	10	100	50	200-1000	-	-	10-50	200	200	1000-5000	-	-	-	-	
Livestock Watering		-	-	20	1000	1000	500-5000	-	3	500	1000	100	50000	-	-	-	-	
Drinking Water		-	1000	5	50	-	1000	-	1	-	-	10	5000	-	-	-	-	
P1A	nov-95	-	-	-	-	-	-	-	-	-	-	-	-	<0.3	5.3	2.0	<0.3	
P1A	April 96	-	-	-	-	-	-	-	-	-	-	-	-	<0.3	4.9	<0.3	<0.3	
P1A	sept-96	-	-	-	-	-	-	-	-	-	-	-	-	<0.3	<0.3	<0.3	<0.3	
P1A	Dec 96*	-	-	-	-	-	-	-	-	-	-	-	-	-	<0.5	<0.5	<0.5	
P1B	nov-95	-	-	-	-	-	-	-	-	-	-	-	-	2.2	5.1	<0.3	<0.3	
P1B	April 96	-	-	-	-	-	-	-	-	-	-	-	-	<0.3	3.6	<0.3	<0.3	
P1B	sept-96	-	-	-	-	-	-	-	-	-	-	-	-	<0.3	<0.3	<0.3	<0.3	
P1B	Dec 96*	-	-	-	-	-	-	-	-	-	-	-	-	-	<0.5	<0.5	<0.5	
P2A	nov-95	-	-	-	-	-	-	-	-	-	-	-	-	<0.3	0.8	1.6	<0.3	
P2A	April 96	-	-	-	-	-	-	-	-	-	-	-	-	<0.3	0.5	<0.3	<0.3	
P2A	sept-96	-	-	-	-	-	-	-	-	-	-	-	-	<0.3	<0.3	<0.3	<0.3	
P2A	Dec 96*	-	-	-	-	-	-	-	-	-	-	-	-	-	<0.5	<0.5	<0.5	
P2B	nov-95	-	-	-	-	-	-	-	-	-	-	-	-	<0.3	1.7	<0.3	<0.3	
P2B	April 96	-	-	-	-	-	-	-	-	-	-	-	-	<0.3	<0.3	<0.3	<0.3	
P2B	sept-96	-	-	-	-	-	-	-	-	-	-	-	-	<0.3	<0.3	<0.3	<0.3	
P2B	Dec 96*	-	-	-	-	-	-	-	-	-	-	-	-	<0.3	<0.3	<0.3	<0.3	
P3A	nov-95	-	-	-	-	-	-	-	-	-	-	-	-	-	<0.5	<0.5	<0.5	
P3A	April 96	-	-	-	-	-	-	-	-	-	-	-	-	5.7	5.6	<0.3	<0.3	
P3A	sept-96	-	-	-	-	-	-	-	-	-	-	-	-	2.9	3.4	<0.3	<0.3	
P3A	déc-96	<5	790	<1	<5	<10	<20	<10	<0.2	<5	<10	<10	10	<0.3	6.6	<0.3	<0.3	
P3A	Dec 96*	-	-	-	-	-	-	-	-	-	-	-	-	<0.3	<0.3	<0.3	<0.3	
P3B	nov-95	-	-	-	-	-	-	-	-	-	-	-	-	-	25-40	<0.5	<0.5	
P3B	April 96	-	-	-	-	-	-	-	-	-	-	-	-	0.9	77.9	2.7	<0.3	
P3B	sept-96	-	-	-	-	-	-	-	-	-	-	-	-	0.9	120.8	1.9	<0.3	
P3B	déc-96	<5	300	<1	<5	<10	<20	<10	<0.2	<5	<10	<10	10	<0.3	79.2	<0.3	<0.3	

TABLE II
ANALYTICAL RESULTS FOR GROUNDWATER COLLECTED AT CFAD DUNDURN

Samples number	Date	COMPOUNDS (ug/l)														Energetic materials		
		Ag	Ba	Cd	Cr	Co	Cu	Sn	Hg	Mo	Ni	Pb	Zn	HMX	RDX	TNT		
CCME criteria																		
Freshwater Aquatic Life		0.1	-	0.2-1.8	2-20	-	2-4	-	0.1	-	25-150	1-7	30	-	-	-	-	
Irrigation		-	-	10	100	50	200-1000	-	-	-	200	200	1000-5000	-	-	-	-	
Livestock Watering		-	-	20	1000	1000	500-5000	-	3	500	1000	100	50000	-	-	-	-	
Drinking Water		-	1000	5	50	-	1000	-	1	-	-	10	5000	-	-	-	-	
P3B	Dec 96*	-	-	-	-	-	-	-	-	-	-	-	-	-	<0.5	<0.5	<0.5	
P4A	nov-95	-	-	-	-	-	-	-	-	-	-	-	-	-	1,1	2,8	<0.3	
P4A	April 96	-	-	-	-	-	-	-	-	-	-	-	-	-	1,1	2,0	<0.3	
P4A	sept-96	-	-	-	-	-	-	-	-	-	-	-	-	-	<0.3	<0.3	<0.3	
P4A	déc-96	<5	300	<1	<5	<10	<20	<10	<0.2	<5	<10	<10	<10	-	-	-	-	
P4A Duplicate	déc-96	<5	300	<1	<5	<10	<20	<10	-	<5	<10	<10	<10	-	-	-	-	
P4A (new)	déc-96	-	-	-	-	-	-	-	-	-	-	-	-	-	<0.5	<0.5	<0.5	
P4B	Dec 96*	-	-	-	-	-	-	-	-	-	-	-	-	-	<0.5	<0.5	<0.5	
P4B	nov-95	-	-	-	-	-	-	-	-	-	-	-	-	-	<0.3	5,8	<0.3	
P4B	April 96	-	-	-	-	-	-	-	-	-	-	-	-	-	<0.3	3,0	<0.3	
P4B	sept-96	-	-	-	-	-	-	-	-	-	-	-	-	-	<0.3	<0.3	<0.3	
P4B	déc-96	<5	360	<1	<5	10	<20	<10	<0.2	10	<10	<10	<10	-	<0.3	3,4	<0.3	
P4B	Dec 96*	-	-	-	-	-	-	-	-	-	-	-	-	-	<0.3	<0.5	<0.5	
P5A	nov-95	-	-	-	-	-	-	-	-	-	-	-	-	-	<0.3	1,4	<0.3	
P5A	April 96	-	-	-	-	-	-	-	-	-	-	-	-	-	<0.3	0,9	<0.3	
P5A	sept-96	-	-	-	-	-	-	-	-	-	-	-	-	-	<0.3	<0.3	<0.3	
P5A	Dec 96*	-	-	-	-	-	-	-	-	-	-	-	-	-	<0.3	<0.5	<0.5	
P5B	nov-95	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
P5B	April 96	-	-	-	-	-	-	-	-	-	-	-	-	-	<0.3	<0.3	<0.3	
P5B	sept-96	-	-	-	-	-	-	-	-	-	-	-	-	-	<0.3	<0.3	<0.3	
P5B	Dec 96*	-	-	-	-	-	-	-	-	-	-	-	-	-	<0.3	<0.5	<0.5	
P6A	nov-95	-	-	-	-	-	-	-	-	-	-	-	-	-	<0.3	1,3	<0.3	
P6A	April 96	-	-	-	-	-	-	-	-	-	-	-	-	-	<0.3	<0.3	<0.3	
P6A	sept-96	-	-	-	-	-	-	-	-	-	-	-	-	-	<0.3	<0.3	<0.3	
P6A	Dec 96*	-	-	-	-	-	-	-	-	-	-	-	-	-	<0.3	<0.3	<0.3	
P6B	nov-95	-	-	-	-	-	-	-	-	-	-	-	-	-	<0.3	<0.5	<0.5	
P6B	April 96	-	-	-	-	-	-	-	-	-	-	-	-	-	<0.3	2,0	2,4	
P6B		-	-	-	-	-	-	-	-	-	-	-	-	-	<0.3	<0.3	<0.3	

2/4

TABLE II
ANALYTICAL RESULTS FOR GROUNDWATER COLLECTED AT CFAD DUNDURN

Samples number	Date	COMPOUNDS (ug/l)													Energetic materials		
															HMX	RDX	TNT
		Ag	Ba	Cd	Cr	Co	Cu	Sn	Hg	Mo	Ni	Pb	Zn				
CCME criteria																	
Freshwater Aquatic Life		0.1	-	0.2-1.8	2-20	-	2-4	-	0.1	-	25-150	1-7	30	-	-	-	-
Irrigation		-	-	10	100	50	200-1000	-	-	-	200	200	1000-5000	-	-	-	-
Livestock Watering		-	-	20	1000	1000	500-5000	-	3	-	1000	100	50000	-	-	-	-
Drinking Water		-	1000	5	50	-	1000	-	1	-	-	10	5000	-	-	-	-
P6B	sept-96	-	-	-	-	-	-	-	-	-	-	-	-	<0.3	<0.3	<0.3	<0.3
P6B	Dec 96*	-	-	-	-	-	-	-	-	-	-	-	-	-	<0.5	<0.5	<0.5
P7A	nov-95	-	-	-	-	-	-	-	-	-	-	-	-	<0.3	<0.3	<0.3	<0.3
P7A	April 96	-	-	-	-	-	-	-	-	-	-	-	-	<0.3	<0.3	<0.3	<0.3
P7A	sept-96	-	-	-	-	-	-	-	-	-	-	-	-	<0.3	<0.3	<0.3	<0.3
P7A	Dec 96*	-	-	-	-	-	-	-	-	-	-	-	-	<0.3	<0.3	<0.3	<0.3
P7B	nov-95	-	-	-	-	-	-	-	-	-	-	-	-	<0.3	1.8	<0.5	<0.5
P7B	April 96	-	-	-	-	-	-	-	-	-	-	-	-	<0.3	<0.3	<0.3	<0.3
P7B	sept-96	-	-	-	-	-	-	-	-	-	-	-	-	<0.3	<0.3	<0.3	<0.3
P7B	Dec 96*	-	-	-	-	-	-	-	-	-	-	-	-	<0.3	<0.3	<0.3	<0.3
P8A	nov-95	-	-	-	-	-	-	-	-	-	-	-	-	<0.3	<0.3	<0.3	<0.3
P8A	April 96	-	-	-	-	-	-	-	-	-	-	-	-	<0.3	<0.3	<0.3	<0.3
P8A	sept-96	-	-	-	-	-	-	-	-	-	-	-	-	<0.3	<0.3	<0.3	<0.3
P8A	Dec 96*	-	-	-	-	-	-	-	-	-	-	-	-	<0.3	<0.3	<0.3	<0.3
P8B	nov-95	-	-	-	-	-	-	-	-	-	-	-	-	<0.3	<0.3	<0.3	<0.3
P8B	April 96	-	-	-	-	-	-	-	-	-	-	-	-	<0.3	<0.3	<0.3	<0.3
P8B	sept-96	-	-	-	-	-	-	-	-	-	-	-	-	<0.3	<0.3	<0.3	<0.3
P8B	Dec 96*	-	-	-	-	-	-	-	-	-	-	-	-	<0.3	<0.3	<0.3	<0.3
P9	Dec 96*	<5	290	<1	<5	<10	<20	<10	<0.2	<5	<10	<10	<10	-	<0.5	<0.5	<0.5
P10	Dec 96*	<5	450	<1	<5	<10	<20	<10	<0.2	<5	<10	<10	<10	<10	<0.5	<0.5	<0.5
P11	Dec 96*	<5	390	<1	<5	<10	<20	<10	<0.2	<5	<10	<10	<10	<10	<0.5	<0.5	<0.5
P12A	Dec 96*	<5	340	<1	<5	<10	<20	<10	<0.2	<5	<10	<10	<10	<10	<0.5	<0.5	<0.5
P12B	Dec 96*	<5	430	<1	10	<10	<20	<10	<0.2	<5	10	<10	20	<10	<0.5	<0.5	<0.5
P13A	Dec 96*	-	-	-	-	-	-	-	-	-	-	-	-	-	<0.5	<0.5	<0.5
P13B	Dec 96*	-	-	-	-	-	-	-	-	-	-	-	-	-	<0.5	<0.5	<0.5
P14A	Dec 96*	<5	350	<1	<5	<10	<20	<10	<0.2	<5	<10	<10	<10	<10	<0.5	<0.5	<0.5

3/4

TABLE II
ANALYTICAL RESULTS FOR GROUNDWATER COLLECTED AT CFAD DUNDURN

Samples number	Date	COMPOUNDS (ug/l)														
														Energetic materials		
		Ag	Ba	Cd	Cr	Co	Cu	Sn	Hg	Mo	Ni	Pb	Zn	HMX	RDX	TNT
CCME criteria																
Freshwater Aquatic Life		0.1	-	0.2-1.8	2-20	-	2-4	-	0.1	-	25-150	1-7	30	-	-	-
Irrigation		-	-	10	100	50	200-1000	-	-	10-50	200	200	1000-5000	-	-	-
Livestock Watering		-	-	20	1000	1000	500-5000	-	3	500	1000	100	50000	-	-	-
Drinking Water		-	1000	5	50	-	1000	-	1	-	-	10	5000	-	-	-
P14A Duplicate	Dec 96*	-	-	-	-	-	-	-	<0.2	-	-	-	-	-	<0.5	<0.5
P14B	Dec 96*	-	-	-	-	-	-	-	-	-	-	-	-	-	<0.5	<0.5
P15A	Dec 96*	-	-	-	-	-	-	-	-	-	-	-	-	-	<0.5	<0.5
P15B	Dec 96*	<5	330	<1	<5	<10	<20	<10	<0.2	<5	<10	<10	<10	<10	<0.5	<0.5
P16	Dec 96*	<5	380	<1	<5	<10	<20	<10	<0.2	<5	<10	<10	70	<10	<0.5	<0.5
P17	Dec 96*	<5	290	<1	<5	<10	<20	<10	<0.2	<5	<10	<10	<10	<10	<0.5	<0.5

Legend

70

: concentration in excess of freshwater aquatic life criterion (CCME)

-: no data available.

HMX: octahydro-1,3,5,7-tetranitro-1,3,5,7-tetrazocine.

RDX: hexahydro-1,3,5-trinitro-1,3,5-triazine.

TNT: 2,4,6-trinitrotoluene.

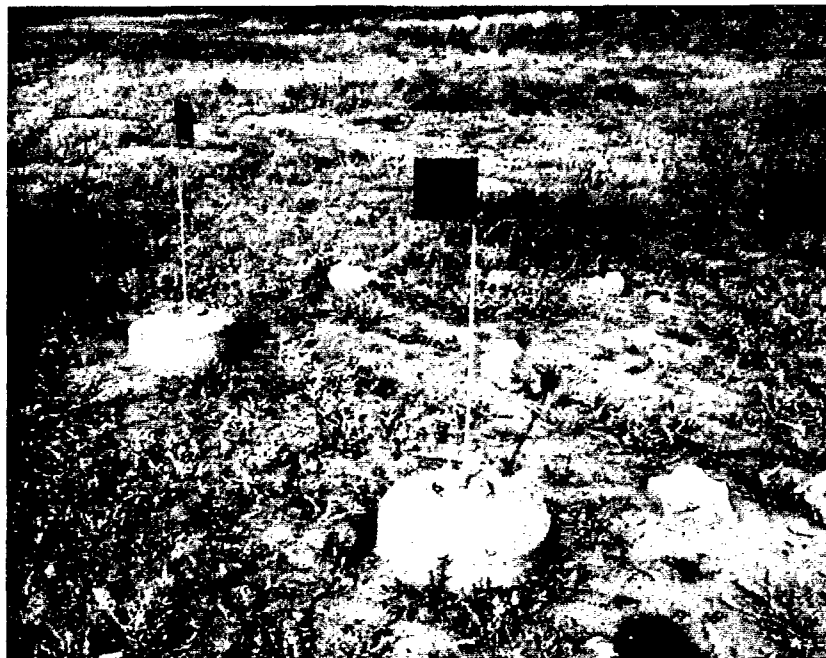
December 96*

: All analytical results in groundwater are from the EPA 8330 method except for Dec 96* which are Dtech for RDX and TNT

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(A)

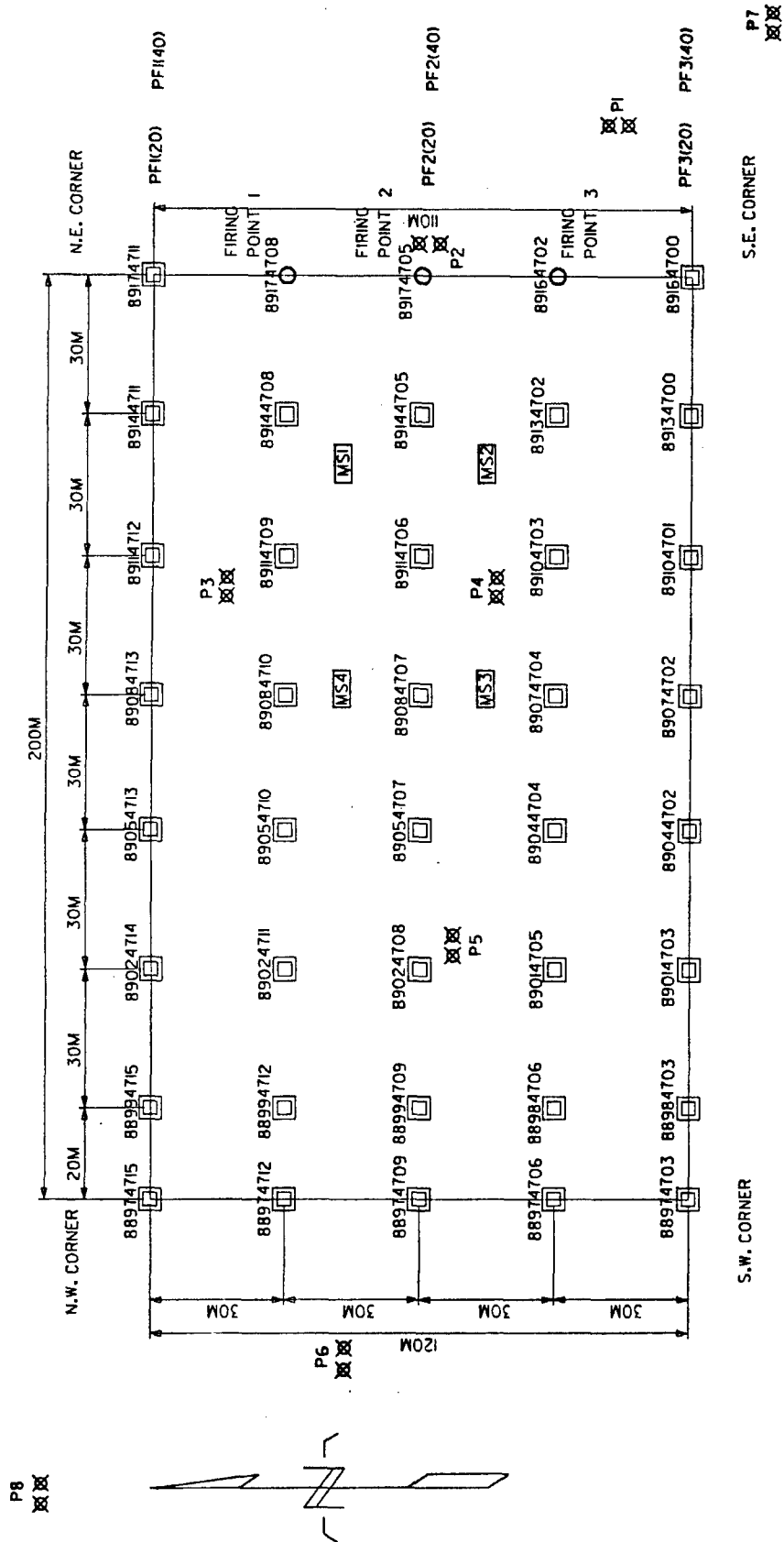


(B)

Figure 1: Pictures of protective casings installed A: Outside or B: Inside the destruction area of CFAD Dundurn

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FIG. 2 CHARACTERIZATION OF THE
SURFACE SOILS AT THE
CFAD DUNDURN DESTRUCTION AREA
(HIGH EXPLOSIVE DESTRUCTION POINT)



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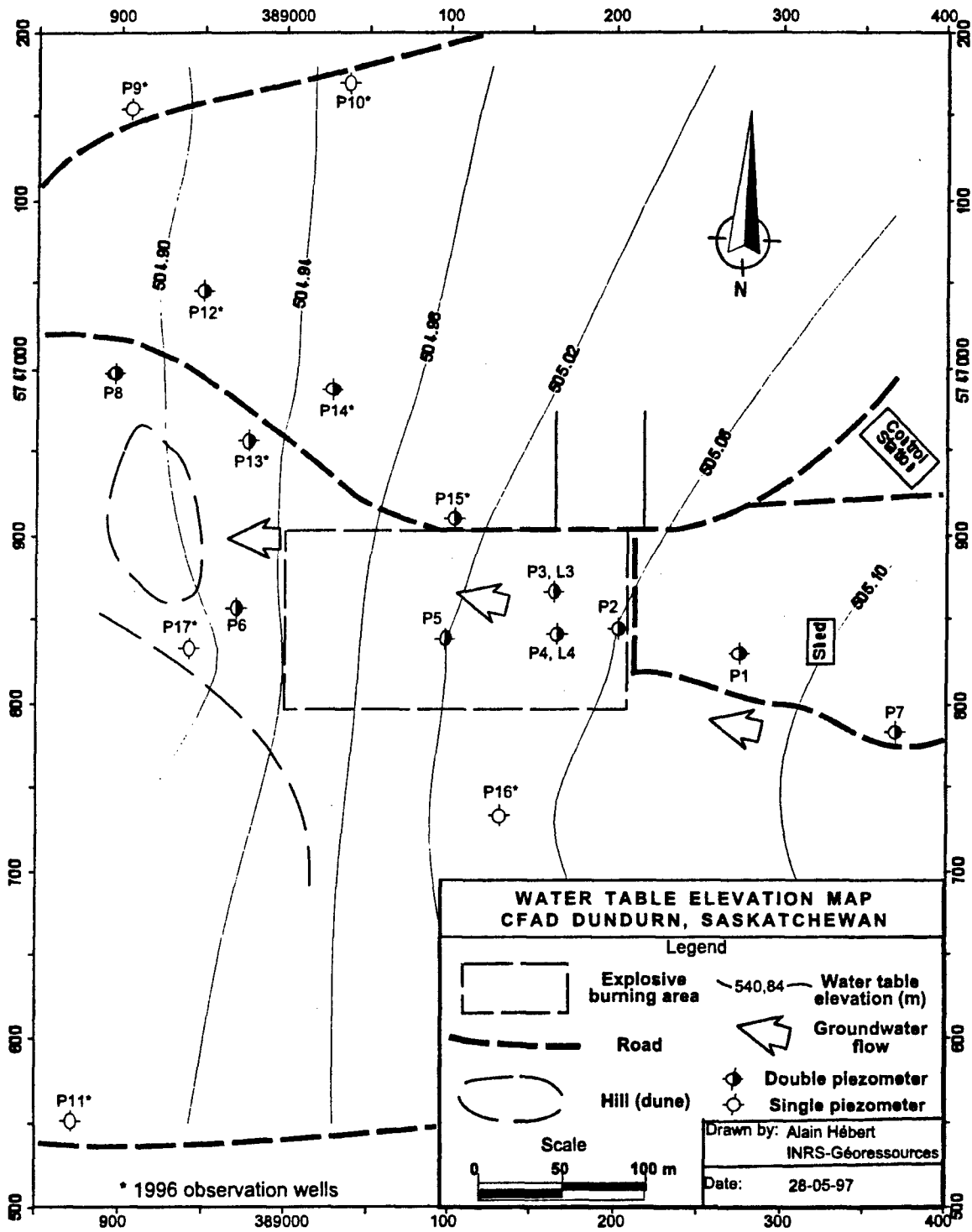


Figure 3: Water table elevation map and groundwater flow, december 96.

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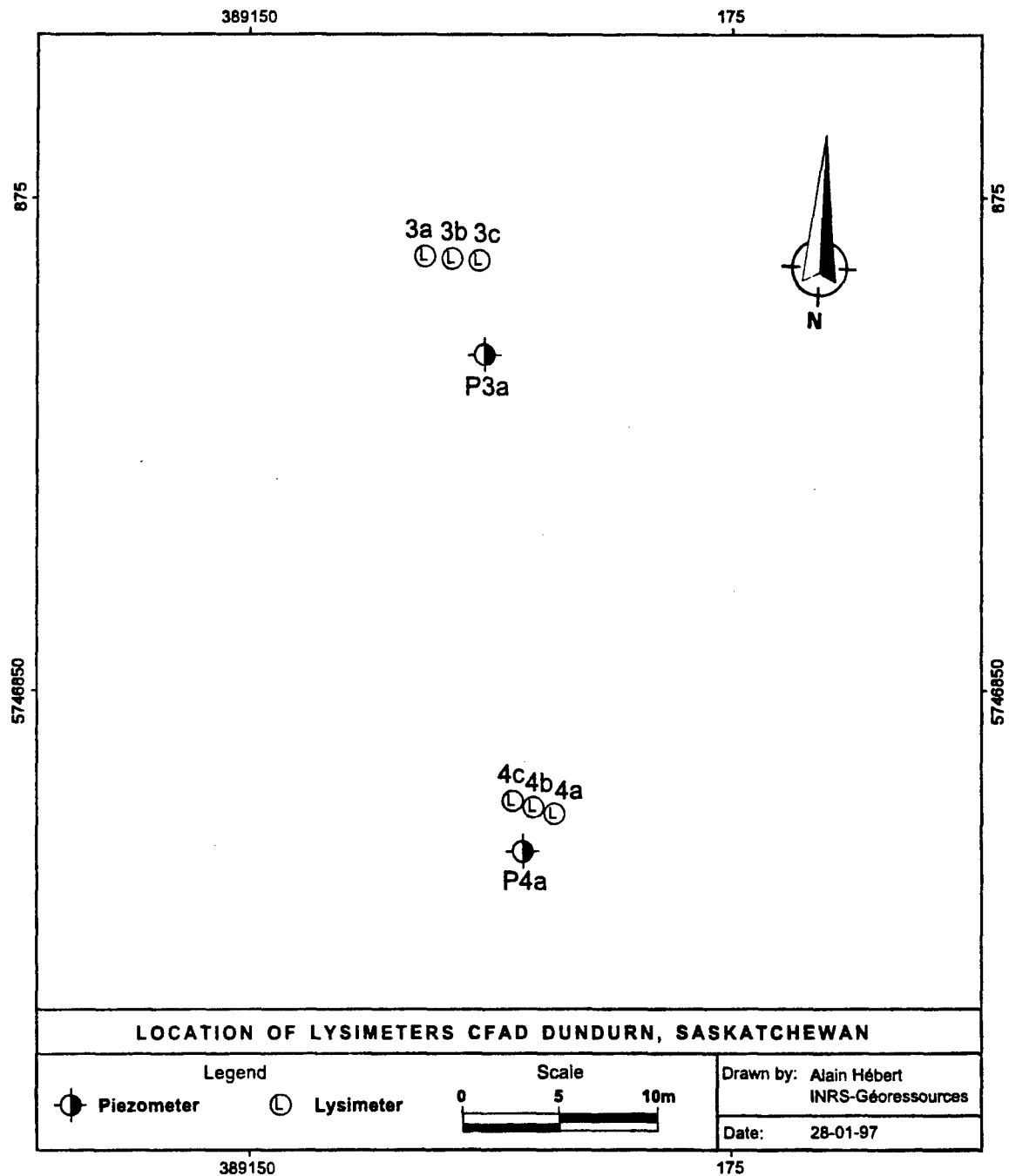


Figure 4: Location of lysimeters.

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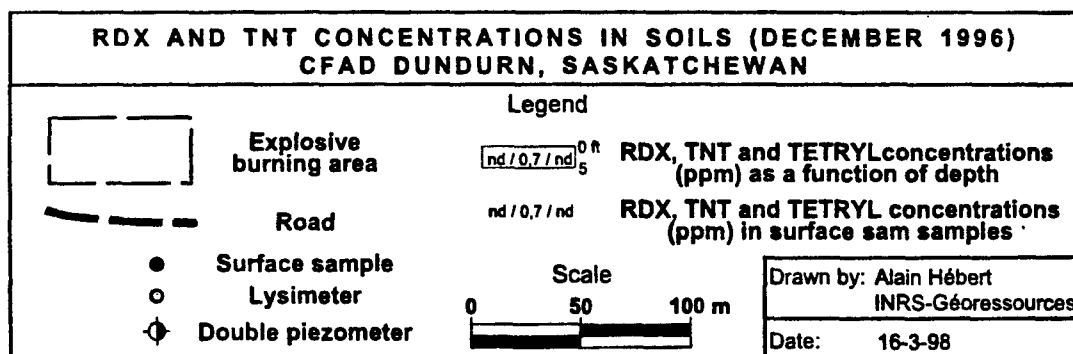
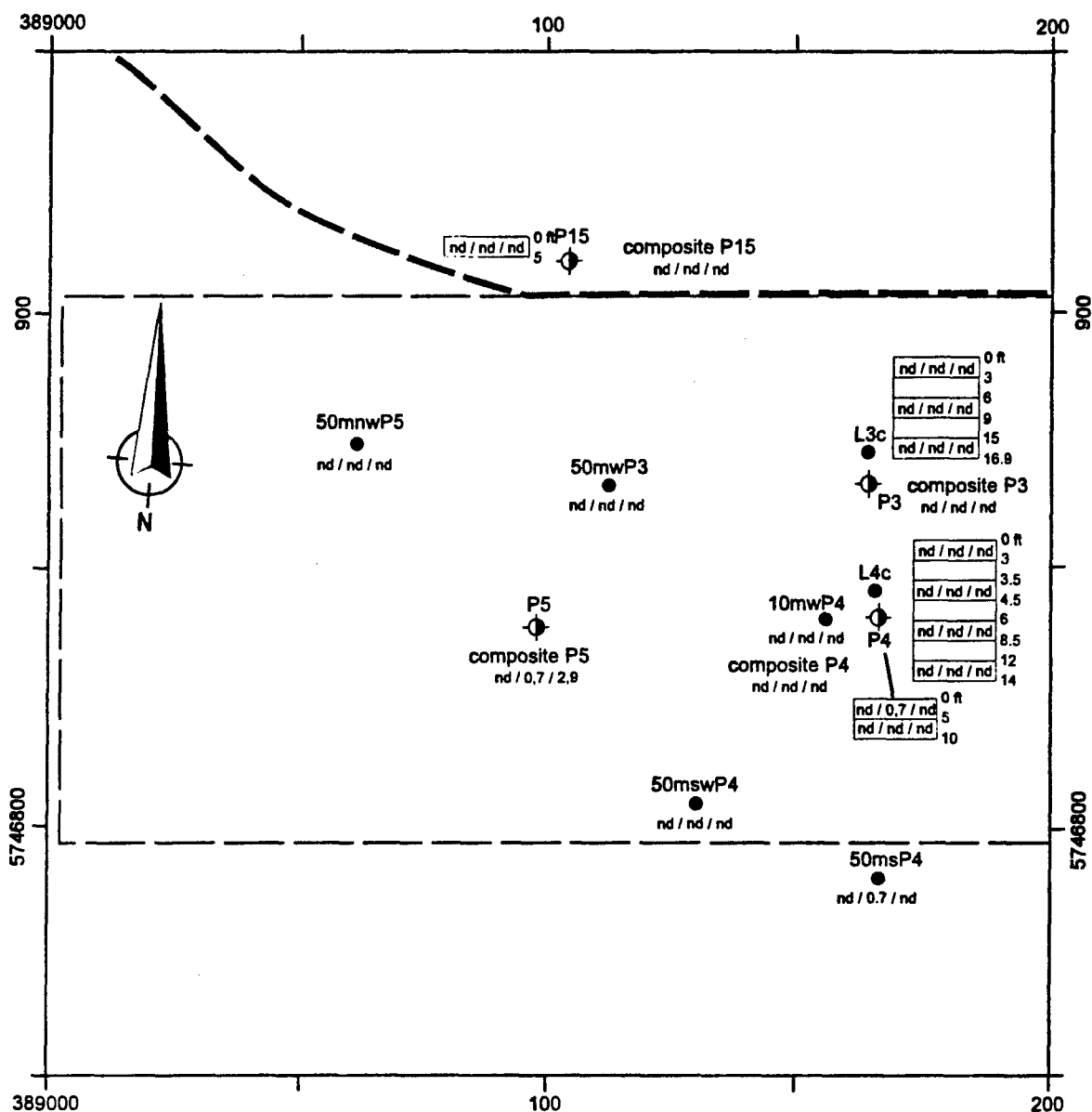


Figure 5: RDX and TNT concentrations in soil samples (EPA 8330 method).

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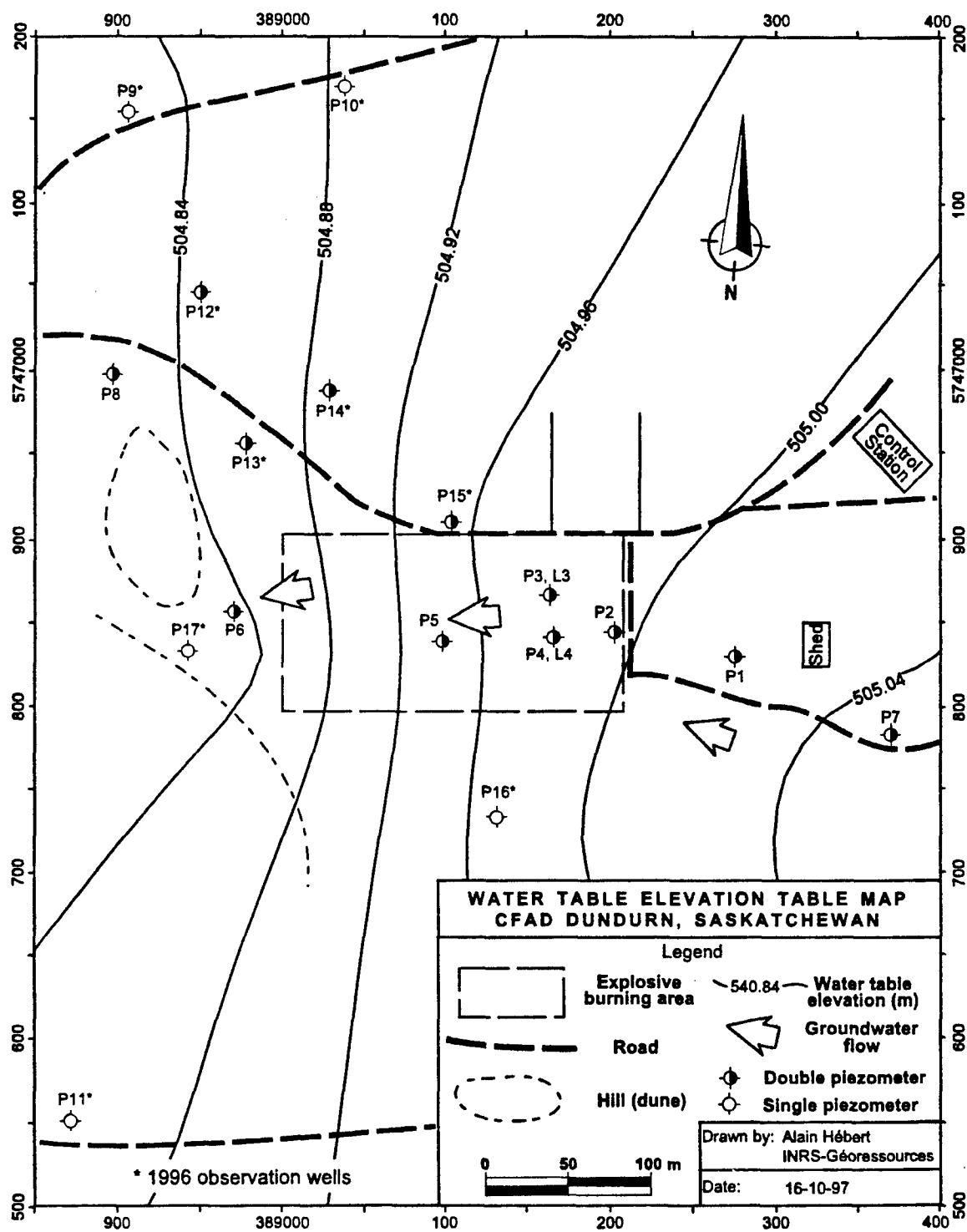


Figure 6: Water table elevation map and groundwater flow, september 97.

**RDX CONCENTRATIONS IN SOILS
CFAD DUNDURN, SASKATCHEWAN**

Legend

- Explosive burning area
- Road
- Hill (dune)
- Double piezometer
- Single piezometer

RDX concentrations (% / ppm) according to DTECH / 8330 as a function of depth

0 ft 5 ft 10 ft 15 ft 20 ft 25 ft 30 ft 35 ft 40 ft 45 ft 50 ft

3% / nd

Drawn by: Alain Hébert
INRS-Géoresources

Date: 16-10-97

Figure 7: RDX concentrations in soil samples.

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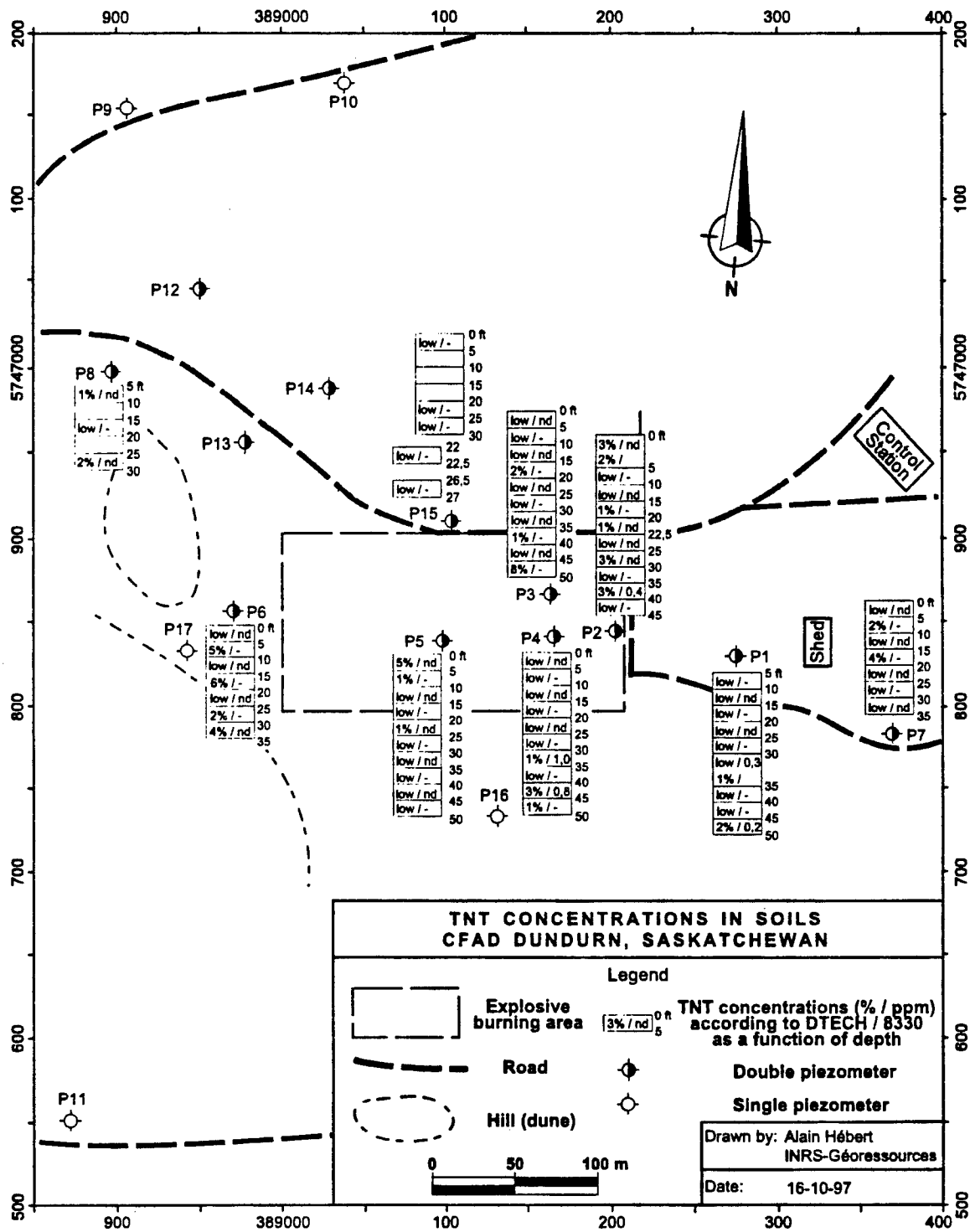


Figure 8: TNT concentrations in soil samples.

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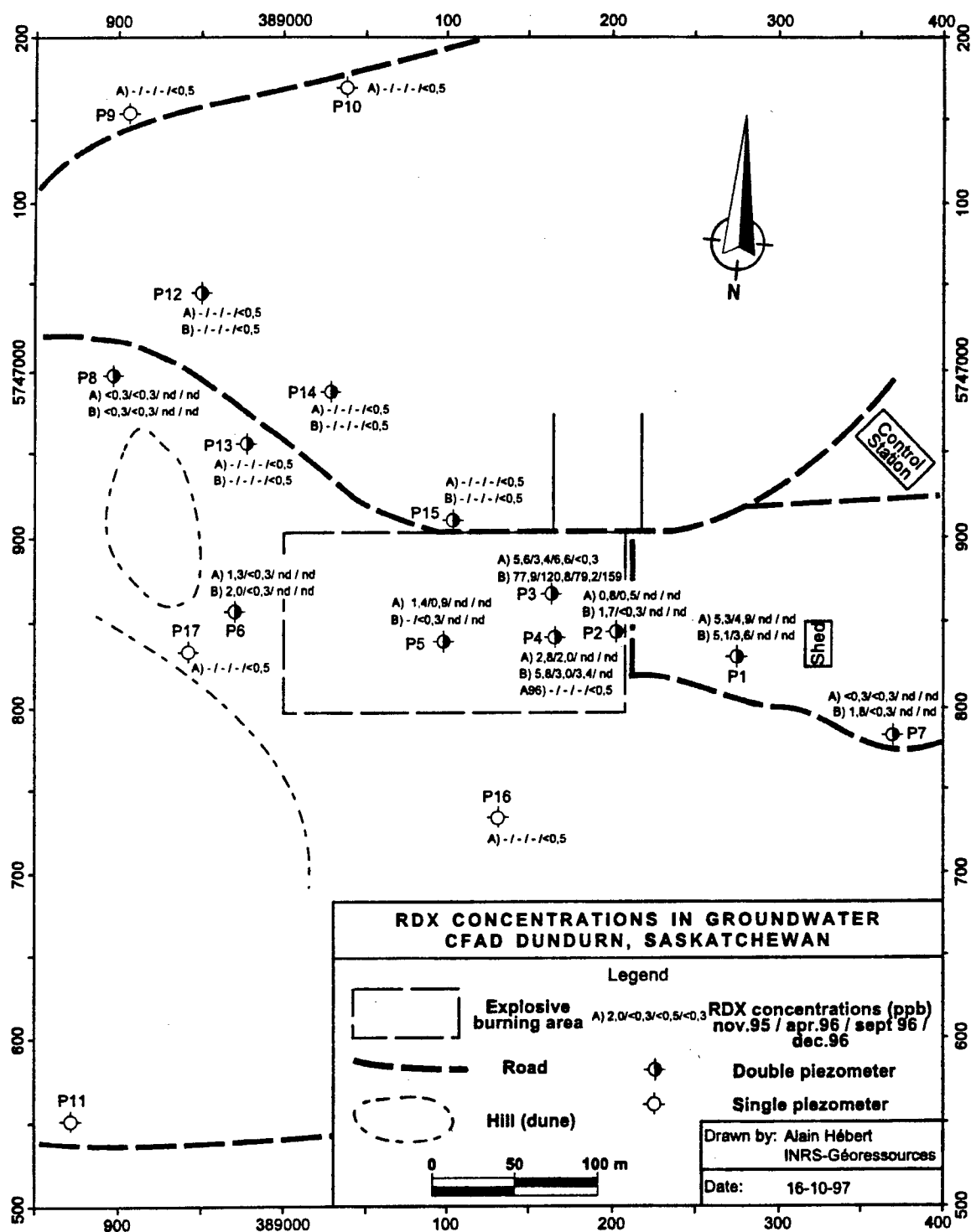


Figure 9: RDX concentrations in groundwater samples.

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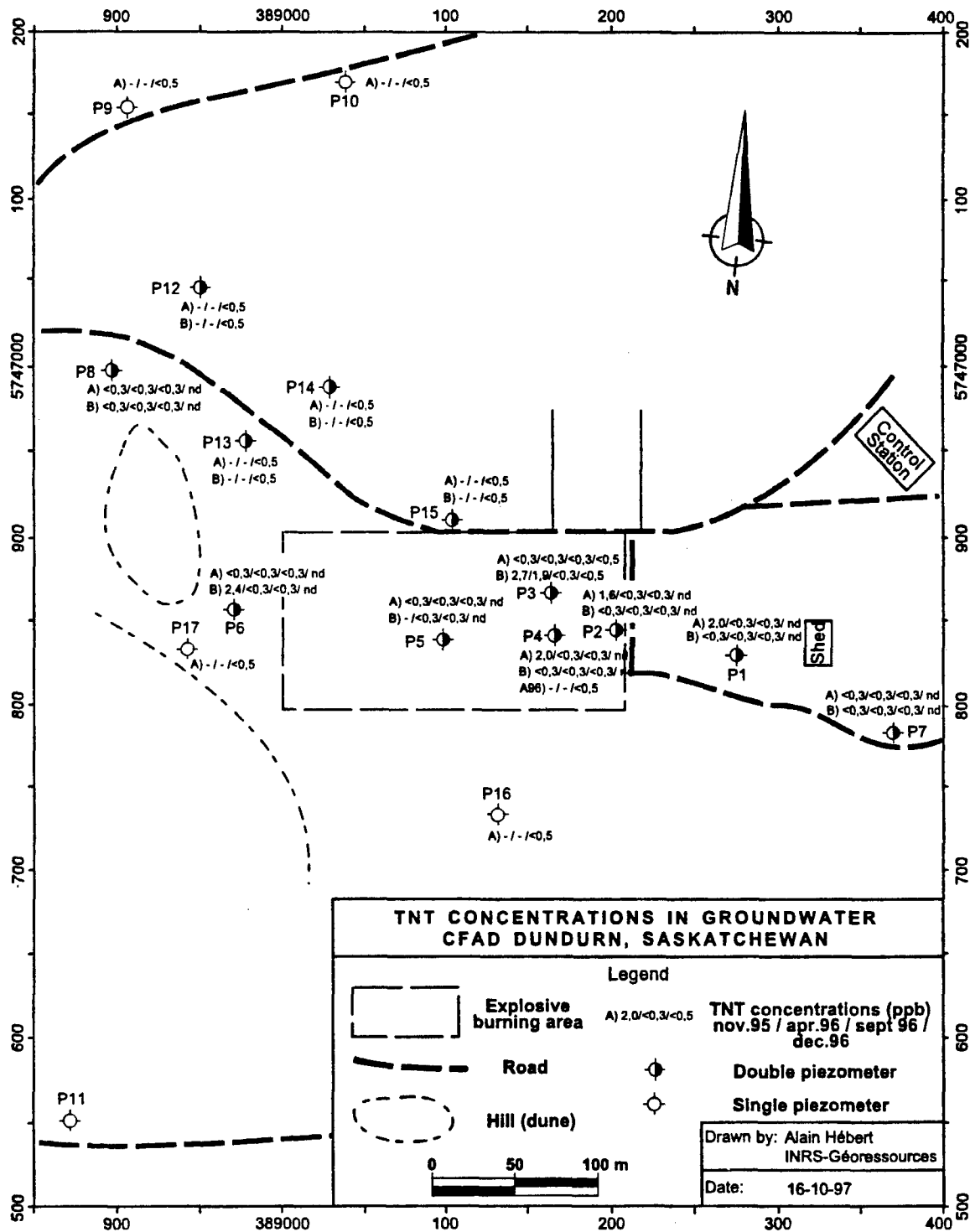


Figure 10: TNT concentrations in groundwater samples.

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Since open burning/open detonation (OB/OD) has been proven elsewhere to be a polluting activity thereby representing a possible threat to human health and to the environment, it was decided to evaluate the impact of this activity on the environment at the largest OB/OD site in Canada, located at the Canadian Forces Ammunition Depot, CFAD Dundurn, Saskatchewan. A thorough investigation was initiated by collecting soils on the site followed by the drilling of boreholes and installation of many observation wells to analyse groundwater contamination by explosives. After four years of studying and performing analyses of soils and groundwater, it appeared that the impact of the open destruction activity on the environment is minimal. Furthermore, because of the site's location, the velocity and the direction of the groundwater flow, there were no adverse effects on human health or ecological receptors. Therefore, it was concluded in this study that the open detonation of obsolete ammunition could be pursued at CFAD Dundurn using the same techniques while implementing a monitoring program of groundwater quality. On the other hand, the open burning activity was not evaluated on this site but study made on other sites showed that open burning is not as clean as open detonation since the temperature of the combustion is not as elevated.

Étant donné qu'il a été démontré que les activités de brûlage/détonation à aire ouverte peuvent être polluantes et représentent donc un danger pour la santé humaine et pour l'environnement, on a pris la décision d'évaluer l'impact de cette activité sur le plus gros site de brûlage/détonation extérieur du Canada situé au dépôt de munitions des forces canadiennes, DMFC Dundurn, Saskatchewan. Une étude poussée a été initiée en échantillonnant les sols sur le site suivie par le forage et l'installation de puits d'observation pour analyser l'eau souterraine quant à la contamination par les explosifs. Après quatre années d'études et d'analyses des sols et de l'eau souterraine, il est apparu que l'impact de la détonation extérieure sur l'environnement est minime. De plus, dû à la localisation du site, à la vitesse et la direction de l'eau souterraine, il n'y a pas d'effets nocifs pour la santé humaine et pour les récepteurs écologiques. En conséquence, il a été conclu dans cette étude que la destruction de matériels désuets par détonation extérieure peut être poursuivie sur le site du dépôt de munitions des forces canadiennes à Dundurn en utilisant les mêmes techniques, tout en instaurant un programme de surveillance de la qualité de l'eau souterraine. D'un autre côté, l'activité de brûlage extérieure n'a pas été évaluée sur ce site mais, une étude faite sur d'autres sites a démontré que le brûlage extérieur n'est pas un procédé aussi propre que la détonation extérieure dû au fait que la température de combustion est moins élevée.

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OB/OD Activity
Site Characterization
RDX
HMX
TNT
Destruction of Ammunition
Groundwater

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