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Defence R&D Canada – Valcartier
Technical Report
DRDC Valcartier TR 2004-204
October 2004

Canada

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Technical Report
DRDC Valcartier TR 2004-204
2004-11-08

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Abstract

This work describes the evaluation of the impacts of the live firing training activities in Cold Lake Air Weapons Range (CLAWR) in Alberta performed during August 03 (Phase II). The study was conducted by DRDC Valcartier in collaboration with the U.S. Army Engineer Research and Development Center (ERDC), Cold Regions Research Engineering Laboratory (CRREL), Hanover, NH, and the ERDC Environmental Laboratory (EL), Vicksburg, MS to complete the first evaluation performed during Phase I. Four ranges on the site were re-visited during August 2003. More precisely, in Alpha and Bravo ranges, more vegetation and background samples were collected for metal analyses while for Jimmy Lake and Shaver River ranges, more sampling was done to ascertain the metal and explosive concentrations. Surface water and sediment were also evaluated in Jimmy Lake and Primerose Lake. The circular sampling strategy was achieved in Jimmy Lake and Shaver River ranges. The linear transect strategy was applied to Alpha and Jimmy Lake ranges. In Shaver River range, another strategy consisting in collecting 100 discrete samples was accomplished in front of the target. In total, 324 soil samples, 69 vegetation samples, 19 surface water and 28 sediment samples were collected during Phase II. Metal analyses were done using Inductively Coupled Plasma /Mass spectrometry (ICP/MS) and explosives concentrations were deternined using the High Pressure Liquid Chromatography (HPLC) Method EPA 8330. Results showed that the quality of soil, vegetation, surface water and sediment is excellent with exception in Jimmy Lake Range where high levels of cadmium and copper were again found. This report describes the approaches and strategies used and the results obtained during this study.

Résumé

Ce travail décrit l'évaluation de l'impact des activités d'entraînement par tir réel faites au secteur d'entraînement des forces de l'air à Cold Lake (CLAWR) en Alberta effectuée en août 2003 (Phase II). Cette étude a été dirigée par RDDC Valcartier en collaboration avec l'US Army Research and Development Center (ERDC), Cold Regions Research Engineering Laboratory (CRREL), Hanover, NH, et l'ERDC Environmental Laboratory (EL) Vicksburg, MS pour compléter la première évaluation faite durant la phase I. Quatre champs de tir du secteur ont été visités en août 2003. Plus précisément, dans Alpha et Bravo, plus de vegetation et d'échantillons témoins ont été ramassés pour l'analyse des métaux alors que pour Jimmy Lake et Shaver River, plus d'échantillonage a été fait pour évaluer les concentrations de métaux et d'explosifs. L'eau de surface et des sédiments ont aussi été analysés dans Jimmy Lake et Primerose Lake. La stratégie d'échantillonnage circulaire a été réalisée dans les sites de Jimmy Lake et de Shaver River. La stratégie d'échantillonnage par section transversale linéaire a été appliquée aux sites Alpha et Jimmy Lake. Dans Shaver River, une autre strategie qui a consisté à prendre 100 échantillons discrets en face de la cible a été accomplie. Au total, 324 échantillons de sol, 69 de végétation, 19 d'eaux de surface et 28 de sédiments ont été recueillis durant la phase II. Les analyses de métaux ont été effectuées par plasma inductif couplé/spectrométrie de masse (PIC/SM) et les concentrations d'explosifs ont été déterminées par la méthode de chromatographie liquide haute pression (CLHP) EPA 8330. Les résultats ont montré que la qualité des sols, de la végétation, de l'eau de surface et des sédiments est excellente à l'exception des échantillons du site de Jimmy Lake où de hautes concentrations de cadmium et de cuivre ont été à nouveau trouvées. Ce rapport décrit les approches et stratégies utilisées ainsi que les résultats obtenus durant cette étude.

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Executive summary

The international context of demilitarization, the closure of military bases and the more stringent aspects of environmental laws have led to the establishment of new areas for research and development. Many activities of the Canadian Forces such as the firing of ammunition, demolition, and the destruction of obsolete ammunition by open burning and open detonation may lead to the dispersion of energetic compounds and other munitions-related contaminants in the environment. It is within this context that the Defence Research and Development Canada Valcartier (DRDC Valcartier) and the US Army Engineer Research and Development Center (ERDC), Cold Regions Research and Engineering Laboratory (CRREL) and the ERDC Environmental Laboratory (EL) initiated research programs to study the environmental impact of energetic materials that are found in the Department of National Defence (DND) and in the US Department of Defence (DoD) ammunition stockpiles. The Programmes on site characterization allowed the development of a unique expertise and positioned our departments to better understand the impacts of live fire training and to be in a readiness state to answer any inquiries and take corrective actions if needed. The first training areas to be characterized within the Programme were mainly army bases such as CFB Chilliwack, Shilo, Valcartier, Gagetown in Canada and, Fort Bliss, Fort Lewis, Yakima, MMR and many others in United States. The Canadian Programme was sponsored by DRDC, DGE, DLE and by a major US Department of Defense (DoD) funding program, the Strategic Environmental R&D Program (SERDP).

During the characterization of CFB Shilo, interest grew from Cold Lake Air Weapon Ranges (CLAWR) to study their training ranges. After discussion with 4-Wing Command unit, preliminary sampling took place in March 2002 followed by the sampling of the main ranges in August 2002. Worldwide, this study represented the first efforts to characterize an entire Air Force Base. Cold Lake Air Weapon Ranges (CLAWR) is located in Alberta and is the largest and the most used air force base in Canada. Therefore, it can be seen as the most representative site for this new area of research. The campaign involved many scientists and contractors, including scientists from ERDC, who are co-authors of the present report. To understand the potential environmental impacts caused by live firing activities, characterization of the main four ranges initated during Phase I was continued during Phase II. The linear transect and the circular strategies developed during Phase I were again used. Soil and vegetation samples were collected using the compositing technique. Surface water and sediment samples were collected in Primerose Lake and in Jimmy Lake. Samples were analyzed for explosive contamination using the High Pressure Liquid Chromatography (HPLC) method EPA 8330. Heavy metals concentrations were also assessed. Generally, results of this study revealed some localized concentrations of contaminants, but in general, the quality of soil, vegetation, surface water and sediment was excellent.

2004. G. Ampleman, S.Thiboutot, J. Lewis, A. Marois, A. Gagnon, M. Bouchard, T.F. Jenkins, T.A. Ranney and J.C. Pennington; Evaluation of the Contamination by Explosives and Metals in Soils, Vegetation, Surface Water and Sediment at Cold Lake Air Weapons Range (CLAWR), Alberta, Phase II, Final Report. DRDC Valcartier. TR 2004-204.

Sommaire

Le contexte international de démilitarisation, de la fermeture de bases et de la sévérité croissante des lois environnementales a conduit à l'émergence de nouveaux champs de R&D. Plusieurs activités des Forces armées canadiennes telles que l'entraînement au tir de diverses munitions et la destruction de munitions, jugées désuètes ou en surplus, par brûlage ou détonation extérieure peuvent conduire à la dispersion de matériaux énergétiques et d'autres contaminants dans l'environnement. C'est dans ce contexte que Recherches et Développement pour la Défense Canada (RDDC Valcartier) en collaboration avec Cold Regions Research and Engineering Laboratory (CRREL) et Environmental Laboratory (EL) de l'US Army ERDC, ont entrepris des programmes de recherches afin d'étudier les impacts environnementaux des composés énergétiques que l'on retrouve au ministère de la défense nationale (MDN) et au Department of Defence (DoD). Les programmes de caractérisation de sites ont permis de développer une expertise unique et ont positionné nos organisations de défense de façon à mieux comprendre les impacts des entraînements au tir réel et à être prêtes à répondre à toute éventualité pour prendre des mesures correctives, si nécessaire. Les premiers sites d'entraînement à être évalués dans le cadre de ce programme étaient des bases de l'armée, telles que BFC Chilliwack, Shilo, Valcartier, Gagetown au Canada et Fort Bliss, Fort Lewis, Yakima, MMR et plusieurs autres aux États-Unis. Le programme canadien a été financé par RDDC, DGE, DLE ainsi que par un programme majeur de fonds américains, le Strategic Environmental R&D Programme (SERDP).

Durant la caractérisation de la BFC Shilo, l'intérêt a grandi pour étudier les secteurs d'entraînement de la base des forces de l'air à Cold Lake. Après discussion avec le commandement du 4-Escadron (4-Wing), un échantillonnage préliminaire a été effectué en mars 2002 et l'échantillonnage principal en août 2002. Mondialement, cette étude représentait les premiers efforts pour caractériser une base entière des forces de l'air. La base des forces de l'air à Cold Lake, située en Alberta, est la plus grande au Canada. Ce site peut donc être vu comme étant le plus représentatif pour ce nouveau champ de recherches. Cette campagne a impliqué plusieurs entrepreneurs et scientifiques, dont ceux de CRREL, co-auteurs de ce rapport. Pour comprendre les impacts environnementaux potentiels causés par les activités à tir réel, la caractérisation des quatre sites initiée durant la phase I a été poursuivie durant la phase II. Les stratégies d'échantillonnage par section transversale linéaire ainsi que circulaire développées durant la phase I ont à nouveau été utilisées. Des sols et de la végétation ont été échantillonnés en utilisant la technique des sous-échantillons composites. Des échantillons d'eau de surface et de sédiments ont été prélevés dans les lacs Primerose et Jimmy. Les échantillons ont été analysés pour la contamination par les explosifs en utilisant la chromatographie liquide haute pression (CLHP), méthode EPA 8330. Les concentrations en métaux lourds ont également été évaluées. De façon générale, les résultats de cette étude ont démontré quelques concentrations localisées de contaminants mais la qualité globale des sols, de la végétation, de l'eau de surface ainsi que des sédiments s'est avérée excellente.

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Table of contents

LIST OF TABLES

LIST OF FIGURES

Acknowledgements

The authors wish to thank the 4-Wing and the Strategic Environmental Research and Development Program (SERDP) for their financial support and vision. The authors also wish to thank Defence Construction Canada (DCC) for their support during this second phase of the surface characterization. More precisely, the authors wish to acknowledge the excellent work performed by Mr Wesley Nash and Ms Sabrina Rock from DCC who were responsible for all of the analytical supplies and analyses during the field work in Cold Lake. Range Control Canadian Forces personnel of CLAWR are especially thanked for their invaluable help, openness and support in all these sampling events. More precisely, we would like to thank Mr. Drew Craig, the Environmental Officer, who gave us all the support and funds needed to accomplish our task. We also wish to thank all personnel of range control at the CLAWR who helped us, more particularly Cpl Kevin Spurrel, Cpl Travor Eades and Cpl Graig Rose, Sgt Berry Machan and Chief Warrant Officer CWO Bruno Tremblay.

1 Introduction

Energetic materials are prominent components of munitions and weapons that can be found in war zones, training ranges and on production sites. During this decade, many needs have already emerged related to the identification, quantification, delimitation and elimination of energetic contaminants dispersed by munitions, or present in explosives dumps, trials or destruction fields, firing areas and production sites 1-25 . Within this context of growing awareness of environmental issues, the Director Research and Development Branch, through DRDC Valcartier, has directed some of its resources to assess and develop expertise related to the environmental risks associated with explosive compounds.

Many Canadian Forces sites used as impact areas, training ranges, demolition and open burning/open detonation (OB/OD) ranges, which were used to destroy out-of-specification materials, were highly suspected of being contaminated with energetic substances as described in the literature 1-14 . To evaluate the contamination of Department of National Defence (DND) sites, sampling and characterization of various ranges were performed over the last ten years. A protocol describing the different methods of sampling and the analytical chemistry was developed 15 . This protocol was recently updated in collaboration with Cold Regions Research and Engineering Laboratory (CRREL) and is presently being reviewed under the auspices of the Technical Cooperation Program (TTCP) by the member nations (Canada, the U.S., the U.K., Australia and New Zealand) in a key technical area (KTA 4-28) 16 . Research results to date have demonstrated that explosives are not common contaminants, since they exhibit limited aqueous solubility and are dispersed in a heterogeneous pattern of contamination. In the United States, a lot of efforts have been made to develop analytical chemistry, to establish the best sampling procedure and to understand the complex fate of explosives in the environment 3, 4, 6-12, 17-25 .

The selection of CLAWR in CFB Cold Lake to conduct the first R&D efforts to assess the environmental aspects of live firing activities on an Air Base was the result of a growing interest by 4- Wing following the characterization of CFB Shilo and also because Cold Lake is the largest Air base in Canada. As the largest and the most used area for Air practice with live weapons, This site is the most representative and the worthiest of studying among Air bases. The problem of air bombing is completely different from problems encountered on Army ranges. The weapons used are different, especially in size and content. Low order detonations of Air weapons may result in high concentrations of explosives in the environment as it was seen in CFB Gagetown 26 . Furthermore, Air Forces use rockets that contain ammonium perchlorate, a newly recognized contaminant that is extensively studied in the US. When these rockets hit the ground, some of them are not completely burned and can break into pieces after the impact with the ground, spreading ammonium perchlorate at the surface. Since this contaminant is ionic, it is highly soluble in water and can go directly to the groundwater.

contamination related to explosives and heavy metals dispersed at the surface in soil and vegetation but also in surface water and sediment. The contamination patterns of surface soils around targets and across the ranges were re-evaluated in Alpha, Jimmy Lake and Shaver River ranges. The same approaches and strategies used during Phase I were applied to re-sample Jimmy Lake and Shaver River ranges. Furthermore, a statistical evaluation of the explosive concentrations was done in Shaver River Range. Background samples were also collected to compare and assess the natural and anthropogenic contribution. The extent of vegetation contamination in the worst-case scenario locations was assessed by collecting vegetation samples to evaluate the phytoaccumulation and the potential risk for wildlife. Moreover, the remote areas were also visited and sampled mainly for metal concentrations. Finally, the quality of surface water and sediment was evaluated in Primerose Lake and Jimmy Lake by collecting surface water and sediment samples in both lakes. In total, 324 soils including 100 discrete samples and 12 composite samples to realize the statistical analysis in Shaver River Range, 69 vegetation, 19 water and 28 sediment samples were collected.

To better assess the contamination and characterize an area, an appropriate definition and understanding of the hydrogeological context of the site is required. Characterizing the groundwater quality, especially on such large ranges, is critical because metals and energetic materials are mobile in sandy environments and may migrate in groundwater, presenting a threat to human health and to the environment. Groundwater flow has to be carefully assessed by determining its velocity and direction. The quality of the groundwater has also to be evaluated since it is often used for irrigation purposes, as a drinking water source by the base and to sustain aquatic ecosystems. Consequently, any contamination could impact human health and aquatic ecosystems. In fact, groundwater flowing under CLAWR discharges into Primerose and Jimmy Lakes and also into rivers such as the Shaver River. All are highly sensitive areas for wildlife and humans receptors. The first phase of the hydrogeological study was accomplished in February 2004 and all of the results from this study will be reported later. Many wells were drilled In February 2004 but groundwater samples were mainly collected in August 2004 since most of the wells were frozen in February. The second phase of this hydrogeological study will take place in November 2004.

In this report, all of the surface work carried out during Phase II in August 2003 is described and results were compared with those of Phase I to better assess the situation in the ranges. This study was performed under the work breakdown element 12NY01, “Characterization of DND Sites Contaminated with Energetic Materials,” and was sponsored mainly by 4-Wing and by the Strategic Environmental R&D Programme (SERDP) for the sampling of the surface soils. All work was done in collaboration with U.S. Army Engineer Research and Development Center (ERDC) scientists from CRREL and EL under the umbrella of Canada-United States Test and Evaluation Programme (CANUSTEP). This joint venture between Canada and the United States was initiated to evaluate the fate of explosives in live firing ranges under the auspices of SERDP, a major funding program in the US DoD. Defence Construction Canada (DCC) was responsible of hiring the analytical laboratory, providing manpower, logistic and making the link with range control personnel.

2 Range Description

4-Wing – Cold Lake is situated in the remote northeastern corner of Alberta on the border with Saskatchewan. It was opened in 1954 to be used as an air weapons training base, and still performs that function today. 4-Wing also takes care of the nearby Cold Lake Air Weapons Range (CLAWR), one of the most sophisticated facilities of its type in the world. It is the only tactical bombing range in Canada, and incorporates over 100 target areas with over 700 individual targets ranging from disused vehicles to dummy surface-to-air missile sites and airfields. CLAWR has been designated a supersonic range, with pilots able to fly their aircraft at speed down to 30 meters altitude. The CLAWR is heavily used during the annual Maple Flag exercise, which brings together several NATO air forces for six weeks of intensive flying above the Cold Lake pine forests.

CLAWR covers an area of approximately 180 km by 65 km and is approximately 54 km northeast of CFB Cold Lake at the junction with Saskatchewan with Primerose Lake as a boundary. This beautiful lake is used for commercial fishing and also serves as an area to approach the ranges. There are four main ranges in CLAWR: Alpha and Bravo ranges that are part of the Primerose Lake Evaluation Range (PLER), Jimmy Lake and Shaver River ranges. Alpha and Bravo ranges are located, respectively, from South to North following the southwest shoreline of Primerose Lake (see Map in Appendix A), while the Jimmy Lake Range is located between Jimmy Lake and Primerose Lake. The Shaver River Range is remote to the Lakes and close to the Shaver River. This range is the one most dedicated to live firing using air bombing with 500 pounders. All ranges in CLAWR contain several ground target complexes for bombing training. Both the Jimmy Lake and Shaver River ranges are licensed for live weapons and use up to 2,000 lbs general purpose bombs and live firing missiles. The Primerose Lake water zones are called drop zones Charlie, Delta and Echo and are used to analyse the performance of stores such as dispenser or cluster munitions.

3 Experimental

3.1 Contractors Involved

Defence Construction Canada (DCC) was responsible of hiring the analytical laboratory and for supplying all of the analytical tools, solvents, bottles, etc., and the manpower to assist DRDC Valcartier, CRREL and EL for the sampling of soils, vegetation and surface water samples. They were also responsible for the shipment of all samples to the laboratories. The analytical work for metals was sub-contracted to Enviro-Test Laboratory (ETL) in Edmonton, Alberta. All of the energetic materials analyses were performed by DRDC Valcartier except the samples collected for the statistical analysis, which were analysed at CRREL.

3.2 Sample Handling and Treatment

Explosives are not volatile compounds, and, therefore, no specific precautions, such as the use of sealed containers, had to be taken during sampling of media containing explosives. Soil samples were composites based on a minimum of 20-30 random sub samples and were stored in polyethylene bags. The bags were immediately stored on ice in coolers in the dark to avoid photodegradation of light-sensitive compounds. The use of polyethylene bags decreased the space needed for storing samples and reduced shipping costs. The soil samples were shipped frozen to ETL who splitted the samples into two sub samples after a thorough hand homogenization. One set of frozen samples was sent to DRDC Valcartier for explosives analysis and the other was digested and analyzed for metals by ETL. Sediment samples were collected in polyethylene bags after sedimentation and removal of the excess water by decantation. These sediment samples were treated as soils and were stored on ice in coolers in the dark and later shipped frozen to the analytical laboratory. Surface water samples for metals analyses were collected in standard 500-ml polyethylene bottles, and acidified to a pH of 2. These water samples were not filtered on site since particles in surface water can be ingested by wildlife. Surface water samples for energetic materials were kept cold in 1-L amber glass bottles, stabilized with sodium bisulfate (1.5 g) and sent to DRDC Valcartier for explosive analysis. Vegetation samples were collected in polyethylene bags, kept frozen in the dark, and sent to ETL. The samples were then cut in small pieces, homogenized, digested and analyzed for metals by ETL.

3.3 Parameters Monitored and Analytical Methods

Soil and surface water samples were analysed for metals and energetic materials while vegetation and sediment samples were analysed only for metals. Metals were analysed by Inductively Coupled Plasma/Mass Spectrometry (ICP/MS) by ETL. All of the parameters available by this method were included in the study. For soils and surface water samples, energetic materials were analysed at DRDC Valcartier using the Reverse Phase High Pressure Liquid Chromatography (RP-HPLC) USA EPA SW 846 Method 8330, a method that can produce a 0.1 ppm detection limit. See the EPA Method 8330 found on their internet site (www.epa.gov) for a complete description of the HPLC method. The same method was used at CRREL for the statistical evaluation of the energetics in Shaver River Range. The HPLC method was preferred over the Gas Chromatography method recently published since reproducible results with the GC/ECD Method were difficult to achieve [22-23]. In our study, the HPLC method gave us a detection limit of 0.25 ppm for all analytes and this detection limit was reduced to 0.06 ppm when the sample extracts were concentrated in a Zymark apparatus.

Soil samples were dried in the dark, homogenized by adding acetone to form a slurry which was then evaporated. Soils were sieved through 25-mesh sieves and extracted at DRDC Valcartier according to the following procedure. Eight grams of soil were put into an amber glass vial and mixed with acetonitrile (10 mL). A vortex was applied for one minute, followed by a sonication period of 18 hours in an ultrasonic bath in the dark. The samples were left to settle for 30 minutes. Acetonitrile (2 ml) was decanted from the vial and diluted with water (2 ml) containing calcium chloride (1%). The solution was filtered on a 0.45 microns filter to get 1 ml of solution ready to inject into the HPLC.

Soil extracts were maintained at 4°C until analyzed by HPLC according to Method EPA 8330 update SW 846 (1994). Analyses were performed with a HPLC Agilent HP 1100 equipped with a degasser G1322A, a quaternary pump model G1311A, an autosampler G1313A and a UV diode array detector model G1315A monitoring at 210, 220 and 254 nm. The injection volume was 20 µl and the column was a Supelcosil LC-8 (25 cm x 3 mm x 5 µm) eluted with 15:85 isopropanol/water (v/v) at a flow rate of 0.75 ml/min. The column temperature was maintained at 25^{o} C during the analysis. Standards and solvents were diluted 1:2, acetonitrile to water (0.5 ml Acn /0.5 ml water). When 8 g in 10 ml of acetonitrile were used for the soil extraction, the detection limit for this method was 0.25 ppm.

In order to obtain lower detection limit (0.062 ppm), we concentrated to dryness 2 ml of acetonitrile from the soil extract with a Zymark evaporator (model TurboVap LV) in a test-tube. Thereafter, we added 0.5 ml of water and 0.5 ml of acetonitrile and used this mixture as the extract to inject for the analysis.

The reporting limits obtained for energetic materials in the present study were typically between 100 to 1000 ppb for soils depending on the analyte. No vegetation samples were analysed for energetic materials, since no explosives were detected in another studies [27-28].

For the analyses of the samples collected for the statistical evaluation performed in Shaver River Range, CRREL used the same HPLC analytical method, but with some small variations in their protocol. Below is a description of the method used by CRREL for their analyses of explosives in the discrete samples and the composite samples collected in front of the Shaver River Range target.

Soil samples were air dried at room temperature. The discrete and composite samples were processed differently because the sample masses were quite different. Discrete samples weighed from 48 to 109 grams, while the composite samples weighed over one kilogram. Discrete samples were dried in the 4-oz amber containers, passed through a #10 (2-mm) sieve to remove oversize material, and returned to the 4-oz containers. Discrete samples were not subsampled, but rather the entire sample was extracted as follows. A volume of acetonitrile in mL, approximately double the mass of the sample in grams, was added to each 4-oz jar unless the sample was too large. For those cases the sample was transferred to an 8-oz jar and acetonitrile was added. All jars were capped and placed on a tabletop shaker overnight. The samples were removed from the shaker and allowed to settle for at least an hour. Each sample was filtered through a 0.45 µm Millex FH filter and placed in a 7-ml amber glass vial. Vials were stored in a refrigerator until analyzed.

Composite soil samples were placed on sheets of aluminum foil to air dry. Dried samples were sieved though a #10 sieve (2.00 mm). The material that passed the sieve was ground in a Model LM2 Laboratory Ring Mill (LabTech Essa Pty. Ltd., Bassendean, WA, Australia) grinder for 60 seconds. After grinding, composite samples were spread in a thin layer on clean aluminum foil. Three subsamples were obtained for each composite sample by collecting at least 30 increments randomly from the layer of ground soil for a mass of about 10 g. Each 10-g subsample was extracted with 20-mL of acetonitrile in an ultrasonic bath overnight at room temperature. After sonication, samples were removed from the bath and allowed to settle for at least an hour. An aliquot was then removed, filtered, and placed in a 7-ml amber vial for storage in a refrigerator.

The extracts from both the discrete and composite samples were all analyzed using the general procedures of SW 846 Method 8330 (EPA 1994). For this analysis, an aliquot of each sample was diluted 1 to 4 with reagent grade water. Analysis was conducted on a modular RP-HPLC system from Thermo Finnigan composed of a SpectraSYSTEM Model P1000 isocratic pump, a SpectraSYSTEM UV2000 dual wavelength UV/VS absorbance detector set at 210 and 254 nm (cell path 1cm), and a SpectraSYSTEM AS300 auto sampler. Samples were introduced by over filling a 100-µL sampling loop. Separations were made on a 15 cm x 3.9 mm (4-µm) NovaPak C-8 column (Waters Chromatography Division, Milford, MA) eluted with 15:85 isopropanol/water (v/v) at 1.4 mL/min. Concentrations were estimated against commercial multianalyte standards (Restek) from peak heights. If concentrations exceeded 20 ppm, an aliquot of the original extract was diluted appropriately with additional acetonitrile prior to the 1 to 4 dilution with reagent grade water.

3.4 Sample Nomenclature

All samples were named according to the following five-parts labelling system during Phase II:

First part: sample type

S:	Soils
SW:	Surface Water
B:	Biomass (Prairie Grass and other species)
SED:	Sediment

Second part: Location by range

AL:	Alpha
BR:	Bravo
JL:	Jimmy Lake
SR:	Shaver River
PL	Primerose Lake
BG:	Background Sample

Third part: Identification of the sample source

Target or crater number (1 and 2) or
Position number
Background location (ex: North of target) or
Background location by GPS or
Background location by number or
LS for linear sampling at XX% of the range
where XX%=% of the overall range length

Fourth part: Identification of the sample

Linear sampling at XX % (A or B): A being the right side of the road access and B the left side; 0% is at the beginning of the road towards the target at 100 % or Systematic target sampling names (A1, B2, C3, etc, according to sampling strategy or Position number).

3.5 QA/QC

Quality assurance and quality control programs were included in this study. Background soil and background vegetation samples were collected away from the ranges. Analyses were done twice for energetic materials (lab replicates), but were done only once for the other parameters. Ten percent of field replicates were also sent for analysis. The contracted laboratory reported their QA/QC including surrogates and blanks, detection limits, and quantification limits. Trip blanks and field blanks were also included in the QA/QC plan.

3.6 Safety and Emergency Plan

The sampling of an UXO-contaminated area represents an increased level of risk for personnel. The Range Control Officers gave a safety briefing to people involved in the sampling program. This briefing explained the precautions to be taken to avoid contact with UXOs and also described the various types of UXOs that may be found on ranges. A safety and emergency plan was also put in place for any incident that could have occurred while sampling. This plan was under the responsibility of the CLAWR Range Control unit. When on site for sampling, personnel were always equipped with radios to contact range control in case of an emergency. Walkie-talkies were available to communicate between the teams. Range control personnel always accompanyied the sampling team.

3.7 Sampling Strategy

During Phase I, soil, vegetation and surface water sampling showed higher concentrations for metals and explosives in Jimmy Lake and Shaver River ranges. During Phase II, these two ranges were re-sampled to verify the results of Phase I. Jimmy Lake Range was evaluated using both circular and linear sampling strategies, while for Shaver River Range, only the circular strategy was applied plus a statistical evaluation using 100 discrete samples. During Phase II, vegetation sampling was accomplished in Alpha Range using the linear transect strategy that had been omitted during Phase I. Moreover, the remote areas were visited by helicopter and sampled for metals. For the remote areas, at each location a different strategy was applied. A total of 324 soil samples including 100 discrete samples plus 12 composite, 15 duplicate and 12 background samples were collected. 69 vegetation samples were also collected including 11 duplicate and 19 background samples. 19 surface water samples including 2 duplicate samples were collected and 28 sediment samples including 5 duplicates were collected during Phase II. The surface water samples were collected mainly in Primerose Lake and Jimmy Lake, but also in Shaver River, in remote areas and in holes containing water in Alpha and Shaver River ranges. Sediment samples were collected in Primerose Lake and in Jimmy Lake. All samples were analyzed for metals (440), while a limited number was analyzed for energetic materials (180 soil and 8 water samples).

Background soil samples are critical to establish the anthropogenic contribution versus the natural contribution for all metal parameters. Background composite samples were collected randomly, in circles of approximately 10 meters diameter in different locations inside and outside the base. A minimum of 30 sub samples was collected to form each background sample. A statistical analysis was conducted to identify a mean background concentration and to define a limit for a value that can be considered normal. Values at the extremities of the lognormal curve were identified. The limits were chosen for a probability of 97.72% (2 times the standard deviation). The probability of finding a result with a value higher than this limit is 2.28 %. When the metals were not detected, a value at half of the detection limit was used for the data analysis.

The usual strategy for soil sampling was based on systematically sampling around a representative number of targets in ranges and also around hot spots (broken casings, UXOs or debris, etc.). Usually, surface soils were collected at a depth of 0-5 cm. This strategy was used in previous studies on antitank ranges, which showed very distinct patterns of contamination around targets [2]. This strategy was used mainly in remote areas. In Bravo Range, only a few samples were collected and most of them were background samples. In Alpha Range, the linear transect strategy was used to collect the vegetation samples. This strategy is the same as the one used during Phase I (Fig. 1). This approach was used to evaluate whether the level of contamination by metals or energetic materials was following a pattern with distance from the target in the ranges. If firing activities led to the accumulation of contaminants in soils or vegetation, higher concentrations should be found around targets. Therefore, composite samples were collected at distances of 20, 40, 60, 100, 120 % and 140% of the distance from the entrance of the range to the target. Most of the time, an access road went directly to the targets in the middle of the ranges. This road was used for maintenance and clean-up. That road was used to build transects (right and left of centerline) perpendicular to the road. Twenty or more increments were taken to build each composite. Transects were fixed with the help of the Global Positioning System (GPS). The GPS locations are reported in Table I. The linear transect samples corresponded to the % of the distance between the range entrance and the target. As an example, at 20% of the distance, we collected on each side of the road by walking perpendicularly to the road using a GPS to keep on a straight line. A minimum of 20 surface sub samples at 0-2 cm depth were collected to build each composite sample with A and B corresponding to the right and left sides of the road. The composites were built by walking 100-200 meters. In some occasions such as hot spots or other artefacts of interest, we used composite sampling that consisted in building the sample using discrete samples around the hot spot (20 minimum). This strategy was also used in the strafing area of Jimmy Lake Range except that the 40 % corresponded to the target area (Fig. 2). Three to four sets of poles held targets for strafing in this range as illustrated in Figure 3. Composite soil samples were collected behind three targets in transects that were split into A and B sections as illustrated (Fig. 2). Transects were parallel to targets at distances of 20, 40, 60, 80, 100, 120, 140 and 160% of a 150 m range. The soil samples collected in this range were comprised of fine grained sand and were collected in transect 0 to 100 %. Samples of vegetation were taken at 20 to 60 % and at 120 to 160% beyond the 150 m length of the range.

In the Bombing area of Jimmy Lake and in Shaver River ranges, the circular sampling strategy developed during Phase I was applied and consisted of sampling around targets by compositing samples taken in a circular pattern. This strategy, based on the circular sampling used at CFB Shilo, was used for specific target evaluation. The strategy was modified to adapt to the specific context of air-to-ground targets and was designed to allow a comparison of the relative concentrations in front of and behind a target. A semi-circular pattern was used to collect composite samples at specific distances from the targets (Fig. 4). Twenty-six soil samples were collected around targets, one within each of the cells around the target. Three circles located at 10, 30 and 50 m radius of the target define these cells. Two composite samples (A1 & A2) were collected in hemispheres of the first 10-m diameter ring (Front and Back of Target). Eight equal-sized rectangles were sampled between 10 and 30 m (B1-B8), and 16 between 30 and 50 m (C1-C16). Twenty or more increments were collected to build 800 g to 1.5 kg composite samples. In Jimmy Lake Range, an old Truck was used as the target, while a tank was used as the center of the circular strategy in Shaver River Range (Figs. 5, 6). In this range, air dropping of 250, 500, and 1000 lbs high explosive (HE) bombs at a stationary target is done on a regular basis and significant explosive concentrations had been measured during Phase I. For this reason, the circular approach was used to verify that the concentrations were of the same order of magnitude even with the range tilling performed regularly. As for the other ranges, the surface was covered with fine grained sands. In front of the target in Shaver River Range, sampling designed for a statictical analysis was conducted.

The purpose of the sampling experiment conducted at the Shaver River Range was to understand the distribution of energetic residues at an Air Force bombing range in order to optimize the sampling strategy for collection of representative surface soil samples at these types of ranges. The emphasis was on surface soils because residues of energetic compounds are deposited as particles at the surface. These surface residues are the largest source of residues for potential migration of these compounds off site. In order to provide a reliable estimate of the mass of these residues at various locations on ranges, it is necessary to provide samples that represent these areas within an acceptable level of uncertainty. The level of uncertainty that would be acceptable is site specific. Our objective is to provide some guidelines to enable a selection of the sampling and subsampling protocols that can provide that level of confidence.

To achieve that goal, a 10-m x 10-m area was selected that was about 15 m from a bombing target in B-1. Four 30-increment composite surface soil samples (0 to 2.5 cm) were collected by two different individuals using the random walk method. Increments were collected using stainless steel scoops because the soils at these installations were coarse grained and not sufficiently cohesive to allow the use of a core sampler. Composite samples were placed in 32-oz glass jars kept in a cooler.

The 10-m x 10-m area was subdivided into one hundred 1-m x 1-m minigrids using wooden sticks (Fig. 7). Within each minigrid, a discrete surface soil sample (10 g, 0 to 2.5 cm) was collected by several individuals at random positions within the minigrid using metal scoops. These discrete samples were placed in 4-oz amber glass containers. Both the grid composite samples and discrete minigrid samples were shipped to CRREL and analyzed with the protocol previously described.

Wherever vegetation samples were collected, the method consisted of building composite samples of indigenous living plants by randomly cutting various types of plants. A minimum of 20-30 sub samples of mixed vegetation material was collected to build the different vegetation samples around targets and in transects. Only the upper part of the plants (without roots) was collected, since grazing animals rarely eat the roots of the plants as verified by consulting an expert from Environment Canada (Lucie Olivier, Environment Canada-Montréal). Metals could bio-accumulate either in the upper plant system or in the roots, depending on their solubility.

For surface water samples, the strategy consisted in collecting at 10 and 13 different locations in Jimmy Lake and in Primerose Lake and to note the GPS locations. Jimmy Lake is much smaller than Primerose Lake. Surface water was also collected in two craters formed by a detonation, one in Alpha Range and the second in Shaver River Range as illustrated in Figure 8. Sediment samples were also collected in Jimmy Lakeand in Primerose Lake using a manual grabber (Fig. 9). Excess water was removed by decantation and the sediment was transferred into polyethylene bags.

Finally, six sites were sampled in the remote areas: C-295, C-284, C-314, A-387, F-332 and E-301. Many of these sites were highly vegetated and very wet and sometimes, collection of water samples only was possible such as in C-295. In these instances, water samples were collected by standing on the Heli-skids. No energetic materials are used in the remote areas; so, most of the analyses were to determine metal concentrations. Usually, wooden targets or existing infrastructures such as old gas wells are used in the remote areas for aiming practice, laser pointing etc. (Figs. 10, 11). Pratice bombs and rockets were found in two different sites (Figs. 12-14). In all of these sites, since our flying time was limited, only targets or infrastructures were sampled using the compositing approach. Efforts were made to collect soil, vegetation and water when possible at each site. Site E-301 which was new and had never been used before was considered as background for our study.

4 Results and Discussion

In our evaluation of the results for the metals concentrations, we chose to compare values for each parameter to values encountered in the background samples. By doing so, we can evaluate if the concentrations of a particular contaminant is anthropogenic or not. GPS locations for each background samples can be found in Table I. For the management point of view, this approach can be valuable, but the site owners want to know if there are problems, at which extent and what can be done to solve them. Scientifically, comparison with the background values is important since it allows the understanding of the first effects of the training activities on the environment and gives us plenty of time to react and possibly eliminate the effects of such activity by applying mitigation methods. Our approach consisted in comparing all the results to background values first then to the agricultural soils quality guideline (ASQG) and finally to the Industrial Soil Quality Guideline (ISQG) established by the Canadian Council of Ministers of Environments (CCME) (see www.ccme.ca or in the file annexed in Appendix B on compact disk). Even if DND properties are not dedicated to agriculture, the ASQG represents the first official threshold value and the fact of having concentrations of a particular parameter higher than the ASQG can raise important questions for the management of the sites. This is particularly true for sites such as WATC Wainright where cows are allowed to graze in the DND properties during summer. The same rationale can applied to the ISQG since the DND properties are not industries, but having concentrations higher than the ISQG can urge the Department to find and apply solutions for due diligence.

In our evaluation of the results, the mean values for background samples were the mean of all collected backgrounds for each parameter measured. When results lower than detection limits were encountered for specific parameters, half of the detection limit for that parameter was used for calculation of the mean value. The results obtained in training areas were compared to the mean value of the background to which was added twice the standard deviation. This allowed the selection of results having values greater than the background means, while being representative. Results are presented for each parameter instead of per sample to facilitate the analysis of trends for each parameter. Backgrounds were always tabulated first with mean, standard deviation, mean plus twice the deviation standard, and CCME threshold criteria values for each metal. Then, results for samples collected in the training areas were tabulated. As mentioned in the first paragraph, surface soil samples were compared to the background values and to the most stringent agricultural CCME threshold levels for metals that were included in the latest published CCME quality guideline. For metals that were not included in the CCME list, results were compared to the mean values added to twice the standard deviation of all soil background samples. Such results exceeding this value were highlighted in blue in Table II. Even if not applicable to DND sites, the CCME agricultural soil criterion is the most stringent reference, and, therefore, shows where contamination should be looked at first and monitored. When metal concentrations were above the agricultural criteria (green), they were also compared to the industrial soil criterion, which is the most permissive criterion. These results were highlighted in red in the tables. For vegetation, there are no CCME criteria. Results higher than the mean values added to twice the standard deviation were highlighted in blue in Table III. Metals concentrations in surface water samples exceeding the CCME water criteria were highlighted in red and are presented in Table IV. For some parameters in surface water samples, the CCME criterion was given as an interval of concentrations such as 5-100 ppb for aluminum. Concentrations within this interval, were highlighted in green. For the surface water samples, the CCME aquatic life threshold criterion is the most appropriate value to use. For sediment samples, all the parameters were compared to the CCME Interim Sediment Quality Guideline (ISQG) and to the CCME Probable Effect Level (PEL), which is more permissive than the ISQG. Values higher than the CCME criteria were highlighted in red in Table V. To facilitate the following discussion, values indicated as *higher than background* are actually higher than the mean plus twice the standard deviation.

During Phase II, 324 soil, 69 vegetation, 19 surface water and 28 sediment samples were collected in August 2003. Analyses for the following metals were conducted on all samples: Sb, As, Ba, Be, Cd, Cr, Co, Cu, Pb, Mo, Ni, Se, Ag, Sr, Tl, Sn, V, and Zn. Soil, water and sediment samples were also analysed for Hg and U. Vegetation and surface water were also analysed for the following: Al, Ca, Fe, Mg, Mn, K, Na and Ti. Only surface water was analysed for Li. Since Plants were not washed, the results for plants are metals both bio-accumulated and deposited on the plants. Analyzing leachates to discriminate between metals in and on plants was not judged necessary, since wildlife ingest both.

For Phase I, no major environmental impacts related to the training activities were identified. In soils, the accumulation of some heavy metals associated with ammunition was observed in some parts of ranges, but concentrations did not reach levels of concern. Phase I results clearly demonstrated no major problems associated with soil contamination except in a few locations such as Jimmy Lake and Shaver River ranges, which were re-sampled during Phase II.

Out of the 324 soils samples, 180 samples were analysed for energetic materials. Eleven parameters were screened for explosives, including the most common explosives RDX, HMX and TNT, using the HPLC method. Analyses for energetics were done at CRREL for the samples collected in the statistical evaluation and at DRDC Valcartier for all other samples. Both labs used the RP-HPLC EPA SW 846 Method 8330 with a reporting limit of usually 100 ppb for most analytes except for DNB, tetryl and PETN, for which limits were slightly higher. The detection limits for all analytes at CRREL are described in Table VI, while at DRDC Valcartier, the detection limit was slightly higher at 64 ppb. The GPS locations for all these samples can be found in Table I. For the purposes of this report, we can consider that energetic compounds fall into two classes, those that are related to propellants and those related to high explosives.

Nitroglycerine (NG), dinitrobenzene (DNB), dinitrotoluene (DNT) and trinitrobenzene (TNB) are either major ingredients or impurities in various types of propellants such as those used in rocket motors. Usually, rockets use either double base propellants composed of nitrocellulose and nitroglycerine or a thermoset polymeric matrix based on hydroxyl-terminated polybutadiene containing ammonium perchlorate as the oxidizer. Perchlorate analyses should be performed in ranges to evaluate impacts by this chemical. However, these analyses are costly and will be performed only for groundwater samples that will be collected during the hydrogeological study. The single base propellants also contain DNT as a plasticizer and impurities such as DNB and TNB coming from the synthesis of energetic materials, starting from toluene containing benzene as an impurity.

High explosives used by both Canada and the United States generally contain either TNT (2,4,6-trinitrotoluene) or mixtures of TNT with RDX (hexahydro-1,3,5-trinitro-1,3,5-triazine), HMX (octahydro-1,3,5,7-tetranitro-1,3,5,7-tetrazocine), or for some older muntitions, tetryl. Most of the air weapons contain TNT with aluminum (tritonal explosives). The most powerful weapons contain Composition B (TNT with RDX) or octol (TNT with HMX). When UXOs are found on sites, they are often blown in place (BIP) using C-4, a mixture of RDX with a polymer. These BIP operations often spread explosives into the environment [11].

Results for energetic materials are presented in Tables VII to X for soil in Jimmy Lake and Shaver River ranges. No table is presented for surface water samples since no explosives were detected in any water samples except for the sample collected in a crater in Shaver River Range (Fig. 8). This sample analysis is reported in Table VIII. When munitions or debris were visually observed, the samples were collected as near as possible to the UXO with sub samples around it.

4.1 Alpha Range

The Alpha Range is located in front of Primerose Lake and was roughly 1.0 km long. This range was covered with grasses growing in fine grained sand. Mainly vegetation samples were collected in this range since these were lacking in Phase I. Vegetation samples were taken in front of the tank target (Fig. 15), in front of the strafing wall (Fig. 16), and as background samples at the boundaries of the range. Linear sampling was also performed along transects (100 m each side) in front of the target going up range at distances of 0, 200, 400, 600, 800 and 1000 m (Fig. 1). No energetic analyses were performed in this range since the concentrations of explosives determined during Phase I were ≤ 1 ppm. No soil samples were collected. A surface water sample was collected in a small puddle 50 meters away from the tank target. 22 vegetation samples were collected, including 4 background samples.

Vegetation

The results for the vegetation samples are found in Table III. Some parameters in blue font exceed the background level value (BGL). Of the 27 parameters analysed, only Al, Sb, As, Cd, Ca, Cu, Fe, Pb, Ni, Na, Sn, Ti, V and Zn were detected at values higher than the BGL. All of the parameters that exceeded the BGL had concentrations very close to the background values except for Al, Fe, Pb Na and Ti in linear transect 0% A. Curiously, no parameters exceeded any background values in all other linear transect samples. Results indicated little or no phytoaccumulation of metals in this range.

Surface water

The only surface water sample collected in a small puddle in Alpha Range was highly contaminated by most of the metals. Al, As, Ba, Cd, Cr, Co, Cu, Fe, Pb, Mn, Ni, Tl, V and Zn were detected at concentrations much higher than the CCME criteria. Based on the aluminum value, a low order detonation of an item containing tritonal may have occurred in that puddle. The metal concentrations were very high but considering the limited amount of water in the puddle, this represents a small impact to the range.

4.2 Bravo Range

The Bravo Range is also located in front of Primerose Lake and is composed mainly of sandy soil with little vegetation. The range was freshly tilled when we arrived on site and many concrete bombs were lying on the ground close to the target (Figs. 17, 18). Since the vegetation was very scarce and the site looked very clean, vegetation was sampled 70 meters in front of the target (two samples, one right, B-Br-T-Front right and one left of the target, B-Br-T-Front left). Background vegetation and soil samples (3 vegetation + 3 duplicates, 1 soil and 1 duplicate) were also collected. No energetic materials were analysed in this range. No surface water samples were collected in Bravo Range.

Vegetation

Some parameters exceeded the background level value and are in blue in Table III. Of the 27 parameters analysed, only Cr, Fe, Pb, Na, Sr, Ti, V and Zn were detected at values higher than the BGL, but concentrations were of the same order of magnitude as in Phase I indicating limited or no accumulation. Some analytes identified as a problem during Phase I, Al, Ba, Cd and Cu were not a problem during Phase II. It is probably because the soil was moved during the cleaning of the sites and this decreases the concentrations by mixing with cleaner deeper soil. Nevertheless, as in Phase I, it is concluded that this site is not contaminated.

4.3 Jimmy Lake Range

In Jimmy Lake Range, the bombing circle and the 20-mm strafing areas were sampled as illustrated in Figures 2 to 5. The practice target was used for concentric circular sampling (Fig. 5) and the linear sampling strategy was used for the 20-mm firing range. For the bombing circle, 30 soil samples including 4 duplicates were collected in the circular sampling, while one vegetation sample, B-JL-BC, was collected. Two vegetation samples, B-JL-BC-1 and B-JL-BC-2, were collected and used as background samples. For the strafing areas, composite soil samples were collected in transects that were split into A and B sections (Fig 2). Transects were perpendicular to the direction of flight (West to East) and were placed at 20, 40, 60, 80, 100, 120, 140 and 160 % of a 120-m range, the 40 % transect being at the target locations (Figs. 2, 3). This strategy was used to detect any progression of the metal concentrations from behind to the front of the targets. In the strafing area, 14 soil samples including 2 duplicates were collected between 0 and 100 %. In addition, 15 samples of vegetation including 3 duplicates were taken at each transect except at 80 and 100% where no vegetation was present. The soil samples collected in this range were comprised of fine-grained sand. The Jimmy Lake Range is located between Jimmy Lake and Primerose Lake. A total of 44 soil samples and 18 vegetation samples were collected in this range. Energetic analyses were performed only on samples collected in the circular strategy, since the strafing area is not supposed to contain energetics.

Soils

Some parameters in blue exceeded the background level values in Tables II A, B, and C. Of the 20 parameters analysed, Cd, Cr, Cu, Pb, Ni, V and Zn were detected at values higher than the BGL or the ASQG, and in some occasions were higher than the Industrial Soil Criteria in the bombing circle area. The strafing area showed only copper at values higher than the BGL especially in front of the targets, showing that our approach was efficient for characterizing the surface. Definitely, the strafing area is not contaminated compared to the bombing circle area, where all the samples showed concentrations higher than the BGL, the ASQG, or the ISQG for the problematic parameters. As observed in Phase I, the same analytes are problematic with cadmium concentrations exceeding the ASQG in all of the samples. High cadmium concentrations can come from the rocket paints that may contain this metal as anti-corrosive or as part of the internal parts of the warheads. The most probable hypothesis is that cadmium is part of the painting of the rockets, since a problem had already been encountered in the warehouse where they were cleaning the launchers. If recovered from the cleaning of the launchers, cadmium vaporization resulting from the intense heat during the firing of the rockets is likely responsible for the deposition of this metal in the launcher. This was confirmed in a recent paper by Thomas Boggs who mentioned that cadmium, zinc and chromium are important metals components of bombs paintings that are released into the environment during open detonation [29]. On impact with the ground or with the target, debris of rockets may deposit cadmium on the ground, explaining thus the high concentrations of this metal in this site. Chromium concentrations exceeded the BGL for many, but not all, of the samples. Copper was observed at concentrations higher than the ISQG in six bombing circle samples, while 14 samples exceeded the ASQG and the other was higher than the BGL. All of the samples of the bombing area exceeded the BGL for Pb, Ni, V and Zn. The concentrations in the bombing area of Jimmy Lake Range are of the same magnitude as during Phase I. The impacts of training activities on Jimmy Lake Range are clearly important. Only copper exceeded the ISQG; therefore, particular attention should be given to this parameter and to cadmium as well. Legally, since the site use will not change, i.e., will continue to be used as a target area, no action is required; however, to demonstrate due diligence, a thorough cleaning of the small surface area should be conducted, the soils should be removed and sent to secure cell, especially if the hydrogeology study demonstrates that cadmium or copper are problematic in groundwater.

Vegetation

Only one vegetation sample was collected in the bombing area while 15 samples were collected in the strafing area. For the sample in the bombing area, some parameters exceeded the BGL and are in blue in Table III. Of the 27 parameters analysed, only Ca, Cu, Fe, Pb, Se, Na and V exceeded the BGL. Most of the parameters that exceeded the BGL in vegetation samples also exceeded the BGL in soil, except for Ca, Na and Se. Surprisingly, cadmium did not exceed the BGL in vegetation. This can be explained by the fact that different metals may have different extractability and some metals are preferentially extracted from the soils by the plants.

Energetic Materials

On Jimmy Lake Range, almost all samples collected in the bombing area contained the propellant-related compound nitroglycerin (NG) (Table VII). Concentrations varied from 170 to 3590 ppb. These results are propellant residues deposited around the target. TNT was detected at 70 ppb in only one sample. Compared to the results obtained during Phase I, the situation is similar but the concentrations of nitroglycerine are higher. Also, during Phase I TNT was found in almost all samples collected in the bombing area; this was not observed in Phase II. The nitroglycerine source is double or triple base propellants that were spread on site by incompletely burned rockets. Since the concentrations of explosives were quite low, no action is required to correct the situation with explosives at this site.

4.4 Shaver River Range

Shaver River Range is located close to the Shaver River and is remote from Jimmy Lake. In Shaver River Range air dropping of 250-, 500-, and 1000-lbs HE bombs at stationary target is done on a regular basis. Again, the circular strategy was applied as performed during Phase I (Fig. 6). As for the other ranges, the surface was covered with fine-grained sands. In Shaver River Range, 33 soil samples including 6 duplicates and 1 surface water sample in a crater close to the target were collected (Fig 8). Three soil samples were collected as background samples. No vegetation samples were collected, since no vegetation was present in the bombing area. Energetic analyses were performed on all the samples collected in this range. Furthermore, 100 discrete soil samples were collected in front of the target in a grid of 100 - 1-square meter minigrids to evaluate the statistical dispersion of the explosives. Moreover, 4 composites were built to assess the heterogeneity by collecting soil samples randomly in the grid. In this range efforts were concentrated mainly on the analyses of energetic materials, since this range was used mainly for live firing. Since the area surrounding the target position at the Shaver River Range is often tilled to minimize the vegetation and reduce the chance of the live-fire activities initiating a forest fire, the area was re-sampled to verify the effect of the tilling and heterogeneity on the results.

Soils

Some metal concentrations in blue exceeded the background level value in Table II A, B, and C. Of the 20 parameters analysed, only Cd, Cu and Pb were detected at values higher than the BGL or the ASQG. Cadmium is again problematic at concentrations higher than the ASQG for most of the samples collected with the circular strategy. Even if most of the cadmium concentrations are higher than the ASQG, the levels are lower than in the Jimmy Lake bombing area. Clearly, the effects of the activity conducted in the Shaver River Range is different from those in Jimmy Lake Range. Copper and lead had concentrations higher than the backgrounds, but not all samples showed these concentrations. Curiously, soil collected in the crater 2-3 meters away from the target showed no concentrations higher than background levels. This shows that the metal concentrations are very localized around the target. Compared with the results from Phase I, the situation is almost identical except that antimony, which had been problematic during Phase I, did not exceed the ISQG during Phase II.

Surface Water

The only surface water sample collected in a crater was highly contaminated with most of the metals. Al, Cd, Cu, Fe, Pb, Mn, Zn were detected at concentrations much higher than the CCME criteria. The high aluminum value suggests that a low-order detonation of an item containing tritonal took place in that crater. The elements of concern in this crater are almost identical to the one encountered in the small puddle in Alpha Range. The same conclusion can be drawn here; the metal concentrations were very high, but considering the limited amount of water in the crater, this represents a small impact to the range.

Energetic Materials

All of the soil samples collected at the Shaver River Range were analysed for energetic materials. Results can be found in Table VIII A and B. No explosives were found in the three background samples S-SR-BG1, 2 and 3. No propellant residues were found in any circular samples except for 1,3,5-TNB at concentrations of 0.23 to 1.66 ppm in 22 out of 32 soil samples from the circular sampling strategy. Propellant residues were found in the surface water sample collected in the crater. NG concentration was 2 ppb while 1,3-DNB, 2,6-DNT and 2,4-DNT were respectively 595, 377 and 6,486 ppb. No 1,3,5-TNB was found in this sample. In the soil samples collected in the crater, only 1,3,5-TNB was detected at 350 ppb.

TNT was found in all soil samples collected in Shaver River Range. The TNT concentrations for the soil samples collected in a circular pattern around the target were much higher than for the other soil samples collected at this site. Concentrations above 50 ppm were found in samples from the A, B, and C rings, with the highest concentration at 165 ppm in A-1 (compared to 332 ppm in C11 during Phase I). Here again, much lower concentrations of TNT-related compounds, such as 2,4-DNT, 2,6-DNT, TNB, 2-ADNT, and 4-ADNT, were found in the samples. In two samples, B1 and C4, from the target area, very low concentrations of RDX and HMX were found, 350 ppb for RDX in B1, 6000 ppb for RDX and 1470 ppb for HMX in C4. Neither RDX nor HMX were detected in the samples that contained the highest concentrations of TNT. Thus the source of these small amounts of RDX found on the Shaver River Range appears to be different from the source of the TNT. The source of TNT at this range is thought to be the tritonal used as the high explosive in Air Force bombs. TNT was found at 79.38 ppm in the soil collected in the crater, while TNT was found at 13.10 ppm in the water collected in the same crater. Strangely, RDX was found at 2 ppm in the surface water sample collected in the crater, this is almost maximum RDX water solubility and may indicate that a blow-in-place operations using C-4 took place and generated that crater. Tetryl was not detected in any samples. Compared to results obtained during Phase I, the situation is very similar with small differences such as no tetryl and a higher TNT maximum concentration during Phase I. In general, in Shaver River Range, the concentrations of explosives (mainly TNT) were much higher than in the other ranges. Most of the TNT explosives-related compounds were found in almost all the samples except for RDX and HMX that were found at very low concentrations. TNT was the most important contaminant.

In front of the target in this range, 100 discrete minigrid samples and 4 composite samples were collected from a 10 x 10-m grid located in B1. Analytical results for the four replicate 30-increment composite samples are shown in Table IX. Results are shown for the individual subsamples for each of the four composite samples along with the mean concentrations for each replicate sample and the grand mean for the 10-m x 10-m grid. Six explosives-related compounds were detected in all of these samples with TNT being present at a factor of 11 or greater than any of the other compounds. The other compounds detected are either manufacturing impurities in military grade TNT (2,4-DNT) or environmental transformation products of TNT (1,3,5-TNB, 1,3-DNA, 2-ADNT, 4-ADNT).

The grand mean concentration of TNT was 10.7 mg/kg in these four replicate samples and the relative standard deviation was 5.55%. The mean concentrations for the other analytes detected in these composite samples (in the order of decreasing concentrations) were 2-ADNT at 1.19 mg/kg, 4-ADNT at 0.776 mg/kg, 3,5–DNA at 0.263mg/kg, 1,3,5-TNB at 0.107 mg/kg, and 2,4-DNT at 0.098 mg/kg. The relative standard deviations for these compounds ranged from 5.83% to 9.20%. Thus very repeatable sampling was achieved for this 10 x 10-m grid area using 30-increment composite samples, even with respect to the minor components present at low concentrations. Subsampling error for each of the four replicates was estimated by pooling the relative standard deviations for the six compounds. These pooled % RSDs ranged from 2.95 to 5.93% (Table IX) indicating that the method used to process these samples was effective at minimizing subsampling error for these large composite samples weighing about a kilogram.

Analytical results for the 100 discrete minigrid samples are presented in Table X. The same six compounds detected in the 30-increment composite samples from this area were also detected in almost all of these discrete samples, although the concentrations varied by as much as three orders of magnitude. RDX and HMX were also detected in 19 and 4 of these discrete samples, respectively, but were not detected in any of the four 30-increment composite samples.

TNT concentrations varied from 0.381 to 289 mg/kg in these discrete samples, a range of nearly three orders of magnitude, with a mean value of 16.2 mg/kg. Clearly, use of a single discrete or even several discrete samples to estimate the mean concentrations in this 10 x 10-m area would be prone to large sampling errors. The highest RDX concentration was 35.4 mg/kg in minigrid # 42, but the TNT in this sample was only 0.657 mg/kg indicating that the source of the RDX was probably not the same source that led to widespread TNT concentrations within the overall 10 x 10-m grid. The source of the RDX is uncertain, but could been C4 used as a donor charge to detonate duded bombs on this range. The fact that none of the other minigrids surrounding minigrid # 42 had RDX concentrations in excess of 0.179 mg/kg indicates that a small piece of RDX-based explosive may have been present in the discrete sample collected from minigrid #42.

The distribution of TNT values for these 100 minigrid samples is shown in Figure 19 as a histogram with a bin size of 5 mg/kg. Clearly, this distribution is non-Gaussian as has been found elsewhere for energetic compounds at other types of training ranges [30-31]. 68 of the TNT concentrations for discrete samples had concentrations that were less than the mean of 16.2 mg/kg. The concentration of TNT versus position within the 10 x 10-m grid is presented in Figure 20. Upon close inspection, one set of higher concentrations of TNT might be present in a line from minigrid #41 (which had the highest TNT concentration of 289 mg/kg) diagonally to minigrid # 5, although other minigrids randomly located within the overall 10 x 10-m grid had similar concentrations. No clear-cut hot spots of high concentrations were distinguishable.

While we collected four 30-increment composite samples within this 10 x 10-m area, multi-increment composites with various numbers of increments from the 100 discrete samples can be mathematically simulated. This is valid because multi-increment composite samples are a physical average of the increments used to create the composite, and equivalent results have been shown if the increments are individually analyzed and combined mathematically or composited and the composite subsampled and analyzed [32].

Sets of 50 multi-increment results for TNT were simulated from the 100 discrete samples for values of n ranging from 5 to 50. A random number generator was used to select values with replacement. The minimum, maximum, mean, median, standard deviation, and tolerance limits (5%) for these distributions are shown in Table XI. Histograms for the distributions for n equal to 5, 30, and 50 are shown in Figures 21, 22, and 23. As expected, as the number of increments per sample increases, the difference between the minimum and maximum decreases and the median and mean become closer together. The trend toward a more Gaussian distribution (as predicted from the central limit theorem of statistics) is less observable in these data than for similar data sets from other sites with residues of energetic compounds [31]. The presence of several high concentrations for individual minigrid samples such as minigrid # 41 where the TNT concentration was 289 mg/kg and minigrid # 37 where the TNT concentration was 100 mg/kg may account for this observation or relationship. Nevertheless, increasing the number of increments per composite samples does reduce the tolerance range (Table XI) and improve the likelihood of obtaining a result that is an acceptable estimate of the mean.

It is interesting to compare the results of the four 30-increment composite samples collected from within this 10-m x 10-m grid with the simulated results for 30-increment composites. The four measured values for TNT ranged from 10.2 to 11.6 mg/kg with a mean of 10.7 mg/kg. The simulated composites ranged from 7.45 to 41.9 mg/kg with a mean of 15.5 mg/kg. Estimates of the uncertainty from these two sets of data are quite different. This difference in measured and simulated uncertainty estimates (minimum to maximum) was unexpected because a similar comparison for samples collected at the Donnelly Training Area indicated nearly identical results [33]. The Donnelly data, however, was for 2,4-DNT at a firing point area whereas the results from the Shaver River Range were for TNT at an impact area. A few of the minigrid samples from Shaver River Range may have included several small pieces of explosive that by chance were not included within the 30-increment composite samples.

4.5 Primerose Lake, Jimmy Lake and the Shaver River

Eight surface water samples were collected in Primerose Lake, in Jimmy Lake and in the Shaver River to evaluate the quality of surface water. Out of these, 6 were analysed for energetic materials. No explosives were detected in any of the surface water samples SW-JL-1, 2 and 3 and SW-PL-2 and 4. Only one surface water sample revealed the presence of energetic materials, the sample collected in the crater on Shaver River Range (Table VIII). In Jimmy Lake, the 3 water samples and the 12 sediment samples including 2 duplicates were collected using a small row boat, while in Primerose Lake a motorized boat was used to collect the 4 surface water samples and the 16 sediment samples including 3 duplicates (Fig. 9). Moreover, a last surface water sample was collected at the mouth of the Shaver River; no explosives were detected in that sample. Therefore, no contamination of the surface water by explosives was detected in the lakes. No explosive analyses were done with the sediment samples. All of the GPS locations of the surface water samples and the sediment samples were noted (Table I).

Sediment

The metal concentrations in sediment samples were determined and compared to the ISQG. Some parameters exceeded the Interim Sediment Quality Quideline (ISQG) or the Probable Effect Level (PEL) and were highlighted in red in Table V A, B and C. Only As and Hg exceeded the CCME threshold criteria. For As, only 2 samples in Jimmy Lake, Sed-JL-7 and Sed-JL-8 and 4 samples in Primerose Lake, Sed-PL-1, 2, 3 and 5, exceeded the most severe ISQG, but were of the same order of magnitude. For mercury, only 3 samples, all in Jimmy Lake, exceeded the ISQG. Sed-JL-3 even exceeded the most permissive PEL criterion. All of the other parameter concentrations were below the CCME ISQG or CCME PEL criteria, showing that the sediment are in excellent condition.

Surface water

Eight surface water samples were analysed for metals including the sample collected at the mouth of the Shaver River. Concentrations for each parameter were compared to CCME aquatic life in freshwater criteria when available or to the CCME drinking or irrigation criteria as stated in Table IV A, B, C and D. Concentrations higher than the CCME criteria were highlighted in red. On some occasions, the CCME criteria was expressed as an interval of values. In these instances, when the concentration of the considered parameter was within the interval, the concentration was highlighted in green. The detection limit for cadmium in water is 0.2 ppb, a value superior to the CCME criteria. According to our evaluation, when not detected, a value at half the detection limit is written but this value of 0.1 ppb is still higher than the criterion. In this case, when cadmium was not detected, it was not highlighted in red even if the value in the table was greater than the CCME criterion.

Out of the 30 parameters measured in surface water samples, only Al, Cd, Cu, Fe and Ag exceeded the CCME threshold criteria. For Aluminum, all samples showed concentrations within the interval of the CCME criterion. High levels of aluminum and arsenic are not unusual in western water bodies. This had already been observed in CFB Shilo where aluminum, arsenic and iron were naturally elevated [28]. Cadmium concentration at 0.3 ppb was observed in only one sample, SW-JL-3. Copper concentrations in surface water samples in Jimmy Lake were within the interval of the CCME criterion, while for the only sample collected in Shaver River, the copper concentration was twice the CCME criterion. Iron was also observed in the

Shaver River sample at three time the CCME criterion. Concentrations of all the other parameters were lower than the CCME criteria, except for one sample in Jimmy Lake where silver was detected at 5 times the CCME criterion. During Phase I, silver was also detected in Jimmy Lake. We have no explanation for this anomaly. No other samples in Jimmy Lake demonstrated the presence of silver. In general, the quality of the surface water is excellent in both lakes.

4.6 Remote Areas

Two days were needed to visit and sample 6 sites in the remote areas. The first visited site was C-295, a very wet airstrip where wooden targets were disposed (Fig. 10). Surface water could only be sampled by standing on the Heli-skids at this site. No energetic materials are used in the remote areas, so most of the analyses were done to determine only metal concentrations. Most of the sites were highly vegetated and very wet. Efforts were made to collect soil, vegetation and water when possible at each site. The second site was C-284 where old oil wells were used as laser pointing targets (Fig. 11). In this site, two big metal reservoirs and four oil rigs were located. Two surface water samples were collected in holes; 4 vegetation and 4 soil samples were collected around the two reservoirs, in the middle of the range and also around the oil wells. The third site was C-314, which was a small island used as a target in Primerose Lake. In the middle of the island, soil and vegetation samples were collected around a small wooden target and also in the areas right and left of the target (Fig. 24). Three vegetation samples and 2 soil samples were collected and were named A, B and C respectively, B being around the wooden target. The fourth site was A-387, another airstrip with a wooden target where planes coming from the lake aimed at the target. In this site, we collected only four vegetation samples in circles A, B, C and D respectively, B being around the target (Fig. 25). The second day, we visited site F-332, a small hill surrounded by a lake (Fig. 26). Much rocket debris was seen at this site. Two vegetation and 2 soil samples were taken on the left and right sides of the area pictured (Fig 26). Just beside site F-332, a minute flight away, we landed to collect two water samples in the airstrip. The last visited site was E-301. This site was new, had never been used before and was highly vegetated. We sampled around two intact wooden targets at this site (Fig. 27). Samples A, B were collected beside the helicopter and C a little farther away. Three vegetation samples and 3 soil samples were collected in A, B and C. One surface water sample was collected in a small river surrounding the site. These samples were considered background.

Soils

Some parameters exceeded the BGL and are in blue in Table II A, B, and C. Of the 20 parameters analysed, only Co, Cu, Pb, Sr, and V were detected at values higher than the BGL in some samples collected in remote areas. No parameters were detected at values higher than the ASQG or the ISQG. Samples collected in site C-284, where the old oil rigs were located, showed the highest number of blue values, but these concentrations were nevertheless quite low. Clearly, the quality of the soils in the remote areas is highly comparable to background showing that the activities have a very limited effect on these environments. No action is required on these sites.

Vegetation

Some parameters exceeded the BGL and are in blue in Table III. Of the 27 parameters analysed, only Al, As, Ba, Cd, Fe, Pb,Mn and Zn exceeded the BGL. The parameters that exceeded the BGL in vegetation samples were not the same as the ones that exceeded the BGL in soils. Nevertheless, the accumulation of these metals was not extensive. Most of the concentrations were very close to the BGL indicating that the vegetation is not very contaminated.

Surface water

Nine surface water samples including 2 duplicates were analysed for metal. All the concentrations were compared to CCME aquatic life in freshwater criteria when it was available or to the CCME drinking or irrigation criteria as stated in Table IV A, B, C and D. When higher than the CCME criteria, concentrations were highlighted in red. On some occasions, the CCME criteria was expressed as an interval of values. In these instances, when the considered parameter was within this interval, the concentration was highlighted in green.

Out of the 30 parameters measured in surface water samples, only Al, Cd, Cu, Fe, Mn, Se and Zn exceeded the CCME threshold criteria. For aluminum, most of the samples showed concentrations higher than the interval of the CCME criterion. High levels of aluminum and arsenic are not unusual in western water bodies as previously mentioned. Cadmium concentrations were observed in 3 water samples mainly in C-295, the first site visited. Copper and iron were found at high concentrations in almost all samples; however, only one or 2 samples showed concentrations higher than the CCME criteria for Mn, Se and Zn.

4.7 Global Results in all Ranges

Generally, the levels of metals in soils in all of the ranges were quite low. Most of the metal exceedances were close to the BGL concentrations. Furthermore, concentrations were typically far below the ASQG or the ISQG. Some metals that were systematically present at high concentrations, such as cadmium, copper and zinc, can be related to firing activities. Compared to results obtained during Phase I, fewer metals exceeded the ISQG in Phase II. Exemples of exceedance include antimony in Shaver River Range and cadmium in Jimmy Lake Range. The fact that metals concentrations were low in the ranges is the direct result of good management of the sites performed at Cold Lake. During both visits in August 2002 and 2003, the sites were clear of debris and of large pieces of metal. Furthermore, often when we arrived on site, thes ranges had been freshly tilled. Even if the sites are often tilled, the results from Phase I and Phase II are comparable, revealing the same tendencies in the two consecutive years. In general, the removal of metals, which is performed on a regular basis, is an excellent practice and makes a significant contribution to environmental stewardship.

When the ranges are compared, the conclusions drawn from Phase I results are still good. Jimmy Lake Range is still the most contaminated site by metals; Bravo Range is less contaminated than Alpha Range; and Shaver River Range is also less contaminated than Alpha Range. In Shaver River Range, fewer metals were detected compared to Alpha Range but the concentrations were of the same order of magnitude. The metals in Shaver River Range that had high concentrations and were of concern, such as cadmium, are similar to the metals of concern encountered in Jimmy Lake but at lower concentrations. Problematic metals seem to be found in different types of weapons. For example, cadmium is not only part of the rocket painting, but can also be part of bomb painting as pointed out by Boggs [29].

The vegetation analyses revealed that some metals are phytoremediated from the soils, since direct relations between soil and vegetation concentrations were identified in almost all of the ranges. The metals phytoaccumulated did not always correspond to the metals with high concentrations in soils. Furthermore, not all the metals were phytoaccumulated, which may be the result of selective adsorption. Considering the results obtained during Phase II, the quality of the vegetation is excellent and compares well with the concentrations of the background samples. Therefore, vegetation concentrations do not represent a risk to wildlife.

Surface water and sediment were sampled during Phase II to assess the quality of Primerose Lake and Jimmy Lake. Many sediment samples were collected in both lakes using a manual grabber. Results indicated that these sediment were not contaminated with only a few exceptions. Surface water sample results also revealed that the metal concentrations were quite low and no explosives were found. In general, neither the sediment nor the surface water was contaminated in Primerose Lake and in Jimmy Lake.

For the energetic materials analyses, our efforts were concentrated mainly on Jimmy Lake and Shaver River ranges during Phase II, since explosive concentrations determined in Alpha and in Bravo ranges during Phase I revealed low ppm levels. In Jimmy Lake Range, in the circular samples, mainly propellant residues were found, such as nitroglycerine which was found in all samples. This indicates that rockets are often used at this site. In Shaver River Range, the situation was the opposite; very little propellant residues were found, but explosives such as TNT were found in almost all samples. This indicates that bombs are mainly used at this site. The metals that showed problems in Shave River Range are the same than in Jimmy Lake Range, but at lower concentrations. Little information about weapon compositions is available that can explain all of these results. The most probable explanation is that the problem metals are found in both rocket and bomb paintings. The maximum TNT concentration obtained during Phase II was lower than the concentration obtained during Phase I. This can be the result of site tilling.

In general, except in Jimmy Lake, the soil, the vegetation, the surface water, and the sediment are of excellent quality. No action is required on any site except to continue to clean and manage the sites as currently. Metal concentrations in the bombing area of Jimmy Lake Range, are especially high. Although, most of them did not exceed the ISQG criteria, many of the results are higher than the ASQG. As already mentioned, legally, no action is required, since the site will not be used for agriculture, but will continue to be used for target practice. The most important results will come from the hydrogeological study. Nevertheless, to exercise due diligence, removing soil from the bombing area and send it to a secure landfill will solve this problem for a very long time.

5 Conclusion

In August 2002 DRDC Valcartier and CRREL conducted Phase I to characterize the soil, vegetation and surface water for metals and energetic materials at Cold lake Air Weapons Range (CLAWR). A total of 193 soil, 16 vegetation and 4 surface water samples were collected during Phase I in Alpha, Bravo, Jimmy Lake, Shaver River, open detonation and rifle ranges. A few surface water samples were collected in Primerose Lake, Jimmy Lake, the Shaver River and in a pond containing ammunition in Shaver River Range. In August 2003, DRDC Valcartier and CRREL conducted Phase II of the study to complete the characterization of the soil, vegetation, surface water and sediment for metals and energetic materials. 324 soil, 69 vegetation, 19 surface water and 28 sediment samples were collected during Phase II. Efforts were mainly in Jimmy Lake and Shaver River ranges, and also in Primerose Lake and Jimmy Lake.

Two strategies were used to collect samples across the ranges. The first consisted in using a linear sampling pattern. This approach was used during Phase I to evaluate whether the level of contamination by metals was following a pattern with distance from the target. The same approach was used in Alpha Range to collect vegetation samples and in Jimmy Lake Range where we modified the strategy by fixing the 40 % transect at the target position. The concentrations behind and in front of the target were then determined. This proved to be a good approach since the results showed that metals accumulated mainly in front of the targets. The second sampling strategy was the circular approach also developed during Phase I and applied to targets in Jimmy Lake and in Shaver River ranges. The strategy consisted of compositing samples taken in a circular pattern around targets. Twenty-six (26) soil samples were collected, one within each of the cells around the target. These cells are defined by three circles located at 10-, 30- and 50-m radius of the target. Two composite samples (A1 & A2) were collected in hemispheres of the first, 10-m diameter ring (in front of and behind the target). Eight equal-sized rectangles were sampled between 10 and 30 m (B1-B8), and 16 between 30 and 50 m (C1-C16). Twenty or more increments were collected to build 800 g to 1.5 kg composite samples. Furthermore, in Shaver River Range, a one hundred 1-m x 1-m minigrids were constructed and 100 discrete samples were collected to evaluate the dispersion and the heterogeneity of the explosives in front of the tank. This statistical evaluation revealed again the great heterogeneity encountered with explosive contamination, and emphasized that compositing with 20-30 increments is the best approach to collect soils for explosive analysis. In all other ranges such as in the remote areas, simple composite sampling was done around targets or existing infrastructures that were used as targets.

Generally, as observed during Phase I, results from Phase II showed that the concentrations of metals in soils in all of the ranges were quite low. Most of the time, the metals detected at concentrations higher than the BGL were only 1 to twice the BGL value. Most of the time, concentrations were far below the ASQG except for some metals such as cadmium, copper and zinc, which were present at higher concentrations. These metals can be related to firing activities. Nevertheless, most of the values were quite low. Only copper in Jimmy Lake Range exceeded the ISQG. The fact that metals concentrations were low is the direct result of good management of the sites. During our visit, the sites were clean and no debris or large pieces of metals were observed. Debris is controlled by the excellent practice of removing the pieces of metals on a regular basis and tilling often. Results from Phase I and Phase II are comparable in two consecutive years.

When the ranges are compared, the conclusions drawn from Phase I results still apply; the Jimmy Lake Range is the most contaminated site by metals; Bravo Range is less contaminated than Alpha Range; and Shaver River Range is also less contaminated than Alpha Range. In Shaver River Range, fewer metals were detected compared to Alpha Range but the concentrations were of the same order of magnitude. The metals in Shaver River Range that had high concentrations and were of concern, such as cadmium, are similar to the metals of concern encountered in Jimmy Lake but at lower concentrations. Problematic metals seem to be found in different types of weapons such as bomb and rocket and should be probably part of their painting.

The vegetation analyses revealed that some metals are phytoaccumulated from the soils, since a direct relation between soil and vegetation concentrations were identified. On some occasions, metals phytoaccumulation did not correspond to the metals concentrations in soils. Not all of the metals were phytoaccumulated possibly due to selective adsorption. Nevertheless, considering the results obtained during Phase II, the quality of the vegetation is excellent and compares well with the concentrations in background samples. Therefore, vegetation does not represent a risk to wildlife.

Surface water and sediment were sampled during Phase II to assess the quality of Primerose Lake and Jimmy Lake. Many sediment samples were collected in both lakes using a manual grabber. Results indicated that these sediment samples are not contaminated with only a few exceptions. Surface water samples also revealed that the concentrations of metals were quite low and no explosives were found. In general, neither the sediment nor the surface water is contaminated in Primerose Lake and in Jimmy Lake.

For the energetic materials analyses, our efforts were concentrated mainly on Jimmy Lake and Shaver River ranges during Phase II, since explosive concentrations determined in Alpha and in Bravo during Phase I revealed low ppm levels. In Jimmy Lake, in the circular samples, mainly propellant residues were found, such as nitroglycerine which was found in all samples. This indicates that rockets are often used at this site. The concentrations of explosives were also low and do not represent a major problem. In Shaver River Range, the situation was the opposite; very little propellant residues were found, but explosives such as TNT were found in almost all samples. This indicates that bombs are mainly used at this site. The metals that showed problems in Shave River Range are the same than in Jimmy Lake Range, but at lower concentrations. Little information about weapon compositions is available that can explain all of these results. The most probable explanation is that the problem metals are found in both rocket and bomb paintings. The maximum TNT concentration obtained during Phase II was lower than the concentration obtained during Phase I. This can be the result of site tilling.

In conclusion, this study demonstrated that the ranges have some accumulation of metals due to firing activities, but the extent of contamination is very low.

Contamination by explosives is also minimal except in Shaver River Range where TNT was found at high concentrations (ppm level). In general, except in Jimmy Lake, the soil, the vegetation, the surface water, and the sediment are of excellent quality. No action is required on any site except to continue to clean and manage the sites the way it is actually done. Metal concentrations in Jimmy Lake Range, in the bombing area are especially high. Although, most of them did not exceed the ISQG criteria, many of the results are higher than the ASQG. As already mentioned, legally, no action is required, since the site will not be used for agriculture, but will continue to be used for target practice. The most important results will come from the hydrogeological study. Nevertheless, to exercise due diligence, removing soil from the bombing area and send it to a secure landfill will solve this problem for a very long time.

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List of symbols/abbreviations/acronyms/initialisms

ASQG	Agricultural Soil Quality Guideline
B	Biomass sample (Vegetation)
BG	Background sample
BGL	Background Level
CCME	Canadian Council of Ministers of Environment
CFB	Canadian Force Base
CLAWR	Cold Lake Air Weapons Range
CRREL	Cold Regions Research and Engineering Laboratory
DCC	Defence Construction Canada
DGE	Director General Environment
DLE	Director Land Environment
DND	Department of National Defence
DoD	Department of Defence
DRDC Valcartier	Defence Research and development Canada Valcartier
EL	Environmental Laboratory
ETL	Enviro-Test Laboratory
GPS	Global Positioning System
ICP/MS	Inductively Coupled Plasma /Mass Spectrometry
ISQG	Industrial Soil Quality Guideline
ISQG	Interim Sediment Quality Guideline
ppb	Parts per billion
ppm	Parts per million
QA/QC	Quality Assurance/ Quality Control
S	Soil Sample
sed	Sediment Sample
SERDP	Strategic Environmental Research and Development Program
SW	Surface Water Sample
UXO	Unexploded Ordnances

TABLE I: GPS LOCATIONS OF SAMPLING

Sampling Locations or Sample ID	Sampling Point	
	X or Northern	Y or Western
Alpha Range		
B-A-1	0560626	6074411
B-A-2	0560650	6074395
B-A-SR	0560269	6074394
B-A-BG-1	0559539	6074556
B-A-BG-2	0560302	6074232
B-A-BG-3	0560371	6074680
B-A-BG-4	0561723	6074111
B-A-0%-A	0561660	6074221
B-A-0%-B	0561565	6074050
B-A-20%-A	0561419	6074230
B-A-20%-B	0561405	6074179
B-A-40%-A	0561224	6074285
B-A-40%-B	0561217	6074236
B-A-60%-A	0561030	6074343
B-A-60%-B	0561021	6074292
B-A-80%-A	0560837	6074398
B-A-80%-B	0560824	6074345
B-A-100%-A	0560652	6074438
B-A-100%-B	0560644	6074389
Bravo Range		
B-BR-BG-1	0560142	6072210
B-BR-BG-2	0559968	6072292
B-BR-BG-3	0559929	6072086
S-BR-BG-1	0559929	6072086
B-BR-Front Left 70 m	Not available	Not available
B-BR-Front Right 70 m	Not available	Not available
Center of target	0560338	6071990
Jimmy Lake Range		
B-JL-BC	Not available	Not available
B-JL-BC-1	Not available	Not available
B-JL-BC-2	Not available	Not available

Sampling Locations or Sample ID	Sampling Point	
	X or Northern	Y or Western
Center of bombing circle	0567520	6084356
LS-0%-center of strafing area	0567044	6084617
LS-0%-A	0567045	6084729
LS-0%-B	0567040	6084512
LS-20%- center of strafing area	0567066	6084616
LS-20%-A	0567066	6084723
LS-20%-B	0567065	6084513
LS-40%- center of strafing area	0567091	6084614
LS-40%-A	0567094	6084720
LS-40%-B	0567092	6084512
LS-60%- center of strafing area	0567116	6084613
LS-60%-A	0567118	6084718
LS-60%-B	0567116	6084512
LS-80%- center of strafing area	0567144	6084613
LS-80%-A	0567146	6084719
LS-80%-B	0567144	6084512
LS-100%- center of strafing area	0567170	6084611
LS-100%-A	0567174	6084718
LS-100%-B	0567170	6084512
LS-120%- center of strafing area	Not available	Not available
LS-120%-A	Not available	Not available
LS-120%-B	Not available	Not available
LS-140%- center of strafing area	Not available	Not available
LS-140%-A	Not available	Not available
LS-140%-B	Not available	Not available
LS-160%- center of strafing area	Not available	Not available
LS-160%-A	Not available	Not available
LS-160%-B	Not available	Not available
Shaver River Range		
S-SR-BG-1	0566489	6088294
S-SR-BG-2	0566506	6087901
S-SR-BG-3	05664472	6087633
Crater close to target, soil and water collected	0567056	6088104
Center of target	0567098	6088102

Sampling Locations or Sample ID	**Sampling Point**	
	X or Northern	**Y or Western**
Water sample in Shaver River	0567590	6088535
Backgrounds outside ranges		
S-BG-X3	0562653	6075724
S-BG-X4	0565363	6078072
S-BG-Jl Sign	0567605	6081183
B-BG-JL Sign	0567605	6081183
Remote Areas		
B-A387-A	0495805	6077625
B-A387-B	0495809	6077647
B-A387-C	0495820	6077703
B-A387-D	0495831	6077734
B-C284-Tank1	Not available	Not available
B-C284-Tank2	Not available	Not available
B-C284-oil rig	Not available	Not available
B-C284-center	05575556	6106760
SW-C284	0556649	6106416
SW-C295-A	0561621	6103951
SW-C295-B	0561623	6103960
B-C314-A	Not available	Not available
B-C314-B	0536149	6083670
B-C314-C	0536171	6083690
S-C314-Crater-A	0536237	6083690
S-C314-Crater-A	0536237	6083690
B-E301-BG-A	0597049	6076210
B-E301-BG-B	0597032	6076230
B-E301-BG-C	0597026	6076246
S-E301-BG-A	0597049	6076210
S-E301-BG-B	0597032	6076230
S-E301-BG-C	0597026	6076246
SW-E301-River-BG	0597046	6076230
B-F332-A	0635745	6080630
B-F332-B	0635727	6080632
S-F332-A	0635745	6080630
S-F332-B	0635727	6080632

Sampling Locations or Sample ID	Sampling Point	
	X or Northern	Y or Western
SW-F332-Airstrip A	0634510	6085414
SW-F332-Airstrip B	0636073	6085675
Primerose and Jimmy Lakes		
Sed-PL-1	0583114	6090563
Sed-PL-2	0580005	6091207
Sed-PL-3	0577096	6091246
Sed-PL-4	0573867	6090393
Sed-PL-5	0571809	6087886
Sed-PL-6	0571463	6086456
Sed-PL-7	0570863	6084818
Sed-PL-8	0568854	6083472
Sed-PL-9	0571934	6075835
Sed-PL-10	0567484	6075984
Sed-PL-11	0565997	6078869
Sed-PL-12	0561859	6074214
Sed-PL-13	0560757	6071623
SW-PL-1	0583157	6090568
SW-PL-2	0568854	6083472
SW-PL-3	0561859	6074214
SW-PL-4	0560757	6071623
Sed-JL-1	0566294	6085021
Sed-JL-2	0566312	6084943
Sed-JL-3	0566354	6084803
Sed-JL-4	0566326	6084621
Sed-JL-5	0566338	6084501
Sed-JL-6	0566246	6084513
Sed-JL-7	0566181	6084590
Sed-JL-8	0566129	6084713
Sed-JL-9	0566086	6084872
Sed-JL-10	0566171	6085003
SW-JL-1	0566326	6084621
SW-JL-2	0566181	6084590
SW-JL-3	0566129	6084713

TABLE II A: METALS CONCENTRATIONS IN SOILS (SB TO CO)

	Sb	As	Ba	Be	Cd	Cr	Co
Sample			**ppm**	**(mg/kg)**			
Background							
S-BR-BG-1	0.1	0.8	31	0.5	0.25	3.8	0.5
S-BR-BG-1 (DUP)	0.1	0.6	23	0.5	0.25	2.7	0.5
S-BG-JL SIGN	0.1	0.4	10	0.5	0.25	1.1	0.5
S-BG-X3	0.1	0.7	17	0.5	0.25	2.3	0.5
S-BG-X3 (DUP)	0.1	0.6	11	0.5	0.25	1.4	0.5
S-BG-X4	0.1	0.5	19	0.5	0.25	1.5	0.5
S-E301-BG-A	0.1	3.1	91	0.5	0.25	10.3	3.0
S-E301-BG-B	0.1	5.3	121	0.5	0.25	9.9	4.0
S-E301-BG-C	0.1	3.8	135	0.5	0.25	11.5	4.0
S-SR-BG1	0.1	0.6	34	0.5	0.25	3.9	2.0
S-SR-BG2	0.1	0.2	19	0.5	0.25	1.7	0.5
S-SR-BG3	0.1	0.4	18	0.5	0.25	2.3	0.5
Average	0.1	1.4	44.1	0.5	0.3	4.4	1.4
Standard deviation	0.0	1.7	44.8	0.0	0.0	3.9	1.4
(2 x St Dev))	0.0	3.4	89.5	0.0	0.0	7.7	2.9
Sum (Ave+(2xStDev)	0.1	4.8	133.6	0.5	0.3	12.1	4.3
CCME ASQG (a)	20	12	750	4	1	64	40
CCME ISQG (b)	40	12	2000	8	22	87	300
Jimmy Lake Range							
S-JL-LS-0%-A	0.1	0.8	16	0.5	0.25	2.8	1.0
S-JL-LS-0%-B	0.1	1.0	18	0.5	0.25	2.9	1.0
S-JL-LS-20%-A	0.1	1.0	19	0.5	0.25	3.4	1.0
S-JL-LS-20%-B	0.1	0.6	12	0.5	0.25	1.8	0.5
S-JL-LS-40%-A	0.1	0.6	11	0.5	0.25	1.6	0.5
S-JL-LS-40%-B	0.1	0.8	14	0.5	0.25	1.9	1.0
S-JL-LS-60%-A	0.1	0.9	18	0.5	0.25	3.1	1.0
S-JL-LS-60%-A (DUP)	0.1	0.6	13	0.5	0.25	2.2	1.0
S-JL-LS-60%-B	0.1	0.6	16	0.5	0.25	2.3	1.0
S-JL-LS-80%-A	0.1	0.7	15	0.5	0.25	2.6	1.0
S-JL-LS-80%-B	0.1	1.0	24	0.5	0.25	3.9	2.0
S-JL-LS-100%-A	0.1	1.0	16	0.5	0.25	2.8	1.0
S-JL-LS-100%-B	0.1	0.8	17	0.5	0.25	2.8	1.0
S-JL-LS-100%-B (DUP)	0.1	1.9	17	0.5	0.25	3.3	1.0

	Sb	As	Ba	Be	Cd	Cr	Co
Sample			**ppm**	**(mg/kg)**			
S-JL-BC-A1	0.1	2.0	67	0.5	12.50	11.8	3.0
S-JL-BC-A2	0.1	2.1	76	0.5	14.90	14.3	4.0
S-JL-BC-B1	0.1	2.0	63	0.5	9.60	11.4	4.0
S-JL-BC-B2	0.1	2.0	59	0.5	9.40	10.8	3.0
S-JL-BC-B3	0.1	1.9	70	0.5	11.40	12.4	4.0
S-JL-BC-B4	0.1	2.0	54	0.5	10.60	11.0	3.0
S-JL-BC-B4 (DUP)	0.1	2.0	66	0.5	12.40	12.1	3.0
S-JL-BC-B5	0.1	2.2	66	0.5	12.90	13.3	3.0
S-JL-BC-B6	0.1	2.0	73	0.5	12.90	14.2	3.0
S-JL-BC-B7	0.1	2.0	59	0.5	10.80	11.5	3.0
S-JL-BC-B7 (DUP)	0.1	2.1	60	0.5	11.10	11.5	3.0
S-JL-BC-B8	0.1	2.1	71	0.5	11.80	13.5	4.0
S-JL-BC-C1	0.1	2.1	64	0.5	8.70	11.6	4.0
S-JL-BC-C2	0.1	2.0	57	0.5	6.40	10.5	4.0
S-JL-BC-C3	0.1	2.2	63	0.5	6.40	10.2	4.0
S-JL-BC-C3 (DUP)	0.1	2.2	60	0.5	6.40	11.0	4.0
S-JL-BC-C4	0.1	2.3	65	0.5	9.60	10.8	4.0
S-JL-BC-C5	0.1	2.4	69	0.5	7.60	11.2	4.0
S-JL-BC-C6	0.1	2.1	67	0.5	9.00	11.2	4.0
S-JL-BC-C7	0.1	2.1	63	0.5	9.60	12.1	3.0
S-JL-BC-C8	0.1	2.1	75	0.5	12.00	14.0	4.0
S-JL-BC-C8 Rep	0.1	2.0	73	0.5	11.50	13.6	4.0
S-JL-BC-C8 (DUP)	0.1	1.8	55	0.5	9.70	10.4	3.0
S-JL-BC-C9	0.1	2.1	66	0.5	11.20	12.7	3.0
S-JL-BC-C10	0.1	1.8	66	0.5	10.40	12.2	3.0
S-JL-BC-C11	0.1	1.9	67	0.5	10.60	12.6	4.0
S-JL-BC-C12	0.1	2.0	74	0.5	9.50	13.8	4.0
S-JL-BC-C13	0.1	2.1	68	0.5	8.50	11.9	4.0
S-JL-BC-C14	0.1	2.1	65	0.5	7.80	11.3	4.0
S-JL-BC-C15	0.1	1.9	50	0.5	6.30	10.2	3.0
S-JL-BC-C16	0.1	2.3	68	0.5	8.80	12.3	4.0
Shaver River Range							
S-SR-T-A1	0.1	0.5	22	0.5	1.90	3.1	0.5
S-SR-T-A1 Rep	0.1	0.5	21	0.5	2.20	3.6	1.0
S-SR-T-A1 (DUP)	0.1	0.7	26	0.5	2.40	4.3	1.0
S-SR-T-A2	0.1	0.6	22	0.5	2.50	4.4	1.0

	Sb	**As**	**Ba**	**Be**	**Cd**	**Cr**	**Co**
Sample			**ppm**	**(mg/kg)**			
S-SR-T-B1	0.1	0.4	21	0.5	3.00	3.4	1.0
S-SR-T-B1 (DUP)	0.1	0.4	21	0.5	3.10	3.3	1.0
S-SR-T-B2	0.1	0.5	23	0.5	2.70	3.7	1.0
S-SR-T-B3	0.1	0.7	23	0.5	2.60	3.4	1.0
S-SR-T-B4	0.1	0.5	20	0.5	2.00	3.7	1.0
S-SR-T-B4 (DUP)	0.1	0.5	21	0.5	1.90	3.8	1.0
S-SR-T-B5	0.1	0.6	21	0.5	2.10	3.2	1.0
S-SR-T-B6	0.1	0.8	24	0.5	2.70	4.0	1.0
S-SR-T-B7	0.1	0.3	19	0.5	1.60	2.6	0.5
S-SR-T-B8	0.1	0.4	23	0.5	2.10	3.0	1.0
S-SR-T-C1	0.1	0.4	23	0.5	2.60	3.1	1.0
S-SR-T-C2	0.1	0.6	22	0.5	2.40	3.1	1.0
S-SR-T-C3	0.1	0.4	25	0.5	2.80	3.5	1.0
S-SR-T-C3 (DUP)	0.1	0.6	38	0.5	3.10	3.7	1.0
S-SR-T-C4	0.1	0.4	26	0.5	2.80	3.2	1.0
S-SR-T-C5	0.1	0.4	23	0.5	2.40	3.0	1.0
S-SR-T-C5 (DUP)	0.1	0.4	23	0.5	2.50	3.3	1.0
S-SR-T-C6	0.1	0.4	18	0.5	1.80	3.6	0.5
S-SR-T-C7	0.1	0.3	19	0.5	1.20	2.6	0.5
S-SR-T-C8	0.1	0.3	18	0.5	1.10	2.4	0.5
S-SR-T-C9	0.1	0.4	16	0.5	0.70	2.1	0.5
S-SR-T-C10	0.1	0.4	21	0.5	0.90	2.7	0.5
S-SR-T-C11	0.1	0.5	27	0.5	1.20	3.1	1.0
S-SR-T-C12	0.1	0.5	27	0.5	1.50	3.3	1.0
S-SR-T-C13	0.1	0.7	27	0.5	1.90	3.0	1.0
S-SR-T-C14	0.1	0.4	25	0.5	1.70	3.1	1.0
S-SR-T-C14 (DUP)	0.1	0.5	25	0.5	1.80	3.0	1.0
S-SR-T-C15	0.1	0.4	24	0.5	1.80	2.9	1.0
S-SR-T-C16	0.1	0.4	24	0.5	2.40	2.9	1.0
S-SR-CRATER SIDE	0.1	0.5	27	0.5	0.25	2.3	1.0
Remote Areas							
S-C284-CENTER	0.1	2.5	42	0.5	0.25	7.8	3.0
S-C284-OIL RIG	0.1	2.5	34	0.5	0.25	7.0	3.0
S-C284-TANK1	0.1	1.5	80	0.5	0.25	5.8	13.0
S-C284-TANK2	0.1	2.0	132	0.5	0.25	8.9	4.0
S-C-314-CRATER A	0.1	0.1	36	0.5	0.25	4.9	1.0

	Sb	As	Ba	Be	Cd	Cr	Co
Sample			**ppm**	**(mg/kg)**			
S-C-314-CRATER B	0.1	0.1	44	0.5	0.25	2.6	0.5
S-F332-A	0.1	0.1	3	0.5	0.25	0.3	0.5
S-F332-A (DUP)	0.1	0.1	12	0.5	0.25	0.9	0.5
S-F332-B	0.1	0.1	8	0.5	0.25	0.8	0.5

a: ASQG agricultural Soil Quality Guideline

b: ISQG Industrial Soil Quality Guideline

Note: half values of the detection limits are used when metals are not detected

Values higher than the background mean + 2 x the standard deviation are highlighted in blue

Values higher than the CCME ASQG are highlighted in green

Values higher than the CCME ISQG are highlighted in red

TABLE II B: METALS CONCENTRATIONS IN SOILS (CU TO SE)

	Cu	Pb	Hg	Mo	Ni	Se
Sample	**ppm (mg/kg)**					
Background						
S-BR-BG-1	1	3	0.03	0.5	1	0.1
S-BR-BG-1 (DUP)	2	3	0.03	0.5	1	0.1
S-BG-JL SIGN	1	3	0.03	0.5	1	0.1
S-BG-X3	1	3	0.03	0.5	2	0.1
S-BG-X3 (DUP)	1	3	0.03	0.5	1	0.1
S-BG-X4	1	3	0.03	0.5	1	0.1
S-E301-BG-A	6	3	0.03	0.5	7	0.1
S-E301-BG-B	7	3	0.03	0.5	7	0.3
S-E301-BG-C	7	3	0.03	0.5	8	0.3
S-SR-BG1	1	3	0.03	0.5	3	0.1
S-SR-BG2	1	3	0.03	0.5	1	0.1
S-SR-BG3	1	3	0.03	0.5	2	0.1
Average	3	3	0.03	0.5	3	0.1
Standard deviation	3	0	0.00	0.0	3	0.1
(2 x St Dev))	5	0	0.00	0.0	5	0.2
Sum (Ave+(2xSt Dev)	8	3	0.03	0.5	8	0.3
CCME ASQG (a)	63	70	6.60	5.0	50	1.0
CCME ISQG (b)	91	600	50.00	40.0	50	3.9
Jimmy Lake Range						
S-JL-LS-0%-A	5	3	0.03	0.5	3	0.1
S-JL-LS-0%-B	6	3	0.03	0.5	3	0.1
S-JL-LS-20%-A	8	3	0.03	0.5	4	0.1
S-JL-LS-20%-B	3	3	0.03	0.5	2	0.1
S-JL-LS-40%-A	5	3	0.03	0.5	1	0.1
S-JL-LS-40%-B	8	3	0.03	0.5	3	0.1
S-JL-LS-60%-A	44	3	0.03	0.5	3	0.1
S-JL-LS-60%-A (DUP)	37	3	0.03	0.5	2	0.1
S-JL-LS-60%-B	16	3	0.03	0.5	3	0.1
S-JL-LS-80%-A	25	3	0.03	0.5	3	0.1
S-JL-LS-80%-B	37	5	0.03	0.5	4	0.1
S-JL-LS-100%-A	10	3	0.03	0.5	3	0.1
S-JL-LS-100%-B	18	3	0.03	0.5	3	0.1
S-JL-LS-100%-B (DUP)	13	3	0.03	0.5	4	0.1

	Cu	Pb	Hg	Mo	Ni	Se
Sample	**ppm (mg/kg)**					
S-JL-BC-A1	75	22	0.03	0.5	14	0.1
S-JL-BC-A2	98	31	0.03	0.5	17	0.1
S-JL-BC-B1	65	16	0.03	0.5	13	0.1
S-JL-BC-B2	57	17	0.03	0.5	12	0.1
S-JL-BC-B3	72	27	0.03	0.5	14	0.1
S-JL-BC-B4	120	18	0.03	0.5	13	0.1
S-JL-BC-B4 (DUP)	79	21	0.03	0.5	14	0.1
S-JL-BC-B5	103	25	0.03	0.5	15	0.1
S-JL-BC-B6	97	29	0.03	0.5	16	0.1
S-JL-BC-B7	71	20	0.03	0.5	13	0.1
S-JL-BC-B7 (DUP)	82	18	0.03	0.5	13	0.1
S-JL-BC-B8	67	26	0.03	0.5	16	0.1
S-JL-BC-C1	50	13	0.03	0.5	13	0.1
S-JL-BC-C2	45	12	0.03	0.5	12	0.1
S-JL-BC-C3	37	12	0.03	0.5	12	0.1
S-JL-BC-C3 (DUP)	48	11	0.03	0.5	12	0.1
S-JL-BC-C4	37	14	0.03	0.5	13	0.1
S-JL-BC-C5	40	15	0.03	0.5	13	0.1
S-JL-BC-C6	53	18	0.03	0.5	13	0.1
S-JL-BC-C7	69	18	0.03	0.5	14	0.1
S-JL-BC-C8	87	27	0.03	0.5	17	0.1
S-JL-BC-C8 Rep	79	23	0.03	0.5	16	0.1
S-JL-BC-C8 (DUP)	60	18	0.03	0.5	12	0.1
S-JL-BC-C9	75	21	0.03	0.5	16	0.1
S-JL-BC-C10	85	22	0.03	0.5	15	0.1
S-JL-BC-C11	112	19	0.03	0.5	14	0.1
S-JL-BC-C12	119	19	0.03	0.5	13	0.1
S-JL-BC-C13	77	16	0.03	0.5	18	0.1
S-JL-BC-C14	64	18	0.03	0.5	13	0.1
S-JL-BC-C15	56	11	0.03	0.5	11	0.1
S-JL-BC-C16	42	14	0.03	0.5	14	0.1
Shaver River Range						
S-SR-T-A1	12	20	0.03	0.5	3	0.1
S-SR-T-A1 Rep	19	19	0.03	0.5	4	0.1
S-SR-T-A1 (DUP)	14	24	0.03	0.5	4	0.1
S-SR-T-A2	15	37	0.03	0.5	4	0.1

	Cu	Pb	Hg	Mo	Ni	Se
Sample	**ppm (mg/kg)**					
S-SR-T-B1	11	12	0.03	0.5	3	0.1
S-SR-T-B1 (DUP)	11	11	0.03	0.5	3	0.1
S-SR-T-B2	15	17	0.03	0.5	3	0.1
S-SR-T-B3	11	14	0.03	0.5	3	0.1
S-SR-T-B4	9	10	0.03	0.5	3	0.1
S-SR-T-B4 (DUP)	7	16	0.03	0.5	3	0.1
S-SR-T-B5	16	30	0.03	0.5	3	0.1
S-SR-T-B6	19	34	0.03	0.5	5	0.1
S-SR-T-B7	7	9	0.03	0.5	3	0.1
S-SR-T-B8	7	8	0.03	0.5	3	0.1
S-SR-T-C1	7	6	0.03	0.5	3	0.1
S-SR-T-C2	7	6	0.03	0.5	3	0.1
S-SR-T-C3	9	10	0.03	0.5	3	0.1
S-SR-T-C3 (DUP)	10	9	0.03	0.5	3	0.1
S-SR-T-C4	11	11	0.03	0.5	3	0.1
S-SR-T-C5	11	13	0.03	0.5	3	0.1
S-SR-T-C5 (DUP)	17	12	0.03	0.5	3	0.1
S-SR-T-C6	7	12	0.03	0.5	2	0.1
S-SR-T-C7	5	3	0.03	0.5	2	0.1
S-SR-T-C8	4	3	0.03	0.5	2	0.1
S-SR-T-C9	3	3	0.03	0.5	1	0.1
S-SR-T-C10	5	5	0.03	0.5	2	0.1
S-SR-T-C11	5	6	0.03	0.5	3	0.1
S-SR-T-C12	7	10	0.03	0.5	3	0.1
S-SR-T-C13	7	10	0.03	0.5	3	0.1
S-SR-T-C14	8	6	0.03	0.5	3	0.1
S-SR-T-C14 (DUP)	7	7	0.03	0.5	3	0.1
S-SR-T-C15	5	5	0.03	0.5	3	0.1
S-SR-T-C16	6	6	0.03	0.5	3	0.1
S-SR-CRATER SIDE	1	3	0.03	0.5	2	0.1
Remote Areas						
S-C284-CENTER	4	7	0.03	0.5	4	0.1
S-C284-OIL RIG	3	6	0.03	0.5	4	0.1
S-C284-TANK1	3	6	0.03	0.5	4	0.1
S-C284-TANK2	8	3	0.03	0.5	8	0.9
S-C-314-CRATER A	6	9	0.03	0.5	3	0.1

Sample	Cu	Pb	Hg	Mo	Ni	Se
	ppm (mg/kg)					
S-C-314-CRATER B	6	3	0.03	0.5	2	0.2
S-F332-A	1	31	0.03	0.5	1	0.1
S-F332-A (DUP)	2	3	0.03	0.5	1	0.1
S-F332-B	3	3	0.03	0.5	1	0.1

a: ASQG agricultural Soil Quality Guideline

b: ISQG Industrial Soil Quality Guideline

Note: half values of the detection limits are used when metals are not detected

Values higher than the background mean + 2 x the standard deviation are highlighted in blue

Values higher than the CCME ASQG are highlighted in green

Values higher than the CCME ISQG are highlighted in red

TABLE II C: METALS CONCENTRATIONS IN SOILS (AG TO ZN)

	Ag	Sr	Tl	Sn	U	V	Zn
Sample			**ppm**	**(mg/kg)**			
Background							
S-BR-BG-1	0.5	6	0.5	2.5	20	6	10
S-BR-BG-1 (DUP)	0.5	4	0.5	2.5	20	4	5
S-BG-JL SIGN	0.5	-	0.5	2.5	20	2	5
S-BG-X3	0.5	-	0.5	2.5	20	4	5
S-BG-X3 (DUP)	0.5	-	0.5	2.5	20	3	5
S-BG-X4	0.5	-	0.5	2.5	20	3	5
S-E301-BG-A	0.5	19	0.5	2.5	20	11	30
S-E301-BG-B	0.5	20	0.5	2.5	20	11	50
S-E301-BG-C	0.5	32	0.5	2.5	20	12	50
S-SR-BG1	0.5	4	0.5	2.5	20	7	10
S-SR-BG2	0.5	2	0.5	2.5	20	3	5
S-SR-BG3	0.5	2	0.5	2.5	20	4	5
Average	0.5	11.1	0.5	2.5	20.0	5.8	15.4
Standard deviation	0.0	11.2	0.0	0.0	0.0	3.6	17.6
(2 x StDev))	0.0	22.3	0.0	0.0	0.0	7.2	35.3
Sum (Ave+(2xStDev)	0.5	33.4	0.5	2.5	20.0	13.0	50.7
CCME ASQG (a)	20	-	1	5	-	130	200
CCME ISQG (b)	40	-	1	300	-	130	360
Jimmy Lake Range							
S-JL-LS-0%-A	0.5	7	0.5	2.5	20	4	10
S-JL-LS-0%-B	0.5	4	0.5	2.5	20	4	5
S-JL-LS-20%-A	0.5	5	0.5	2.5	20	6	10
S-JL-LS-20%-B	0.5	3	0.5	2.5	20	2	5
S-JL-LS-40%-A	0.5	3	0.5	2.5	20	3	5
S-JL-LS-40%-B	0.5	8	0.5	2.5	20	3	5
S-JL-LS-60%-A	0.5	5	0.5	2.5	20	4	20
S-JL-LS-60%-A (DUP)	0.5	4	0.5	2.5	20	3	10
S-JL-LS-60%-B	0.5	7	0.5	2.5	20	4	10
S-JL-LS-80%-A	0.5	5	0.5	2.5	20	4	10
S-JL-LS-80%-B	0.5	7	0.5	2.5	20	5	20
S-JL-LS-100%-A	0.5	4	0.5	2.5	20	5	10
S-JL-LS-100%-B	0.5	5	0.5	2.5	20	4	10

	Ag	Sr	Tl	Sn	U	V	Zn
Sample			**ppm**	**(mg/kg)**			
S-JL-LS-100%-B (DUP)	0.5	5	0.5	2.5	20	6	10
S-JL-BC-A1	0.5	10	0.5	2.5	20	113	90
S-JL-BC-A2	0.5	11	0.5	2.5	20	115	120
S-JL-BC-B1	0.5	10	0.5	2.5	20	83	80
S-JL-BC-B2	0.5	10	0.5	2.5	20	69	80
S-JL-BC-B3	0.5	10	0.5	2.5	20	73	90
S-JL-BC-B4	0.5	9	0.5	2.5	20	71	100
S-JL-BC-B4 (DUP)	0.5	10	0.5	2.5	20	84	100
S-JL-BC-B5	0.5	10	0.5	2.5	20	97	120
S-JL-BC-B6	0.5	9	0.5	2.5	20	87	110
S-JL-BC-B7	0.5	9	0.5	2.5	20	78	70
S-JL-BC-B7 (DUP)	0.5	9	0.5	2.5	20	85	80
S-JL-BC-B8	0.5	11	0.5	2.5	20	104	100
S-JL-BC-C1	0.5	10	0.5	2.5	20	85	90
S-JL-BC-C2	0.5	9	0.5	2.5	20	52	60
S-JL-BC-C3	0.5	11	0.5	2.5	20	46	50
S-JL-BC-C3 (DUP)	0.5	10	0.5	2.5	20	48	80
S-JL-BC-C4	0.5	11	0.5	2.5	20	48	60
S-JL-BC-C5	0.5	11	0.5	2.5	20	45	60
S-JL-BC-C6	0.5	10	0.5	2.5	20	59	70
S-JL-BC-C7	0.5	9	0.5	2.5	20	61	110
S-JL-BC-C8	0.5	10	0.5	2.5	20	80	110
S-JL-BC-C8 Rep	0.5	10	0.5	2.5	20	76	110
S-JL-BC-C8 (DUP)	0.5	9	0.5	2.5	20	61	90
S-JL-BC-C9	0.5	9	0.5	2.5	20	74	110
S-JL-BC-C10	0.5	9	0.5	2.5	20	72	100
S-JL-BC-C11	0.5	11	0.5	2.5	20	56	110
S-JL-BC-C12	0.5	10	0.5	2.5	20	60	140
S-JL-BC-C13	0.5	10	0.5	2.5	20	63	70
S-JL-BC-C14	0.5	10	0.5	2.5	20	65	60
S-JL-BC-C15	0.5	9	0.5	2.5	20	67	70
S-JL-BC-C16	0.5	13	0.5	2.5	20	84	70
Shaver River Range							
S-SR-T-A1	0.5	3	0.5	2.5	20	3	20
S-SR-T-A1 Rep	0.5	3	0.5	2.5	20	3	20
S-SR-T-A1 (DUP)	0.5	3	0.5	2.5	20	4	30

	Ag	**Sr**	**Tl**	**Sn**	**U**	**V**	**Zn**
Sample			**ppm**	**(mg/kg)**			
S-SR-T-A2	0.5	3	0.5	2.5	20	4	30
S-SR-T-B1	0.5	3	0.5	2.5	20	4	20
S-SR-T-B1 (DUP)	0.5	3	0.5	2.5	20	4	20
S-SR-T-B2	0.5	3	0.5	2.5	20	4	30
S-SR-T-B3	0.5	3	0.5	2.5	20	4	20
S-SR-T-B4	0.5	3	0.5	2.5	20	4	20
S-SR-T-B4 (DUP)	0.5	3	0.5	2.5	20	4	20
S-SR-T-B5	0.5	3	0.5	2.5	20	4	20
S-SR-T-B6	0.5	3	0.5	2.5	20	4	30
S-SR-T-B7	0.5	3	0.5	2.5	20	3	20
S-SR-T-B8	0.5	3	0.5	2.5	20	4	20
S-SR-T-C1	0.5	3	0.5	2.5	20	4	20
S-SR-T-C2	0.5	3	0.5	2.5	20	4	20
S-SR-T-C3	0.5	3	0.5	2.5	20	4	20
S-SR-T-C3 (DUP)	0.5	3	0.5	2.5	20	5	20
S-SR-T-C4	0.5	3	0.5	2.5	20	4	20
S-SR-T-C5	0.5	3	0.5	2.5	20	4	30
S-SR-T-C5 (DUP)	0.5	3	0.5	2.5	20	4	20
S-SR-T-C6	0.5	3	0.5	2.5	20	3	20
S-SR-T-C7	0.5	2	0.5	2.5	20	3	10
S-SR-T-C8	0.5	2	0.5	2.5	20	3	5
S-SR-T-C9	0.5	2	0.5	2.5	20	3	5
S-SR-T-C10	0.5	3	0.5	2.5	20	4	10
S-SR-T-C11	0.5	3	0.5	2.5	20	5	20
S-SR-T-C12	0.5	3	0.5	2.5	20	5	20
S-SR-T-C13	0.5	3	0.5	2.5	20	4	20
S-SR-T-C14	0.5	3	0.5	2.5	20	4	20
S-SR-T-C14 (DUP)	0.5	3	0.5	2.5	20	5	20
S-SR-T-C15	0.5	3	0.5	2.5	20	4	20
S-SR-T-C16	0.5	3	0.5	2.5	20	4	20
S-SR-CRATER SIDE	0.5	3	0.5	2.5	20	3	5
Remote Areas							
S-C284-CENTER	0.5	7	0.5	2.5	20	18	20
S-C284-OIL RIG	0.5	5	0.5	2.5	20	18	20
S-C284-TANK1	0.5	7	0.5	2.5	20	12	20
S-C284-TANK2	0.5	38	0.5	2.5	20	15	20

Sample	Ag	Sr	Tl	Sn	U	V	Zn
			ppm	(mg/kg)			
S-C-314-CRATER A	0.5	11	0.5	2.5	20	6	20
S-C-314-CRATER B	0.5	12	0.5	2.5	20	3	20
S-F332-A	0.5	1	0.5	2.5	20	1	5
S-F332-A (DUP)	0.5	3	0.5	2.5	20	2	5
S-F332-B	0.5	2	0.5	2.5	20	2	10

a: ASQG agricultural Soil Quality Guideline

b: ISQG Industrial Soil Quality Guideline

Note: half values of the detection limits are used when metals are not detected

Values higher than the background mean + 2 x the standard deviation are highlighted in blue

Values higher than the CCME ASQG are highlighted in green

Values higher than the CCME ISQG are highlighted in red

TABLE III A: METALS CONCENTRATIONS IN VEGETATION SAMPLES (AL TO CD)

Sample	Al	Sb	As	Ba	Be	Cd
			ppm	(mg/kg)		
Background						
B-A-BG-1	167	0.02	0.1	26.3	0.1	0.04
B-A-BG-2	149	0.05	0.1	45.5	0.1	0.04
B-A-BG-3	177	0.05	0.1	68.9	0.1	0.90
B-A-BG-4	145	0.06	0.1	47.8	0.1	0.04
B-BR-BG1	1030	0.06	0.1	143.0	0.1	0.23
B-BR-BG1 (DUP)	1080	0.04	0.1	154.0	0.1	0.19
B-BR-BG2	607	0.04	0.1	123.0	0.1	0.28
B-BR-BG2 (DUP)	785	0.05	0.1	130.0	0.1	0.26
B-BR-BG3	643	0.07	0.2	68.3	0.1	0.26
B-BR-BG3 (DUP)	445	0.06	0.1	92.3	0.1	0.29
B-JL-BC-1	1180	0.14	0.3	46.3	0.1	1.76
B-JL-BC-2	471	0.08	0.1	23.7	0.1	1.47
B-BG-JL SIGN	519	0.05	0.1	44.7	0.1	0.04
B-BG-X3	149	0.07	0.1	43.8	0.1	0.04
B-BG-X3 (DUP)	132	0.04	0.1	43.0	0.1	0.04
B-BG-X4	131	0.05	0.1	42.0	0.1	0.04
B-E301-BG-A	709	0.05	0.1	57.0	0.1	0.47
B-E301-BG-B	130	0.02	0.1	34.5	0.1	0.04
B-E301-BG-C	1630	0.06	0.4	35.7	0.1	8.87
Average BG	541	0.06	0.1	67	0.1	0.81
Standard deviation	440	0.03	0.1	41	0.0	2.01
(2 x StDev)	880	0.05	0.2	82	0.0	4.03
Sum (Ave+(2xStDev)	1421	0.11	0.3	149	0.1	4.83
Alpha Range						
B-A-1	157	0.11	0.3	37.9	0.1	0.44
B-A-1 (DUP)	191	0.05	0.1	109.0	0.1	0.04
B-A-2	726	0.11	0.1	21.8	0.1	0.21
B-A-SR	739	0.05	0.1	72.8	0.1	6.86
B-A-0% A	4240	0.06	0.4	82.8	0.1	0.11
B-A-0% B	370	0.06	0.1	52.8	0.1	0.04
B-A-20% A	100	0.05	0.1	35.5	0.1	0.04
B-A-20% A (DUP)	93	0.04	0.1	34.2	0.1	0.04
B-A-20% B	228	0.02	0.1	48.0	0.1	0.04

	Al	Sb	As	Ba	Be	Cd
Sample			**ppm**	**(mg/kg)**		
B-A-40% A	39	0.02	0.1	29.5	0.1	0.04
B-A-40% A (DUP)	85	0.04	0.1	35.1	0.1	0.04
B-A-40% B	126	0.02	0.1	41.8	0.1	0.04
B-A-60% A	120	0.06	0.1	46.3	0.1	0.04
B-A-60% B	165	0.04	0.1	34.4	0.1	0.04
B-A-80% A	75	0.05	0.1	37.8	0.1	0.04
B-A-80% B	209	0.02	0.1	51.5	0.1	0.04
B-A-100% A	210	0.05	0.1	33.3	0.1	0.04
B-A-100% B	274	0.06	0.1	29.5	0.1	0.04
Bravo Range						
B-BR-T-FRONT LEFT (70M)	368	0.04	0.1	47.1	0.1	0.23
B-BR-T-FRONT RIGHT (70M)	607	0.06	0.2	39.0	0.1	0.11
Jimmy Lake Range						
B-JL-BC	336	0.02	0.1	30.2	0.1	0.17
B-JL-(-20%)-A	909	0.07	0.4	37.3	0.1	0.04
B-JL-(-20%)-B	155	0.07	0.1	36.6	0.1	0.21
B-JL-(-40%)-A	1220	0.07	0.2	71.6	0.1	0.28
B-JL-(-40%)-B	263	0.05	0.1	69.8	0.1	0.04
B-JL-(-60%)-A	971	0.05	0.1	40.3	0.1	0.09
B-JL-(-60%)-A (DUP)	312	0.04	0.1	50.1	0.1	0.16
B-JL-(-60%)-B	517	0.08	0.1	33.6	0.1	0.04
B-JL-(-60%)-B (DUP)	229	0.02	0.1	24.0	0.1	0.04
B-JL-(-120%)-A	113	0.05	0.1	34.0	0.1	0.15
B-JL-(-120%)-B	59	0.02	0.1	31.4	0.1	0.04
B-JL-(-140%)-A	103	0.05	0.1	29.2	0.1	0.04
B-JL-(-140%)-B	120	0.06	0.1	34.3	0.1	0.04
B-JL-(-140%)-B (DUP)	104	0.02	0.1	30.5	0.1	0.04
B-JL-(-160%)-A	306	0.06	0.2	44.1	0.1	0.04
B-JL-(-160%)-B	67	0.04	0.1	26.0	0.1	0.04
Remote Areas						
B-A-387-A	517	0.05	0.1	29.5	0.1	0.12
B-A-387-B	248	0.02	0.1	37.7	0.1	0.25
B-A-387-C	491	0.06	0.1	28.5	0.1	0.99
B-A-387-D	955	0.04	0.2	25.7	0.1	0.04
B-C284-CENTRE	919	0.07	0.3	30.8	0.1	0.08
B-C284-OIL RIGS	531	0.05	0.1	25.6	0.1	0.18

	Al	Sb	As	Ba	Be	Cd
Sample			ppm	(mg/kg)		
B-C284-TANK 1	172	0.06	0.1	21.1	0.1	0.04
B-C284-TANK 2	357	0.05	0.1	31.1	0.1	0.33
B-C314-A	215	0.05	0.1	28.9	0.1	0.10
B-C314-A (DUP)	309	0.05	0.1	35.3	0.1	0.39
B-C314 B	158	0.02	0.1	27.4	0.1	0.14
B-C314 C	142	0.04	0.1	38.2	0.1	0.21
B-F332-A	2930	0.05	0.3	146.0	0.1	7.83
B-F332-B	1340	0.06	0.1	150.0	0.1	7.62

Values higher than the background mean + 2 x the standard deviation are highlighted in blue

TABLE III B: METALS CONCENTRATIONS IN VEGETATION SAMPLES (CA TO MG)

	Ca	Cr	Co	Cu	Fe	Pb	Mg
Sample			ppm	(mg/kg)			
Background							
B-A-BG-1	2330	1.8	0.10	2.71	111	0.25	680
B-A-BG-2	3500	0.1	0.11	4.29	91	0.15	1070
B-A-BG-3	16900	0.1	1.38	4.77	90	0.13	2570
B-A-BG-4	3350	0.8	0.04	5.12	111	0.14	1540
B-BR-BG1	9240	6.3	0.56	6.18	491	0.44	3410
B-BR-BG1 (DUP)	8180	4.0	0.52	6.70	469	0.54	2730
B-BR-BG2	7910	2.7	0.46	6.37	256	0.27	3010
B-BR-BG2 (DUP)	8610	2.3	0.41	7.24	290	0.37	2800
B-BR-BG3	5210	6.8	1.26	4.46	313	0.34	3960
B-BR-BG3 (DUP)	8230	10.0	1.82	3.62	282	0.21	4190
B-JL-BC-1	5080	9.6	0.49	6.71	731	0.50	1160
B-JL-BC-2	7120	0.9	0.19	4.79	286	0.27	1710
B-BG-JL SIGN	10500	1.6	0.20	5.09	301	0.23	3020
B-BG-X3	6280	0.9	0.10	5.91	116	0.12	2500
B-BG-X3 (DUP)	6490	0.4	0.11	7.67	93	0.08	3100
B-BG-X4	4870	1.2	0.04	3.66	100	0.09	1980
B-E301-BG-A	5570	0.8	0.09	3.50	120	0.11	1300
B-E301-BG-B	30	0.1	0.09	3.12	1	0.15	8
B-E301-BG-C	5220	0.1	0.04	3.45	83	0.06	1160
Average BG	6559	2.7	0.42	5.02	228	0.23	2205
Standard Deviation	3585	3.2	0.51	1.49	183	0.14	1145
(2 x StDev)	7169	6.4	1.03	2.99	365	0.29	2291
Sum (Ave+(2xStDev)	13728	9.0	1.45	8.00	593	0.52	4496
Alpha Range							
B-A-1	4590	0.1	0.04	4.60	81	0.23	1620
B-A-1 (DUP)	5600	0.1	0.08	3.66	107	0.12	1920
B-A-2	4170	8.3	0.40	9.44	415	0.29	1760
B-A-SR	14200	2.4	0.72	5.22	392	0.27	2520
B-A-0% A	11100	8.3	0.94	6.14	1640	1.20	3730
B-A-0% B	3850	1.0	0.04	2.81	217	0.19	1650
B-A-20% A	2850	0.7	0.08	2.28	83	0.10	1300
B-A-20% A (DUP)	2810	0.1	0.04	2.53	67	0.09	1240

	Ca	Cr	Co	Cu	Fe	Pb	Mg
Sample			**ppm**	**(mg/kg)**			
B-A-20% B	4130	0.1	0.04	3.37	131	0.15	1580
B-A-40% A	1470	0.1	0.04	3.02	50	0.09	886
B-A-40% A (DUP)	1810	0.1	0.04	2.87	67	0.09	880
B-A-40% B	3260	1.7	0.04	2.87	100	0.10	1380
B-A-60% A	2800	0.1	0.14	3.63	90	0.16	1050
B-A-60% B	3580	0.1	0.04	3.92	108	0.13	1440
B-A-80% A	2470	0.1	0.04	3.47	72	0.11	999
B-A-80% B	5010	0.4	0.04	2.98	130	0.16	1650
B-A-100% A	3310	0.3	0.11	2.69	157	0.17	997
B-A-100% B	3940	0.5	0.04	2.50	168	0.24	1150
Bravo Range							
B-BR-T-FRONT LEFT (70M)	9140	18.9	1.23	7.00	1170	1.24	4290
B-BR-T-FRONT RIGHT (70M)	10300	7.5	1.19	7.74	563	0.54	2920
Jimmy Lake Range							
B-JL-BC	14100	4.8	0.60	8.93	991	1.10	2890
B-JL-(-20%)-A	13300	0.8	0.25	6.35	344	0.21	3750
B-JL-(-20%)-B	9350	2.9	0.41	5.58	323	0.27	2660
B-JL-(-40%)-A	9530	4.4	0.31	4.44	245	0.15	2540
B-JL-(-40%)-B	10300	0.8	0.40	5.14	317	0.31	3240
B-JL-(-60%)-A	9090	2.0	0.25	3.91	538	0.41	3380
B-JL-(-60%)-A (DUP)	11300	2.9	0.36	4.95	660	0.44	4920
B-JL-(-60%)-B	11500	1.8	0.17	7.52	253	0.45	2950
B-JL-(-60%)-B(DUP)	7480	0.4	0.08	4.16	124	0.20	2730
B-JL-(-120%)-A	9130	0.7	0.24	8.70	207	0.26	2440
B-JL-(-120%)-B	14000	1.6	0.20	8.08	152	0.27	2700
B-JL-(-140%)-A	13900	0.5	0.58	10.10	231	0.14	3180
B-JL-(-140%)-B	8460	0.9	0.11	12.30	112	0.16	2130
B-JL-(-140%)-B (DUP)	7960	0.1	0.10	7.78	100	0.17	2050
B-JL-(-160%)-A	8850	1.4	0.46	5.12	411	0.28	2540
B-JL-(-160%)-B	8400	0.1	0.11	7.26	112	0.14	3070
Remote Areas							
B-A-387-A	3900	0.7	0.25	1.72	617	0.42	1190
B-A-387-B	8360	1.3	0.17	3.42	127	0.17	3490
B-A-387-C	6170	3.5	0.40	4.57	516	1.12	1280
B-A-387-D	4480	0.4	0.12	3.30	188	0.24	1280
B-C284-CENTRE	2200	2.1	0.49	3.30	562	0.70	889

	Ca	Cr	Co	Cu	Fe	Pb	Mg
Sample			ppm	(mg/kg)			
B-C284-OIL RIGS	5190	1.4	0.78	3.28	182	0.25	1600
B-C284-TANK 1	2590	1.3	0.41	3.66	795	0.77	783
B-C284-TANK 2	4240	0.9	0.13	2.13	222	0.34	1180
B-C314-A	3020	0.1	0.08	4.85	98	0.30	683
B-C314-A (DUP)	2830	0.1	0.04	4.05	79	0.17	636
B-C314 B	2870	0.5	0.10	3.10	92	0.23	740
B-C314 C	5190	1.6	0.09	4.48	86	0.43	813
B-F332-A	2890	2.9	0.09	3.45	184	0.32	1020
B-F332-B	20	3.2	0.09	3.59	1	0.26	8

Values higher than the background mean + 2 x the standard deviation are highlighted in blue

TABLE III C: METALS CONCENTRATIONS IN VEGETATION SAMPLES (MN TO AG)

	Mn	**Mo**	**Ni**	**P**	**K**	**Se**	**Ag**
Sample			**ppm**	**(mg/kg)**			
Background							
B-A-BG-1	253	6.41	54.5	1640	8150	0.1	0.04
B-A-BG-2	710	2.53	8.5	1730	12200	0.1	0.04
B-A-BG-3	152	0.17	5.6	2010	9700	0.1	0.04
B-A-BG-4	56	1.98	14.8	3460	22700	0.1	0.04
B-BR-BG1	170	0.57	55.6	3050	16600	0.1	0.04
B-BR-BG1 (DUP)	183	0.79	15.1	3140	18300	0.1	0.04
B-BR-BG2	249	1.28	15.6	4080	17300	0.1	0.04
B-BR-BG2 (DUP)	200	1.98	14.3	3920	19100	0.1	0.04
B-BR-BG3	460	0.98	101.0	1630	11800	0.1	0.04
B-BR-BG3 (DUP)	500	0.99	278.0	1820	11700	0.1	0.04
B-JL-BC-1	42	7.40	223.0	1420	8110	0.1	0.04
B-JL-BC-2	29	29.50	25.9	1460	11500	0.3	0.04
B-BG-JL SIGN	37	3.69	9.2	2450	12200	0.1	0.04
B-BG-X3	29	4.31	6.1	3250	10700	0.1	0.04
B-BG-X3 (DUP)	28	3.61	7.1	3600	15800	0.1	0.04
B-BG-X4	48	3.01	2.8	4080	26500	0.1	0.04
B-E301-BG-A	178	0.24	48.9	1310	7940	0.1	0.04
B-E301-BG-B	1	0.32	5.2	10	41	0.1	0.04
B-E301-BG-C	107	0.34	1.8	1870	8580	0.1	0.04
Average BG	181	3.69	47.0	2417	13101	0.1	0.04
Standard Deviation	190	6.59	76.6	1139	6074	0.0	0.00
(2 x StDev)	380	13.17	153.2	2277	12148	0.1	0.00
Sum (Ave+(2xStDev)	561	16.86	200.2	4695	25249	0.2	0.04
Alpha Range							
B-A-1	213	0.57	5.4	1300	10000	0.1	0.04
B-A-1 (DUP)	56	0.61	12.8	1370	12500	0.1	0.04
B-A-2	81	0.64	292.0	2770	20900	0.1	0.04
B-A-SR	91	2.76	68.0	2100	11900	0.2	0.04
B-A-0% A	58	2.93	47.3	3190	13100	0.1	0.04
B-A-0% B	29	2.98	12.4	1680	11100	0.1	0.04
B-A-20% A	109	1.33	40.6	1260	11000	0.1	0.04
B-A-20% A (DUP)	92	1.13	8.1	1240	10500	0.1	0.04
B-A-20% B	34	4.71	11.7	1950	12400	0.1	0.04

	Mn	Mo	Ni	P	K	Se	Ag
Sample			**ppm**	**(mg/kg)**			
B-A-40% A	222	3.85	8.2	1390	5480	0.1	0.04
B-A-40% A (DUP)	302	3.04	5.0	1470	5860	0.1	0.04
B-A-40% B	33	4.85	24.5	1700	12100	0.1	0.04
B-A-60% A	267	1.59	28.8	1480	7740	0.1	0.04
B-A-60% B	56	4.96	8.0	1820	9990	0.1	0.04
B-A-80% A	200	1.21	10.2	1590	11300	0.1	0.04
B-A-80% B	70	7.50	10.3	2350	11000	0.1	0.04
B-A-100% A	67	1.59	20.9	1150	9630	0.1	0.04
B-A-100% B	29	4.96	11.2	2070	9610	0.1	0.04
Bravo Range							
B-BR-T-FRONT LEFT (70M)	95	0.68	73.8	2870	20800	0.1	0.04
B-BR-T-FRONT RIGHT (70M)	116	0.77	152.0	3920	20900	0.1	0.04
Jimmy Lake Range							
B-JL-BC	62	4.24	116.0	2560	17100	0.5	0.04
B-JL-(-20%)-A	60	18.50	23.7	3170	11600	0.2	0.04
B-JL-(-20%)-B	46	14.00	37.5	2600	9490	0.3	0.04
B-JL-(-40%)-A	59	27.70	212.0	2790	11400	0.4	0.04
B-JL-(-40%)-B	43	5.20	43.3	2210	7840	0.5	0.04
B-JL-(-60%)-A	59	14.30	13.2	2930	12600	0.5	0.04
B-JL-(-60%)-A (DUP)	77	16.20	36.2	4280	11400	0.4	0.04
B-JL-(-60%)-B	38	7.67	26.5	2620	14500	0.3	0.04
B-JL-(-60%)-B (DUP)	51	14.70	21.0	2300	11300	0.1	0.04
B-JL-(-120%)-A	58	10.60	9.2	2670	13400	0.3	0.04
B-JL-(-120%)-B	35	6.75	46.3	2330	16100	0.7	0.04
B-JL-(-140%)-A	60	3.73	26.5	2950	14000	0.2	0.04
B-JL-(-140%)-B	78	6.92	17.1	3190	20100	0.1	0.04
B-JL-(-140%)-B (DUP)	75	9.12	10.2	3210	16900	0.2	0.04
B-JL-(-160%)-A	54	2.52	54.8	1720	7640	0.1	0.04
B-JL-(-160%)-B	130	9.67	8.1	3150	15800	0.2	0.04
Remote Areas							
B-A-387-A	461	0.45	13.9	1400	9320	0.1	0.04
B-A-387-B	714	0.77	57.9	1800	6820	0.1	0.04
B-A-387-C	210	0.40	38.2	1570	5990	0.1	0.04
B-A-387-D	538	0.60	5.0	1700	8890	0.1	0.04
B-C284-CENTRE	401	0.37	44.7	1110	8400	0.1	0.04
B-C284-OIL RIGS	357	0.64	18.3	1390	9270	0.1	0.04

	Mn	Mo	Ni	P	K	Se	Ag
Sample			ppm	(mg/kg)			
B-C284-TANK 1	202	0.84	24.5	730	7080	0.1	0.04
B-C284-TANK 2	168	0.52	12.7	778	6480	0.1	0.04
B-C314-A	674	2.01	8.4	1710	6570	0.1	0.04
B-C314-A (DUP)	656	2.01	6.1	1780	6890	0.1	0.04
B-C314 B	566	0.55	20.4	1650	8810	0.1	0.04
B-C314 C	381	1.42	50.6	2270	6810	0.1	0.04
B-F332-A	215	3.65	25.8	2160	11300	0.1	0.04
B-F332-B	1	1.83	33.9	11	49	0.1	0.04

Values higher than the background mean + 2 x the standard deviation are highlighted in blue

TABLE III D: METALS CONCENTRATIONS IN VEGETATION SAMPLES (NA TO ZN)

	Na	Sr	Tl	Sn	Ti	V	Zn
Sample			**ppm**	**(mg/kg)**			
Background							
B-A-BG-1	181	5.90	0.02	0.02	0.38	0.32	14.7
B-A-BG-2	201	10.20	0.02	0.02	1.53	0.28	24.8
B-A-BG-3	182	46.90	0.02	0.02	4.91	0.25	76.0
B-A-BG-4	172	9.99	0.02	0.02	5.50	0.24	22.2
B-BR-BG1	328	59.00	0.02	0.02	38.80	1.45	50.9
B-BR-BG1 (DUP)	375	50.30	0.02	0.02	39.50	1.51	62.3
B-BR-BG2	184	38.90	0.02	0.02	22.60	0.85	59.3
B-BR-BG2 (DUP)	225	41.10	0.02	0.11	25.50	1.00	57.0
B-BR-BG3	230	49.20	0.02	0.02	13.60	1.08	49.8
B-BR-BG3 (DUP)	197	68.70	0.02	0.09	10.40	0.56	46.0
B-JL-BC-1	629	14.30	0.02	2.32	21.00	5.51	41.5
B-JL-BC-2	306	12.00	0.02	0.66	10.50	1.61	20.6
B-BG-JL SIGN	158	17.00	0.02	0.02	N/A	0.76	20.0
B-BG-X3	161	12.50	0.02	1.72	N/A	0.21	34.5
B-BG-X3 (DUP)	76	15.50	0.02	0.02	N/A	0.22	38.8
B-BG-X4	94	13.70	0.02	0.02	N/A	0.22	33.0
B-E301-BG-A	177	18.80	0.02	0.02	1.45	0.22	22.5
B-E301-BG-B	1	18.20	0.02	0.02	4.15	0.66	35.6
B-E301-BG-C	245	14.50	0.02	0.02	1.18	0.18	40.7
Average BG	217	27.19	0.02	0.27	13.40	0.90	39.5
Standard Deviation	132	19.52	0.00	0.64	13.24	1.22	16.8
(2 x StDev)	263	39.04	0.00	1.28	26.49	2.43	33.6
Sum (Ave+(2xStDev)	480	66.23	0.02	1.55	39.89	3.33	73.1
Alpha Range							
B-A-1	198	16.90	0.02	0.72	0.05	0.27	53.0
B-A-1 (DUP)	232	15.20	0.02	0.04	2.84	0.29	19.0
B-A-2	387	8.84	0.02	2.23	15.20	0.90	35.0
B-A-SR	287	38.50	0.02	0.04	15.10	1.22	81.4
B-A-0% A	1230	33.80	0.05	0.04	81.00	4.38	18.1
B-A-0% B	142	10.40	0.02	0.04	9.13	0.53	15.0
B-A-20% A	60	8.82	0.02	0.04	2.00	0.15	13.7
B-A-20% A (DUP)	60	9.25	0.02	0.04	1.86	0.15	12.2

	Na	Sr	Tl	Sn	Ti	V	Zn
Sample			**ppm**	**(mg/kg)**			
B-A-20% B	150	14.30	0.02	0.04	5.09	0.31	11.6
B-A-40% A	56	5.58	0.02	0.04	0.82	0.09	29.4
B-A-40% A (DUP)	66	6.76	0.02	0.04	1.41	0.15	34.3
B-A-40% B	168	9.97	0.02	0.04	0.92	0.21	10.4
B-A-60% A	91	9.27	0.02	0.87	2.10	0.22	23.7
B-A-60% B	170	9.19	0.02	0.04	1.21	0.26	15.7
B-A-80% A	136	7.10	0.02	0.04	1.44	0.09	23.8
B-A-80% B	163	9.89	0.02	0.04	2.12	0.32	11.5
B-A-100% A	153	8.67	0.02	0.04	4.89	0.36	18.8
B-A-100% B	192	8.23	0.02	0.04	5.73	0.41	10.7
Bravo Range							
B-BR-T-FRONT LEFT (70M)	888	77.40	0.05	0.04	66.20	4.85	77.1
B-BR-T-FRONT RIGHT (70M)	336	68.20	0.02	0.04	34.80	1.75	77.7
Jimmy Lake Range							
B-JL-BC	855	20.00	0.02	0.04	33.60	8.05	33.0
B-JL-(-20%)-A	332	21.70	0.02	0.04	14.80	1.30	20.5
B-JL-(-20%)-B	247	14.40	0.02	0.04	14.00	1.03	26.3
B-JL-(-40%)-A	195	16.20	0.02	0.14	4.49	0.51	21.6
B-JL-(-40%)-B	266	17.70	0.02	0.19	15.50	0.93	36.3
B-JL-(-60%)-A	324	18.00	0.02	0.04	21.00	1.75	17.2
B-JL-(-60%)-A (DUP)	392	21.30	0.02	0.04	30.50	2.12	29.7
B-JL-(-60%)-B	234	19.20	0.02	0.04	10.90	1.04	22.7
B-JL-(-60%)-B (DUP)	239	13.90	0.02	0.14	3.16	0.33	21.7
B-JL-(-120%)-A	218	16.80	0.02	0.04	10.20	0.64	47.9
B-JL-(-120%)-B	260	25.20	0.02	0.78	4.00	0.38	36.1
B-JL-(-140%)-A	251	17.40	0.02	0.04	6.20	0.62	33.3
B-JL-(-140%)-B	230	17.60	0.02	0.04	4.11	0.37	34.2
B-JL-(-140%)-B (DUP)	217	20.90	0.02	0.46	3.27	0.30	30.0
B-JL-(-160%)-A	323	14.80	0.02	0.12	17.50	1.21	42.2
B-JL-(-160%)-B	173	20.70	0.02	0.04	2.64	0.29	35.4
Remote Areas							
B-A-387-A	434	24.10	0.02	0.19	16.10	1.85	32.5
B-A-387-B	202	35.80	0.02	0.93	4.33	0.28	129.0
B-A-387-C	366	35.10	0.02	0.31	20.50	1.68	39.1
B-A-387-D	139	18.30	0.02	0.27	5.91	0.55	35.1
B-C284-CENTRE	333	8.08	0.02	0.04	20.50	1.65	20.6

	Na	Sr	Tl	Sn	Ti	V	Zn
Sample	ppm (mg/kg)						
B-C284-OIL RIGS	242	15.10	0.02	0.04	4.98	0.51	21.3
B-C284-TANK 1	319	8.86	0.02	0.35	9.22	0.86	29.3
B-C284-TANK 2	227	7.30	0.02	0.04	3.93	0.42	16.5
B-C314-A	234	6.86	0.02	0.04	1.81	0.18	34.5
B-C314-A (DUP)	157	5.92	0.02	0.04	0.97	0.11	31.7
B-C314 B	159	6.37	0.02	0.04	1.49	0.19	22.4
B-C314 C	203	8.95	0.02	0.04	1.41	0.18	28.7
B-F332-A	234	12.80	0.02	0.04	3.74	0.49	19.4
B-F332-B	1	17.60	0.02	0.15	0.03	0.49	29.5

Values higher than the background mean + 2 x the standard deviation are highlighted in blue

TABLE IV A: METALS CONCENTRATIONS IN SURFACE WATER SAMPLES (AL TO CD)

	Al	**Sb**	**As**	**Ba**	**Be**	**B**	**Cd**
Sample			**ppb**	**(µg/L)**			
Alpha Range							
SW-A-1	198000	2.2	38.4	1360	8	160	1.2
Jimmy Lake							
SW-JL-1	20	0.9	0.7	2	1	25	0.1
SW-JL-2	20	0.8	0.7	2	1	25	0.1
SW-JL-3	30	1.1	1.0	3	1	25	0.3
Primerose Lake							
SW-PL-1	50	0.2	1.0	38	1	25	0.1
SW-PL-2	30	0.2	1.0	42	1	25	0.1
SW-PL-3	5	0.2	0.9	40	1	25	0.1
SW-PL-4	10	0.2	0.9	40	1	25	0.1
Shaver River							
SW-SR	50	0.2	1.8	8	1	25	0.1
SW-SR-CRATER	4020	0.9	1.1	133	1	25	7.8
Remote Areas							
SW-C284	650	0.9	1.3	9	1	25	0.1
SW-C284-Rep	1040	1.0	0.2	4	1	25	0.1
SW-C284 (DUP)	100	0.8	0.9	12	1	25	0.1
SW-C284 (DUP) Rep	90	0.8	1.0	12	1	25	0.3
SW-C295-A	260	0.8	0.8	8	1	25	16.9
SW-C295-B	210	0.9	0.7	7	1	25	10
SW-E301-RIVER-BG	160	0.8	3.4	52	1	25	0.1
SW-F332-AIR STRIP A	20	0.8	0.6	9	1	25	0.1
SW-F332-AIR STRIP B	50	0.9	0.6	13	1	25	0.1
CCME	5 - 100 (a)	6.0 (b)	5.0 (a)	1000 (b)	100 (c)	500 (d)	0.017 (a)

(a): criteria for aquatic life in freshwater
(b): Interim Maximum Acceptable Concentrations in Drinking Water
(c): Maximum Acceptable Concentrations in Drinking Water
(d): criteria for irrigation and/or livestock
Note: half values of the detection limit are used when metals are not detected
Values higher than the criteria are in red
Values within the interval of the criteria are in green

TABLE IV B: METALS CONCENTRATIONS IN SURFACE WATER SAMPLES (CA TO LI)

	Ca	Cr	Co	Cu	Fe	Pb	Li
Sample			**ppb**	**(µg/L)**			
Alpha Range							
SW-A-1	37000	289	70	152	220000	82.0	100
Jimmy Lake							
SW-JL-1	7900	3	1	2	52	0.1	50
SW-JL-2	7900	3	1	4	51	0.1	50
SW-JL-3	8000	3	1	3	64	0.4	50
Primerose Lake							
SW-PL-1	25800	3	1	1	175	0.1	50
SW-PL-2	30900	3	1	1	110	0.1	50
SW-PL-3	31500	3	1	1	22	0.1	50
SW-PL-4	32200	3	1	1	39	0.1	50
Shaver River							
SW-SR	8700	3	1	8	1060	0.1	50
SW-SR-CRATER	8300	3	3	9	3100	5.3	50
Remote Areas							
SW-C284	2700	3	1	3	680	0.2	50
SW-C284-Rep	3400	3	1	12	1190	0.2	50
SW-C284 (DUP)	3500	3	1	12	314	0.9	50
SW-C284 (DUP) Rep	3600	3	1	2	317	0.5	50
SW-C295-A	1600	3	1	21	488	0.3	50
SW-C295-B	1400	3	1	12	790	0.4	50
SW-E301-RIVER-BG	29800	3	1	7	1330	0.1	50
SW-F332-AIR STRIP A	7900	3	1	1	164	0.1	50
SW-F332-AIR STRIP B	8400	3	1	3	1320	0.3	50
CCME	-	50 (c)	50 (d)	2 - 4 (a)	300 (a)	1 - 7 (a)	2500 (d)

(a): criteria for aquatic life in freshwater
(b): Interim Maximum Acceptable Concentrations in Drinking Water
(c): Maximum Acceptable Concentrations in Drinking water
(d): criteria for irrigation and/or livestock
Note: half values of the detection limit are used when metals are not detected
Values higher than the criteria are in red
Values within the interval of the criteria are in green

TABLE IV C: METALS CONCENTRATIONS IN SURFACE WATER SAMPLES (MG TO SE)

	Mg	Mn	Hg	Mo	Ni	K	Se
Sample			ppb	(µg/L)			
Alpha Range							
SW-A-1	48500	2540	0.1	13	179	37700	0.2
Jimmy Lake							
SW-JL-1	4500	45	0.1	2.5	1	1600	0.2
SW-JL-2	4600	47	0.1	2.5	1	1600	0.2
SW-JL-3	4400	48	0.1	2.5	1	1600	0.2
Primerose Lake							
SW-PL-1	8800	43	0.1	2.5	1	1500	0.2
SW-PL-2	9700	41	0.1	2.5	1	1500	0.2
SW-PL-3	9900	10	0.1	2.5	1	1600	0.2
SW-PL-4	9900	15	0.1	2.5	1	1600	0.2
Shaver River							
SW-SR	3100	30	0.1	2.5	3	300	0.2
SW-SR-CRATER	2000	849	0.1	2.5	3	3200	0.2
Remote Areas							
SW-C284	1000	31	0.1	2.5	1	700	0.2
SW-C284-Rep	1200	99	0.1	2.5	1	1000	0.2
SW-C284 (DUP)	2100	157	0.1	2.5	1	50	1.9
SW-C284 (DUP) Rep	2100	149	0.1	2.5	1	100	0.2
SW-C295-A	500	88	0.1	2.5	1	50	0.2
SW-C295-B	400	61	0.1	2.5	1	400	0.2
SW-E301-RIVER-BG	9100	127	0.1	2.5	1	900	0.2
SW-F332-AIR STRIP A	3800	92	0.1	2.5	1	600	0.2
SW-F332-AIR STRIP B	3700	245	0.1	2.5	1	300	0.2
CCME	-	200 (d)	0.1	73 (a)	25 - 150 (a)	-	1 (a)

(a): criteria for aquatic life in freshwater
(b): Interim Maximum Acceptable Concentrations in Drinking Water
(c): Maximum Acceptable Concentrations in Drinking water
(d): criteria for irrigation and/or livestock
Note: half values of the detection limit are used when metals are not detected
Values higher than the criteria are in red
Values within the interval of the criteria are in green

TABLE IV D: METALS CONCENTRATIONS IN SURFACE WATER SAMPLES (AG TO ZN)

	Ag	Na	Sr	Tl	Sn	Ti	U	V	Zn
Sample	**ppb (µg/L)**								
Alpha Range									
SW-A-1	0.2	500	221	4.0	25	4250	4.8	408.0	847
Jimmy Lake									
SW-JL-1	0.2	500	13	0.1	25	1	0.1	0.1	7
SW-JL-2	0.2	500	14	0.1	25	1	0.1	0.1	9
SW-JL-3	0.5	500	14	0.2	25	1	0.4	0.1	9
Primerose Lake									
SW-PL-1	0.2	7000	91	0.1	25	2	0.1	0.1	9
SW-PL-2	0.2	8000	102	0.1	25	1	0.1	0.1	14
SW-PL-3	0.2	8000	99	0.1	25	1	0.1	0.1	9
SW-PL-4	0.2	8000	101	0.1	25	1	0.1	0.1	16
Shaver River									
SW-SR	0.2	2000	25	0.1	25	2	0.1	0.1	13
SW-SR-CRATER	0.2	2000	61	0.1	25	98	0.1	0.5	39
Remote Areas									
SW-C284	0.2	500	9	0.1	25	18	0.2	1.0	12
SW-C284-Rep	0.2	500	8	0.1	25	16	0.1	1.0	15
SW-C284 (DUP)	0.2	500	13	0.1	25	2	0.1	0.1	26
SW-C284 (DUP) Rep	0.2	500	16	0.2	25	5	0.4	0.1	19
SW-C295-A	0.2	500	8	0.1	25	4	0.1	0.8	46
SW-C295-B	0.2	500	7	0.1	25	5	0.1	0.2	33
SW-E301-RIVER-BG	0.2	10000	105	0.1	25	7	0.1	0.1	20
SW-F332-AIR STRIP A	0.2	500	18	0.1	25	1	0.1	0.1	13
SW-F332-AIR STRIP B	0.2	500	23	0.1	25	2	0.1	0.1	13
CCME	0.1 (a)			0.8 (a)			10 (d)	100 (d)	30 (a)

(a): criteria for aquatic life in freshwater
(b): Interim Maximum Acceptable Concentrations in Drinking Water
(c): Maximum Acceptable Concentrations in Drinking water
(d): criteria for irrigation and/or livestock
Note: half values of the detection limit are used when metals are not detected
Values higher than the criteria are in red
Values within the interval of the criteria are in green

TABLE V A: METALS CONCENTRATIONS IN SEDIMENT SAMPLES (SB TO CO)

	Sb	As	Ba	Be	Cd	Cr	Co
Sample			**ppm**	**(mg/kg)**			
Jimmy Lake							
Sed-JL-1	0.1	0.7	16	0.5	0.3	2.2	0.5
Sed-JL-2	0.1	3.0	72	0.5	0.3	9.1	2.0
Sed-JL-3	0.1	0.3	8	0.5	0.3	0.7	0.5
Sed-JL-4	0.1	2.4	78	0.5	0.3	6.7	2.0
Sed-JL-5	0.1	3.4	98	0.5	0.3	5.7	1.0
Sed-JL-6	0.1	2.3	112	0.5	0.3	8.6	1.0
Sed-JL-7	0.1	9.6	120	0.5	0.3	8.6	3.0
Sed-JL-7 (DUP)	0.1	3.3	85	0.5	0.3	6.4	3.0
Sed-JL-8	0.1	7.2	150	0.5	0.3	13.2	5.0
Sed-JL-9	0.1	3.2	72	0.5	0.3	10.0	2.0
Sed-JL-10	0.1	3.0	70	0.5	0.3	11.3	3.0
Sed-JL-10 (DUP)	0.1	4.7	81	0.5	0.3	9.9	5.0
Primerose Lake							
Sed-PL-1	0.1	7.3	89	0.5	0.3	13.1	4.0
Sed-PL-2	0.1	8.6	126	0.5	0.3	36.8	7.0
Sed-PL-3	0.1	6.1	107	0.5	0.3	8.1	3.0
Sed-PL-4	0.1	3.5	44	0.5	0.3	8.1	3.0
Sed-PL-4 (DUP)	0.1	2.3	32	0.5	0.3	4.2	2.0
Sed-PL-5	0.1	13.1	159	0.5	0.3	19.4	7.0
Sed-PL-6	0.1	3.9	63	0.5	0.3	7.9	4.0
Sed-PL-7	0.1	0.3	3	0.5	0.3	0.3	0.5
Sed-PL-8	0.1	0.6	10	0.5	0.3	0.5	0.5
Sed-PL-8 (DUP)	0.1	0.8	14	0.5	0.3	1.0	0.5
Sed-PL-9	0.1	0.8	15	0.5	0.3	1.2	0.5
Sed-PL-10	0.1	5.1	120	0.5	0.3	10.2	7.0
Sed-PL-11	0.1	0.3	3	0.5	0.3	0.3	0.5
Sed-PL-12	0.1	0.9	9	0.5	0.3	0.5	0.5
Sed-PL-13	0.1	0.9	9	0.5	0.3	0.9	0.5
Sed- PL-13 (DUP)	0.1	1.0	11	0.5	0.3	0.8	0.5
CCME ISQG	-	5.9	-	-	0.6	37.3	-
CCME PEL	-	17.0	-	-	3.5	90	-

CCME ISQG: Interim Sediment Quality Guideline, PEL: Probable Effect Level

Values higher than the criteria are in red

Note: half values of the detection limit are used when metals are not detected

TABLE V B: METALS CONCENTRATIONS IN SEDIMENT SAMPLES (CU TO SE)

	Cu	Pb	Hg	Mo	Ni	Se
Sample			**ppm**	**(mg/kg)**		
Jimmy Lake						
Sed-JL-1	1	3	0.03	1	2	0.2
Sed-JL-2	7	3	0.34	3	12	1.2
Sed-JL-3	1	3	0.03	1	1	0.1
Sed-JL-4	8	6	0.57	2	9	1.1
Sed-JL-5	5	3	0.03	1	7	1.0
Sed-JL-6	5	3	0.03	1	9	0.8
Sed-JL-7	8	3	0.26	2	13	1.1
Sed-JL-7 (DUP)	7	3	0.03	1	10	0.8
Sed-JL-8	13	6	0.03	2	18	0.7
Sed-JL-9	7	3	0.03	3	14	1.2
Sed-JL-10	7	3	0.03	3	14	1.0
Sed-JL-10 (DUP)	10	5	0.03	2	15	0.9
Primerose Lake						
Sed-PL-1	9	5	0.03	1	14	0.7
Sed-PL-2	14	8	0.03	1	33	0.7
Sed-PL-3	7	5	0.03	1	9	0.7
Sed-PL-4	4	3	0.03	1	8	0.4
Sed-PL-4 (DUP)	4	3	0.03	1	4	0.2
Sed-PL-5	16	9	0.03	1	25	1.0
Sed-PL-6	5	3	0.03	1	7	0.4
Sed-PL-7	1	3	0.03	1	1	0.1
Sed-PL-8	3	3	0.03	1	1	0.1
Sed-PL-8 (DUP)	4	3	0.03	1	1	0.1
Sed-PL-9	1	3	0.03	1	1	0.1
Sed-PL-10	13	9	0.03	1	18	0.5
Sed-PL-11	1	3	0.03	1	1	0.1
Sed-PL-12	1	3	0.03	1	1	0.1
Sed-PL-13	1	3	0.03	1	1	0.1
Sed- PL-13 (DUP)	1	3	0.03	1	1	0.1
CCME ISQG	36	35	0.17	-	-	-
CCME PEL	197	91	0.49	-	-	-

CCME ISQG: Interim Sediment Quality Guideline, PEL: Probable Effect Level

Values higher than the criteria are in red

Note: half values of the detection limit are used when metals are not detected

TABLE V C: METALS CONCENTRATIONS IN SEDIMENT SAMPLES (AG TO ZN)

	Ag	**Sr**	**Tl**	**Sn**	**U**	**V**	**Zn**
Sample			**ppb (µg/L)**				
Jimmy Lake							
Sed-JL-1	0.5	7	0.5	2.5	20	2	20
Sed-JL-2	0.5	29	0.5	2.5	20	6	80
Sed-JL-3	0.5	4	0.5	2.5	20	1	20
Sed-JL-4	0.5	37	0.5	2.5	20	5	80
Sed-JL-5	0.5	62	0.5	2.5	20	5	30
Sed-JL-6	0.5	58	0.5	2.5	20	5	40
Sed-JL-7	0.5	79	0.5	2.5	20	10	80
Sed-JL-7 (DUP)	0.5	40	0.5	2.5	20	7	50
Sed-JL-8	0.5	58	0.5	2.5	20	15	80
Sed-JL-9	0.5	34	0.5	2.5	20	7	80
Sed-JL-10	0.5	29	0.5	2.5	20	10	70
Sed-JL-10 (DUP)	0.5	35	0.5	2.5	20	11	70
Primerose Lake							
Sed-PL-1	0.5	44	0.5	2.5	20	11	60
Sed-PL-2	0.5	53	0.5	2.5	20	15	70
Sed-PL-3	0.5	72	0.5	2.5	20	10	50
Sed-PL-4	0.5	20	0.5	2.5	20	7	40
Sed-PL-4 (DUP)	0.5	13	0.5	2.5	20	6	30
Sed-PL-5	0.5	38	0.5	2.5	20	19	80
Sed-PL-6	0.5	32	0.5	2.5	20	6	40
Sed-PL-7	0.5	2	0.5	2.5	20	1	5
Sed-PL-8	0.5	6	0.5	2.5	20	1	10
Sed-PL-8 (DUP)	0.5	8	0.5	2.5	20	1	10
Sed-PL-9	0.5	5	0.5	2.5	20	2	5
Sed-PL-10	0.5	38	0.5	2.5	20	14	70
Sed-PL-11	0.5	2	0.5	2.5	20	1	5
Sed-PL-12	0.5	5	0.5	2.5	20	1	5
Sed-PL-13	0.5	7	0.5	2.5	20	2	5
Sed- PL-13 (DUP)	0.5	4	0.5	2.5	20	2	5
CCME ISQG	-	-	-	-	-	-	123
CCME PEL	-	-	-	-	-	-	315

CCME ISQG: Interim Sediment Quality Guideline, PEL: Probable Effect Level

Values higher than the criteria are in red

Note: half values of the detection limit are used when metals are not detected

TABLE VI: EXPLOSIVES DETECTION LIMITS FOR SOIL ANALYSIS BY HPLC

Analyte	Soil, microgram/kg (ppb)	
	RP-HPLC	
	Detection limit	Reporting limit
HMX	26	100
RDX	34	100
1,3,5-TNB	16	100
TNT	16	100
2,6-DNT	19	100
2,4-DNT	28	100
2-ADNT	32	100
4-ADNT	32	100
NG	20	100
1,3-DNB	100	200
TETRYL	600	1000
PETN	500 (est.)	500

Note: 3,5-DNA co-elutes with NB

TABLE VII A: EXPLOSIVES IN JIMMY LAKE RANGE SOIL BY HPLC IN PPM (NG TO TNB)

Sample	NG	1,3-DNB	2,6-DNT	2,4-DNT	1,3,5-TNB
S-JL-BC-A1	3.59	n.d.	n.d.	n.d.	n.d.
S-JL-BC-A2	0.81	n.d.	n.d.	n.d.	n.d.
S-JL-BC-B1	1.43	n.d.	n.d.	n.d.	n.d.
S-JL-BC-B2	1.24	n.d.	n.d.	n.d.	n.d.
S-JL-BC-B3	0.33	n.d.	n.d.	n.d.	n.d.
S-JL-BC-B4	1.90	n.d.	n.d.	n.d.	n.d.
S-JL-BC-B4 (DUP)	0.49	n.d.	n.d.	n.d.	n.d.
S-JL-BC-B5	0.94	n.d.	n.d.	n.d.	n.d.
S-JL-BC-B6	0.34	n.d.	n.d.	n.d.	n.d.
S-JL-BC-B7	1.01	n.d.	n.d.	n.d.	n.d.
S-JL-BC-B7 (DUP)	0.66	n.d.	n.d.	n.d.	n.d.
S-JL-BC-B8	0.38	n.d.	n.d.	n.d.	n.d.
S-JL-BC-C1	0.38	n.d.	n.d.	n.d.	n.d.
S-JL-BC-C2	1.75	n.d.	n.d.	n.d.	n.d.
S-JL-BC-C3	0.79	n.d.	n.d.	n.d.	n.d.
S-JL-BC-C3 (DUP)	0.67	n.d.	n.d.	n.d.	n.d.
S-JL-BC-C4	0.09	n.d.	n.d.	n.d.	n.d.
S-JL-BC-C5	0.17	n.d.	n.d.	n.d.	n.d.
S-JL-BC-C6	0.43	n.d.	n.d.	n.d.	n.d.
S-JL-BC-C7	2.04	n.d.	n.d.	n.d.	n.d.
S-JL-BC-C8	1.24	n.d.	n.d.	n.d.	n.d.
S-JL-BC-C8 (DUP)	0.54	n.d.	n.d.	n.d.	n.d.
S-JL-BC-C9	1.10	n.d.	n.d.	n.d.	n.d.
S-JL-BC-C10	0.33	n.d.	n.d.	n.d.	n.d.
S-JL-BC-C11	0.52	n.d.	n.d.	n.d.	n.d.
S-JL-BC-C12	0.47	n.d.	n.d.	n.d.	n.d.
S-JL-BC-C13	1.24	n.d.	n.d.	n.d.	n.d.
S-JL-BC-C14	n.d.	n.d.	n.d.	n.d.	n.d.
S-JL-BC-C15	0.34	n.d.	n.d.	n.d.	n.d.
S-JL-BC-C16	1.72	n.d.	n.d.	n.d.	n.d.

n.d.: not detected, n.a.: not analysed
nitrobenzene was not detected in any samples

TABLE VII B: EXPLOSIVES IN JIMMY LAKE RANGE SOIL BY HPLC IN PPM (TNT TO HMX)

Sample	TNT	RDX	2-ADNT	4-ADNT	TÉTRYL	HMX
S-JL-BC-A1	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
S-JL-BC-A2	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
S-JL-BC-B1	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
S-JL-BC-B2	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
S-JL-BC-B3	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
S-JL-BC-B4	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
S-JL-BC-B4 (DUP)	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
S-JL-BC-B5	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
S-JL-BC-B6	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
S-JL-BC-B7	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
S-JL-BC-B7 (DUP)	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
S-JL-BC-B8	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
S-JL-BC-C1	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
S-JL-BC-C2	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
S-JL-BC-C3	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
S-JL-BC-C3 (DUP)	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
S-JL-BC-C4	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
S-JL-BC-C5	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
S-JL-BC-C6	0.07	n.d.	n.d.	n.d.	n.d.	n.d.
S-JL-BC-C7	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
S-JL-BC-C8	n.d	n.d	n.d	n.d	n.d	n.d
S-JL-BC-C8 (DUP)	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
S-JL-BC-C9	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
S-JL-BC-C10	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
S-JL-BC-C11	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
S-JL-BC-C12	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
S-JL-BC-C13	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
S-JL-BC-C14	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
S-JL-BC-C15	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
S-JL-BC-C16	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.

n.d.: not detected
nitrotoluene were not detected

TABLE VIII A: EXPLOSIVES IN SHAVER RIVER RANGE SOIL BY HPLC IN PPM (NG TO TNB)

Sample	NG	1,3-DNB	2,6-DNT	2,4-DNT	1,3,5-TNB
S-SR-BG1	n.d.	n.d.	n.d.	n.d.	n.d.
S-SR-BG2	n.d.	n.d.	n.d.	n.d.	n.d.
S-SR-BG3	n.d.	n.d.	n.d.	n.d.	n.d.
S-SR-T-A1	n.d.	n.d.	n.d.	n.d.	n.d.
S-SR-T-A1 (DUP)	n.d.	n.d.	n.d.	n.d.	1.66
S-SR-T-A2	n.d.	n.d.	n.d.	n.d.	0.91
S-SR-T-B1	n.d.	n.d.	n.d.	n.d.	0.65
S-SR-T-B1 (DUP)	n.d.	n.d.	n.d.	n.d.	1.36
S-SR-T-B2	n.d.	n.d.	n.d.	n.d.	1.04
S-SR-T-B3	n.d.	n.d.	n.d.	n.d.	n.d.
S-SR-T-B4	n.d.	n.d.	n.d.	n.d.	0.23
S-SR-T-B4 (DUP)	n.d.	n.d.	n.d.	n.d.	n.d.
S-SR-T-B5	n.d.	n.d.	n.d.	n.d.	1.07
S-SR-T-B6	n.d.	n.d.	n.d.	n.d.	0.30
S-SR-T-B7	n.d.	n.d.	n.d.	n.d.	n.d.
S-SR-T-B8	n.d.	n.d.	n.d.	n.d.	n.d.
S-SR-T-C1	n.d.	n.d.	n.d.	n.d.	n.d.
S-SR-T-C2	n.d.	n.d.	n.d.	n.d.	0.90
S-SR-T-C3	n.d.	n.d.	n.d.	n.d.	1.54
S-SR-T-C3 (DUP)	n.d.	n.d.	n.d.	n.d.	0.68
S-SR-T-C4	n.d.	n.d.	n.d.	n.d.	0.72
S-SR-T-C5	n.d.	n.d.	n.d.	n.d.	0.42
S-SR-T-C5 (DUP)	n.d.	n.d.	n.d.	n.d.	0.54
S-SR-T-C6	n.d.	n.d.	n.d.	n.d.	0.60
S-SR-T-C7	n.d.	n.d.	n.d.	n.d.	0.44
S-SR-T-C8	n.d.	n.d.	n.d.	n.d.	0.33
S-SR-T-C9	n.d.	n.d.	n.d.	n.d.	0.28
S-SR-T-C10	n.d.	n.d.	n.d.	n.d.	0.37
S-SR-T-C11	n.d.	n.d.	n.d.	n.d.	0.80
S-SR-T-C12	n.d.	n.d.	n.d.	n.d.	n.d.
S-SR-T-C13	n.d.	n.d.	n.d.	n.d.	n.d.
S-SR-T-C14	n.d.	n.d.	n.d.	n.d.	n.d.
S-SR-T-C14 (DUP)	n.d.	n.d.	n.d.	n.d.	n.d.
S-SR-T-C15	n.d.	n.d.	n.d.	n.d.	0.40

Sample	NG	1,3-DNB	2,6-DNT	2,4-DNT	1,3,5-TNB
S-SR-T-C16	n.d.	n.d.	n.d.	n.d.	0.57
S-SR-CRATER SIDE	n.d.	n.d.	n.d.	n.d.	0.35
SW-SR-Crater*	0.002	0.595	0.377	6.486	n.a

n.d.: not detected
n.a.: not analysed
nitrobenzene was not detected in any samples

* analysis done by GC/ECD on a water sample collected in a crater near the Shaver target

TABLE VIII B: EXPLOSIVES IN SHAVER RIVER RANGE SOIL BY HPLC IN PPM (TNT TO HMX)

Sample	TNT	RDX	2-ADNT	4-ADNT	TÉTRYL	HMX
S-SR-BG1	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
S-SR-BG2	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
S-SR-BG3	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
S-SR-T-A1	22.76	n.d.	n.d.	0.81	n.d.	n.d.
S-SR-T-A1 (DUP)	165.03	n.d.	n.d.	n.d.	n.d.	n.d.
S-SR-T-A2	59.39	n.d.	n.d.	n.d.	n.d.	n.d.
S-SR-T-B1	28.99	0.35	n.d.	n.d.	n.d.	n.d.
S-SR-T-B1 (DUP)	66.38	n.d.	1.44	n.d.	n.d.	n.d.
S-SR-T-B2	81.78	n.d.	n.d.	0.92	n.d.	n.d.
S-SR-T-B3	63.54	n.d.	n.d.	n.d.	n.d.	n.d.
S-SR-T-B4	11.42	n.d.	n.d.	n.d.	n.d.	n.d.
S-SR-T-B4 (DUP)	30.22	n.d.	n.d.	n.d.	n.d.	n.d.
S-SR-T-B5	93.13	n.d.	1.47	n.d.	n.d.	n.d.
S-SR-T-B6	19.40	n.d.	n.d.	n.d.	n.d.	n.d.
S-SR-T-B7	49.09	n.d.	n.d.	n.d.	n.d.	n.d.
S-SR-T-B8	8.02	n.d.	n.d.	n.d.	n.d.	n.d.
S-SR-T-C1	16.63	n.d.	n.d.	n.d.	n.d.	n.d.
S-SR-T-C2	64.26	n.d.	n.d.	n.d.	n.d.	n.d.
S-SR-T-C3	61.34	n.d.	n.d.	n.d.	n.d.	n.d.
S-SR-T-C3 (DUP)	31.38	n.d.	n.d.	n.d.	n.d.	n.d.
S-SR-T-C4	29.69	6.01	n.d.	n.d.	n.d.	1.47
S-SR-T-C5	25.98	n.d.	n.d.	n.d.	n.d.	n.d.
S-SR-T-C5 (DUP)	31.74	n.d.	n.d.	n.d.	n.d.	n.d.
S-SR-T-C6	51.18	n.d.	n.d.	n.d.	n.d.	n.d.
S-SR-T-C7	81.52	n.d.	n.d.	n.d.	n.d.	n.d.
S-SR-T-C8	49.44	n.d.	n.d.	n.d.	n.d.	n.d.
S-SR-T-C9	60.44	n.d.	n.d.	n.d.	n.d.	n.d.
S-SR-T-C10	56.67	n.d.	n.d.	n.d.	n.d.	n.d.
S-SR-T-C11	71.87	n.d.	n.d.	n.d.	n.d.	n.d.
S-SR-T-C12	10.60	n.d.	n.d.	n.d.	n.d.	n.d.
S-SR-T-C13	14.87	n.d.	n.d.	n.d.	n.d.	n.d.
S-SR-T-C14	2.95	n.d.	n.d.	n.d.	n.d.	n.d.
S-SR-T-C14 (DUP)	1.33	n.d.	n.d.	n.d.	n.d.	n.d.
S-SR-T-C15	34.07	n.d.	n.d.	n.d.	n.d.	n.d.

Sample	TNT	RDX	2-ADNT	4-ADNT	TÉTRYL	HMX
S-SR-T-C16	33.29	n.d.	n.d.	n.d.	n.d.	n.d.
S-SR-CRATER SIDE	79.38	n.d.	n.d.	n.d.	n.d.	n.d.
SW-SR-Crater*	13.10	2.046	n.d.	n.d.	n.d.	n.d.

n.d.: not detected
n.a.: not analysed

* analysis done by GC/ECD on a water sample collected in a crater near the Shaver target

TABLE IX: EXPLOSIVES IN SHAVER RIVER RANGE SOIL BY HPLC IN PPM (COMPOSITING IN FRONT OF THE TARGET IN B1)

Sample	HMX	TNB	RDX	TNT	3,5-DNA	2,4-DNT	2-ADNT	4-ADNT
SR-1-1	<d	0.104	<d	9.44	0.284	0.106	1.29	0.844
SR-1-2	<d	0.110	<d	10.7	0.300	0.112	1.37	0.888
SR-1-3	<d	0.110	<d	10.6	0.270	0.100	1.23	0.802
mean		**0.108**		**10.2**	**0.285**	**0.106**	**1.30**	**0.845**
Std Dev		0.003		0.688	0.015	0.006	0.072	0.043
%RSD		**3.21**		**6.72**	**5.27**	**5.66**	**5.57**	**5.09**
SR-2-1	<d	0.098	<d	12.8	0.248	0.082	1.10	0.730
SR-2-2	<d	0.094	<d	11.3	0.252	0.090	1.13	0.746
SR-2-3	<d	0.092	<d	10.7	0.246	0.086	1.08	0.706
mean		**0.095**		**11.6**	**0.249**	**0.086**	**1.10**	**0.727**
Std Dev		0.003		1.073	0.003	0.004	0.023	0.020
%RSD		**3.23**		**9.28**	**1.23**	**4.65**	**2.11**	**2.77**
SR-3-1	<d	0.112	<d	11.0	0.260	0.094	1.10	0.716
SR-3-2	<d	0.098	<d	10.9	0.268	0.100	1.16	0.744
SR-3-3	<d	0.108	<d	10.4	0.254	0.100	1.10	0.698
mean		**0.106**		**10.8**	**0.261**	**0.098**	**1.12**	**0.719**
Std Dev		0.007		0.314	0.007	0.003	0.036	0.023
%RSD		**6.80**		**2.92**	**2.69**	**3.53**	**3.25**	**3.22**
SR-4-1	<d	0.118	<d	10.5	0.264	0.096	1.27	0.806
SR-4-2	<d	0.126	<d	10.3	0.252	0.096	1.22	0.800
SR-4-3	<d	0.112	<d	10.3	0.258	0.110	1.24	0.826
mean		**0.119**		**10.4**	**0.258**	**0.101**	**1.25**	**0.811**
Std Dev		0.007		0.1	0.006	0.008	0.027	0.014
%RSD		**5.92**		**1.11**	**2.33**	**8.03**	**2.18**	**1.68**
Mean[1]	**<d**	**0.107**	**<d**	**10.7**	**0.263**	**0.098**	**1.19**	**0.776**
Std Dev[1]		0.010		0.596	0.015	0.008	0.094	0.062
%RSD[1]		**9.20**		**5.55**	**5.83**	**8.66**	**7.91**	**7.98**
%RSD[2]		**5.05**		**5.93**	**2.95**	**5.71**	**3.56**	**3.42**
Blank	<d	<d	<d	<d	<d	<d	<d	<d
LCS*	**1.00**	**0.926**	**0.930**	**1.00**	**NA**	**1.06**	**1.03**	**1.03**

<d: smaller than detection limits

1: these values are for Grand mean, Grand Std dev and % RSD for samples

2: this is pooled %RSD for subsamples

*: soil spiked at 1 ppm

TABLE X: EXPLOSIVES IN SHAVER RIVER RANGE SOIL BY HPLC IN PPM (DISCRETE SAMPLING IN FRONT OF THE TARGET IN B1)

Sample	HMX	TNB	RDX	TNT	3,5-DNA	2,4-DNT	2-ADNT	4-ADNT
SR-1	<d	0.286	0.048	16.9	0.316	0.128	2.14	1.71
SR-2	<d	0.096	<d	3.62	0.198	0.126	1.67	1.33
SR-3	<d	0.170	<d	29.4	0.220	0.108	1.68	1.30
SR-4	<d	0.100	<d	24.1	0.090	0.096	0.607	0.582
SR-5	<d	0.203	<d	46.3	0.351	0.155	2.28	1.67
SR-6	0.310	0.115	3.40	3.80	0.233	0.155	1.09	0.845
SR-7	<d	0.050	0.044	18.4	0.081	0.044	0.666	0.660
SR-8	<d	0.092	<d	1.91	0.172	0.080	1.12	0.832
SR-9	<d	0.044	0.058	11.5	0.072	0.044	0.685	0.707
SR-10	<d	0.114	<d	8.83	0.154	0.082	1.30	1.04
SR-11	<d	0.451	<d	71.1	0.401	0.140	2.40	1.67
SR-12	<d	0.118	0.066	21.9	0.198	0.124	1.32	1.02
SR-13	<d	0.155	<d	9.94	0.265	0.147	1.83	1.29
SR-14	<d	0.314	0.270	27.4	0.290	0.222	2.04	1.40
SR-15	<d	0.395	0.160	6.85	0.353	0.182	1.78	1.26
SR-16	<d	0.217	<d	9.99	0.251	0.119	1.64	1.22
SR-17	<d	0.313	<d	4.02	0.317	0.151	2.11	1.44
SR-18	<d	0.158	0.042	42.1	0.174	0.146	1.35	1.01
SR-19	<d	0.193	<d	38.2	0.235	0.171	1.79	1.40
SR-20	<d	0.122	<d	3.76	0.188	0.174	1.65	1.31
SR-21	<d	0.197	0.058	7.87	0.323	0.108	1.65	1.11
SR-22	<d	0.223	<d	2.19	0.351	0.122	1.96	1.24
SR-23	<d	0.242	<d	30.6	0.338	0.126	2.00	1.31
SR-24	<d	0.195	<d	3.46	0.318	0.111	1.88	1.23
SR-25	<d	0.050	<d	1.49	0.179	0.060	0.946	0.667
SR-26	<d	0.096	<d	1.11	0.276	0.094	1.28	0.829
SR-27	<d	0.058	<d	11.3	0.148	0.066	0.956	0.722
SR-28	<d	0.094	<d	14.0	0.168	0.080	1.17	0.971
SR-29	<d	0.142	<d	25.3	0.261	0.138	1.74	1.27
SR-30	<d	0.194	<d	8.08	0.227	0.118	1.59	1.28
SR-31	<d	0.070	<d	6.94	0.152	0.050	0.900	0.752
SR-32	<d	0.150	<d	17.8	0.299	0.096	1.65	1.14
SR-33	<d	0.088	<d	2.29	0.273	0.086	1.39	0.934
SR-34	<d	0.122	<d	2.21	0.213	0.050	0.941	0.712

Sample	HMX	TNB	RDX	TNT	3,5-DNA	2,4-DNT	2-ADNT	4-ADNT
SR-35	<d	0.080	<d	1.68	0.185	0.054	1.07	0.782
SR-36	<d	0.078	<d	53.0	0.124	0.056	0.726	0.600
SR-37	<d	0.094	<d	100	0.084	0.050	0.723	0.852
SR-38	<d	0.086	<d	1.46	0.234	0.082	1.05	0.644
SR-39	<d	0.114	0.146	6.56	0.185	0.092	1.07	0.861
SR-40	<d	0.129	0.078	4.71	0.336	0.153	1.71	1.29
SR-41	<d	0.737	<d	289	0.215	0.100	1.12	0.804
SR-42	3.98	<d	35.4	0.657	0.171	0.052	0.748	0.519
SR-43	<d	0.096	0.179	59.0	0.193	0.066	0.917	0.706
SR-44	<d	0.064	<d	2.01	0.191	0.048	0.822	0.520
SR-45	<d	0.066	<d	35.4	0.148	0.058	0.687	0.493
SR-46	<d	0.128	<d	12.3	0.232	0.070	0.989	0.672
SR-47	<d	0.090	<d	24.8	0.136	0.058	0.533	0.351
SR-48	<d	0.179	0.048	6.48	0.398	0.113	1.53	0.863
SR-49	<d	0.198	<d	5.37	0.279	0.086	1.16	0.736
SR-50	<d	0.228	<d	6.57	0.296	0.106	1.63	1.03
SR-51	<d	0.142	<d	18.2	0.146	<d	0.393	0.219
SR-52	<d	<d	<d	1.66	0.068	<d	0.260	0.158
SR-53	<d	0.059	<d	0.393	0.167	<d	0.491	0.261
SR-54	<d	0.343	<d	3.03	0.327	0.066	1.08	0.677
SR-55	<d	1.62	<d	3.03	0.369	0.080	1.03	0.560
SR-56	<d	0.092	<d	0.873	0.255	0.072	0.809	0.482
SR-57	<d	0.114	<d	1.52	0.212	0.058	0.755	0.457
SR-58	<d	0.160	<d	5.09	0.234	0.084	0.954	0.631
SR-59	<d	0.218	<d	22.6	0.302	0.092	1.15	0.679
SR-60	<d	0.310	<d	4.42	0.384	0.134	1.86	1.21
SR-61	<d	0.134	<d	17.7	0.217	0.054	0.654	0.371
SR-62	<d	0.068	<d	0.459	0.196	0.050	0.619	0.329
SR-63	<d	0.076	<d	1.13	0.260	0.058	0.797	0.376
SR-64	<d	0.076	<d	1.29	0.145	<d	0.444	0.245
SR-65	<d	0.125	<d	18.6	0.167	<d	0.518	0.346
SR-66	<d	0.168	<d	3.23	0.260	0.066	0.926	0.573
SR-67	<d	0.142	<d	1.44	0.282	0.100	1.09	0.700
SR-68	<d	0.078	<d	0.950	0.148	0.054	0.510	0.306
SR-69	<d	0.325	<d	11.1	0.438	0.151	1.80	1.15
SR-70	<d	0.266	<d	2.94	0.415	0.148	1.75	1.17
SR-71	<d	0.461	<d	26.0	0.400	0.098	1.10	0.619

Sample	HMX	TNB	RDX	TNT	3,5-DNA	2,4-DNT	2-ADNT	4-ADNT
SR-72	<d	0.048	<d	0.483	0.160	0.065	0.606	0.333
SR-73	<d	0.307	<d	16.9	0.340	0.082	0.971	0.543
SR-74	<d	0.153	<d	37.0	0.185	0.048	0.707	0.458
SR-75	0.339	0.347	1.88	16.1	0.308	0.076	1.10	0.629
SR-76	<d	0.141	<d	1.36	0.283	0.082	1.06	0.693
SR-77	<d	0.209	<d	33.2	0.328	0.095	1.23	0.778
SR-78	0.615	0.112	3.44	22.4	0.232	0.082	0.879	0.577
SR-79	<d	0.164	<d	6.63	0.384	0.118	1.57	0.977
SR-80	<d	0.197	<d	4.85	0.373	0.136	1.51	1.01
SR-81	<d	0.133	<d	0.772	0.447	0.097	1.14	0.520
SR-82	<d	0.126	<d	5.32	0.311	0.064	1.16	0.540
SR-83	<d	0.134	<d	0.971	0.482	0.132	1.37	0.660
SR-84	<d	0.181	<d	12.7	0.355	0.097	1.12	0.614
SR-85	<d	0.076	<d	1.56	0.260	0.099	0.962	0.604
SR-86	<d	0.092	<d	47.0	0.261	0.102	1.02	0.652
SR-87	<d	0.183	<d	2.53	0.468	0.135	1.92	1.20
SR-88	<d	0.240	<d	31.9	0.472	0.147	1.85	1.19
SR-89	<d	0.151	<d	3.44	0.405	0.125	1.51	0.892
SR-90	<d	0.189	<d	32.4	0.374	0.169	1.34	0.898
SR-91	<d	0.123	<d	5.83	0.416	0.147	1.43	0.881
SR-92	<d	<d	<d	0.381	0.090	<d	0.293	0.174
SR-93	<d	0.064	<d	1.07	0.234	0.072	0.836	0.495
SR-94	<d	0.088	<d	6.95	0.263	0.078	0.976	0.632
SR-95	<d	0.124	<d	1.87	0.384	0.116	1.49	0.946
SR-96	<d	0.121	<d	4.62	0.360	0.106	1.35	0.916
SR-97	<d	0.134	<d	5.76	0.405	0.116	1.51	1.01
SR-98	<d	0.163	0.060	3.26	0.454	0.157	1.75	1.24
SR-99	<d	0.284	0.064	8.97	0.501	0.157	1.76	1.11
SR-100	<d	0.490	0.076	19.5	0.688	0.260	2.20	1.31
Min	**<d**	**0.010**	**<d**	**0.381**	**0.068**	**0.010**	**0.260**	**0.158**
Max	**3.98**	**1.62**	**35.4**	**289**	**0.688**	**0.260**	**2.40**	**1.71**
Median		**0.134**		**6.57**	**0.261**	**0.097**	**1.13**	**0.780**
Mean		**0.183**		**16.2**	**0.271**	**0.103**	**1.23**	**0.836**
Sd		**0.184**		**32.3**	**0.112**	**0.042**	**0.492**	**0.359**

<d: smaller than detection limits

TABLE XI: STATISTICAL RESULTS FOR TNT DISTRIBUTIONS OF MATHEMATICALLY-SIMULATED MULTI-INCREMENT COMPOSITE SAMPLES FOR 10-M X 10-M GRID

	TNT Concentrations in ppm					
n	5	10	20	30	40	50
min	3.84	3.58	5.47	7.45	8.35	10.50
max	74.10	49.50	33.30	41.90	29.10	30.10
median	13.35	14.40	15.65	13.30	14.80	15.25
mean	19.20	17.10	16.60	15.50	15.80	16.60
std dev	17.30	10.70	6.99	6.79	4.82	4.79
95% Tolerance range min	-15.6	-4.47	2.56	1.82	6.17	6.95
95% Tolerance range max	57.9	38.6	30.7	29.1	25.5	26.2

Figures

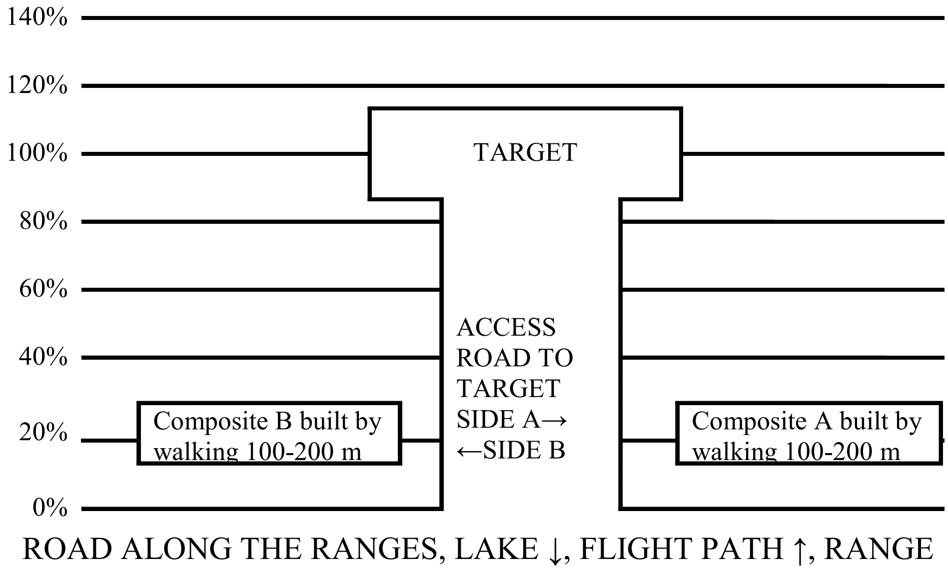

Figure 1: Schematic of the Linear Sampling Strategy

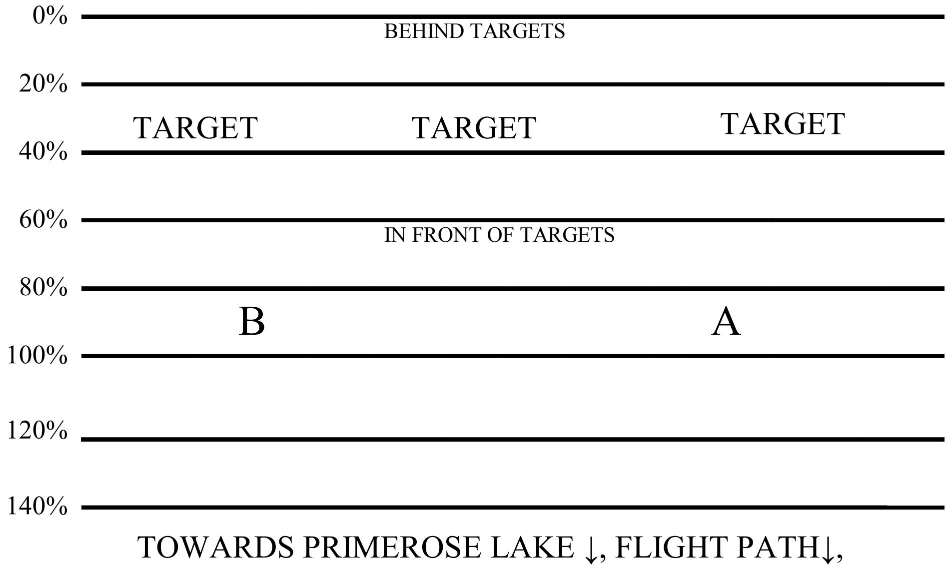

Figure 2: Modified Linear Strategy in Jimmy Lake Range

Figure 3: Targets in the Strafing Area of Jimmy Lake Range

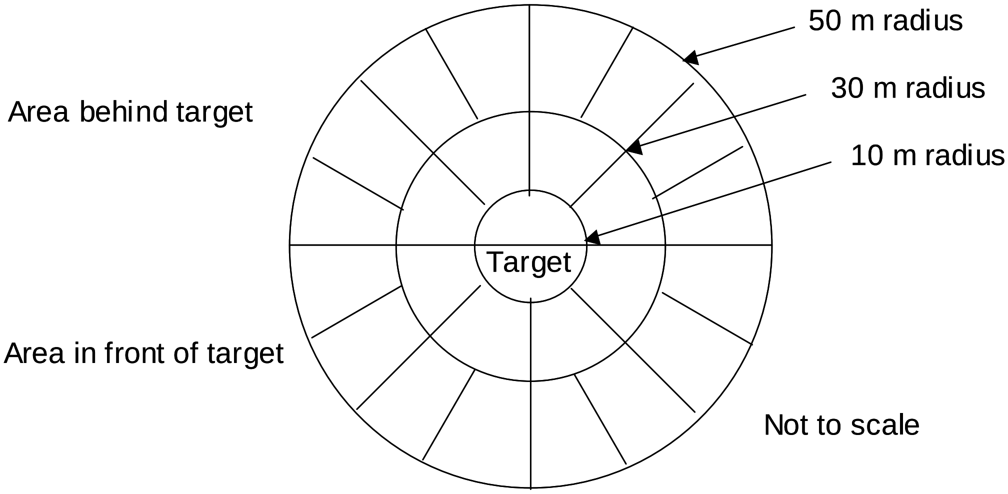

Figure 4: Schematic of the Circular Sampling Strategy

Figure 5: Target of the Bombing Circle in Jimmy Lake Range

Figure 6: Circular Strategy in Shaver River Range

Figure 7: Statistical Evaluation of the Explosive Concentrations in Discrete Samples

Figure 8: Sampling of Water in a Crater in Shaver River Range

Figure 9: Sediment Sampling in Primerose Lake

Figure 10: Wooden Trgets in Remote Area C-295

Figure 11: Laser Pointing Targets in Remote Area C-284

Figure 12: Pratice Bomb in Remote Area C-284

Figure 13: Rocket Debris in Remote Area F-332

Figure 14: Rocket Motor in Remote Area F-332

Figure 15: Vegetation Collection in Front of the Tank Target in Alpha Range

Figure 16: Vegetation Collection in Front of the Strafing Wall in Alpha Range

Figure 17: Target in Bravo Range

Figure 18: Practice Bombs in Bravo Range

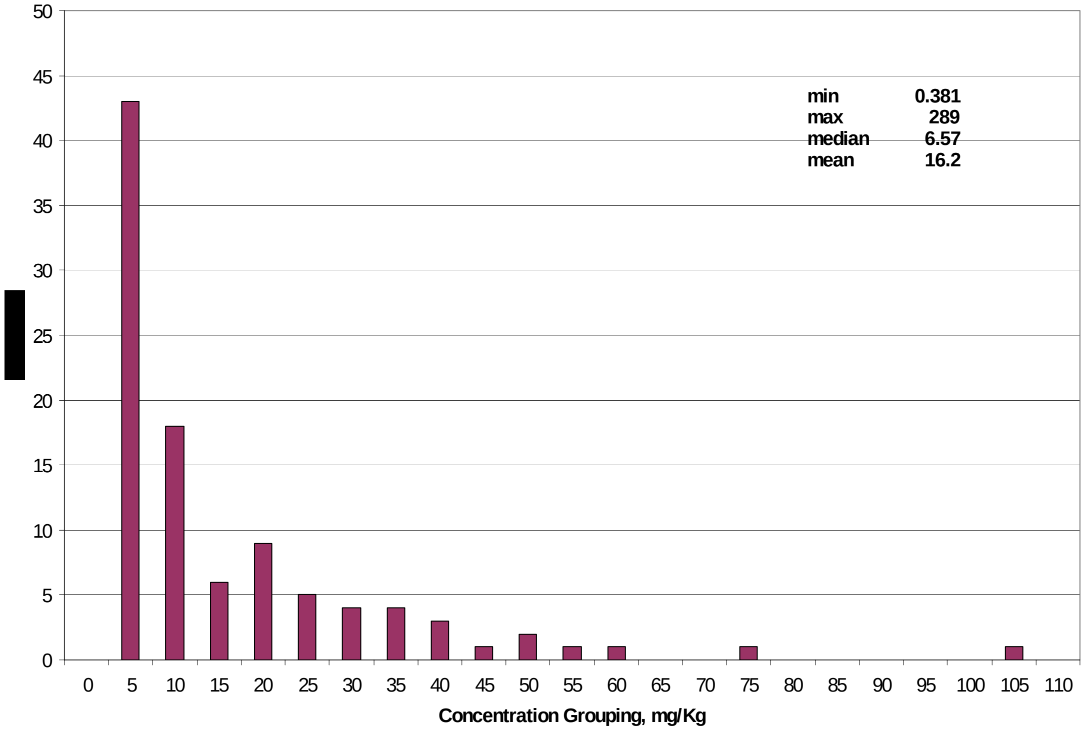

Figure 19: Distribution of TNT Concentrations at Shaver River Range

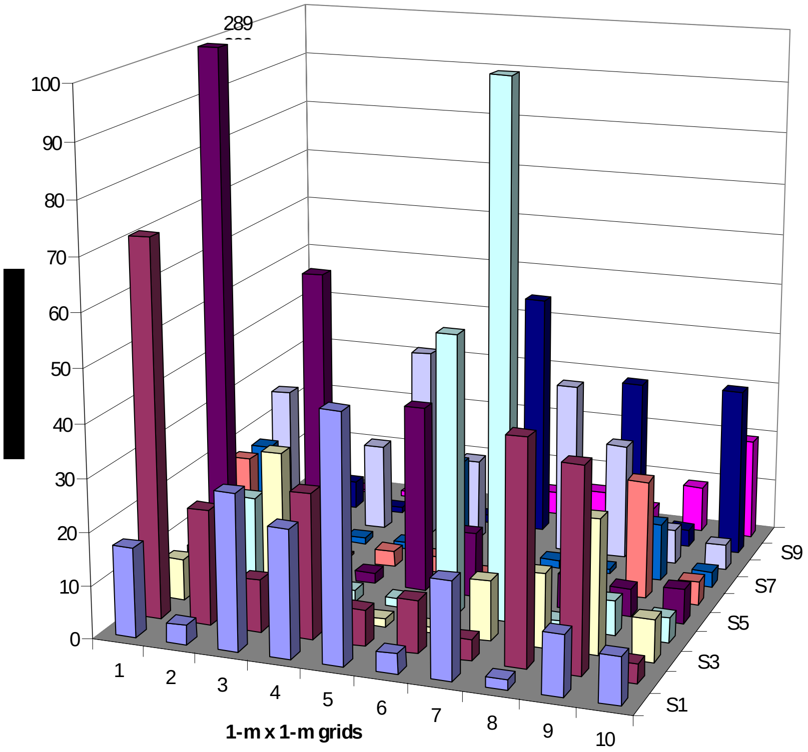

Figure 20: Position of TNT Concentrations at Shaver River Range

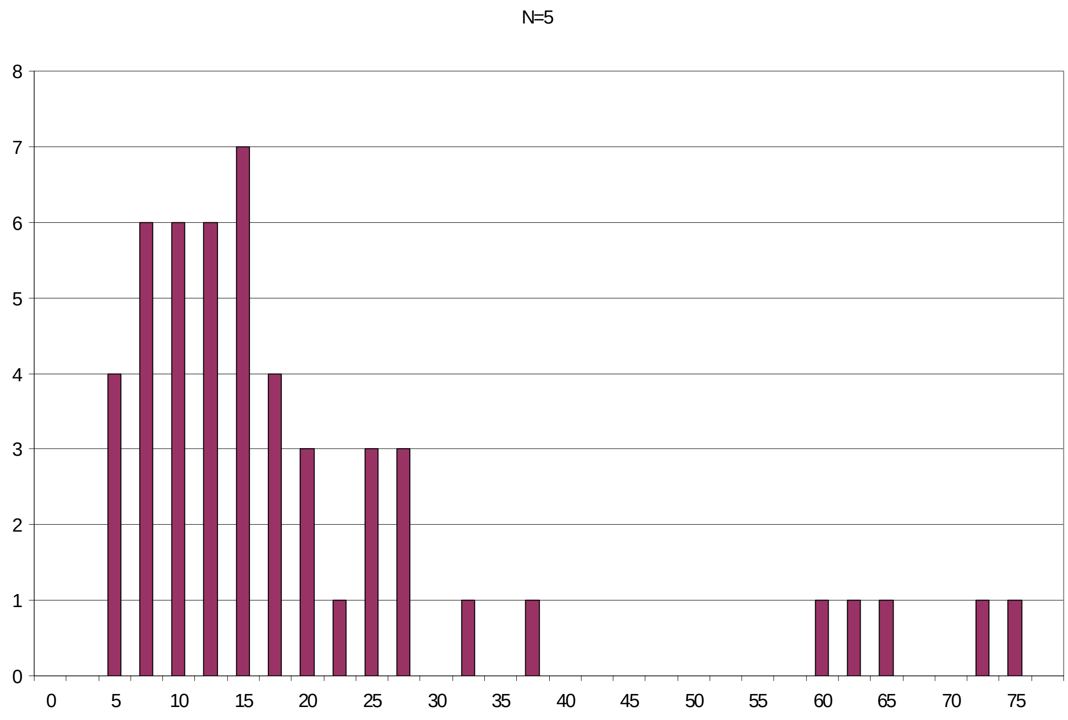

Figure 21: Histograms of TNT Concentrations Distribution Using n = 5

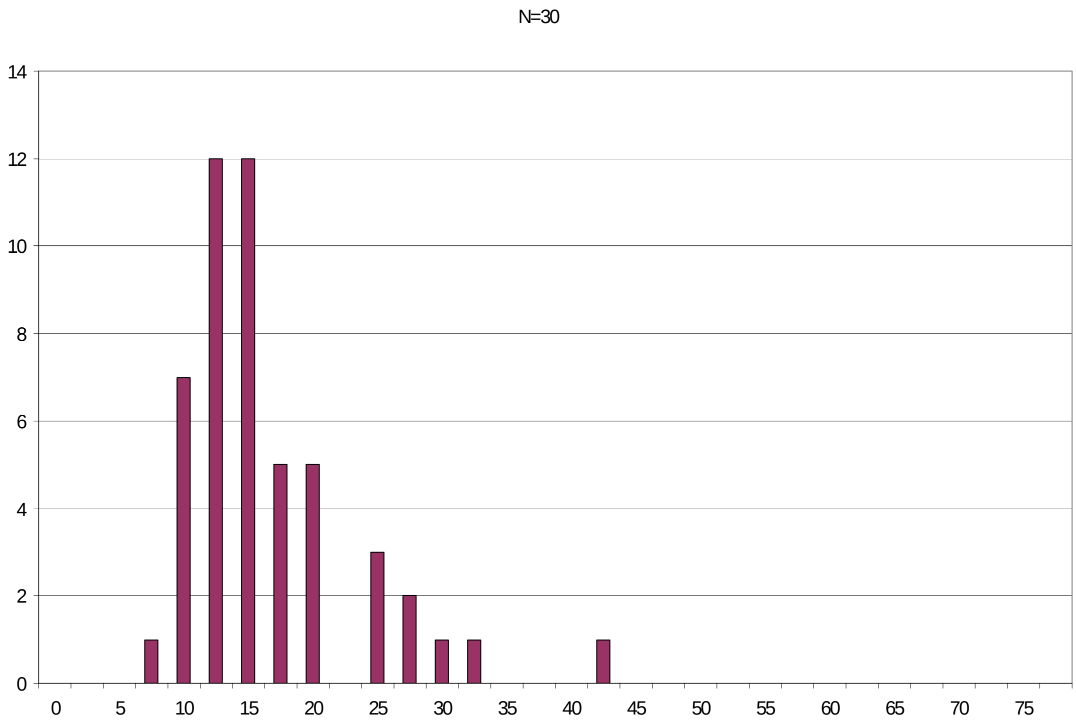

Figure 22: Histogram of TNT Concentrations Distribution Using n = 30

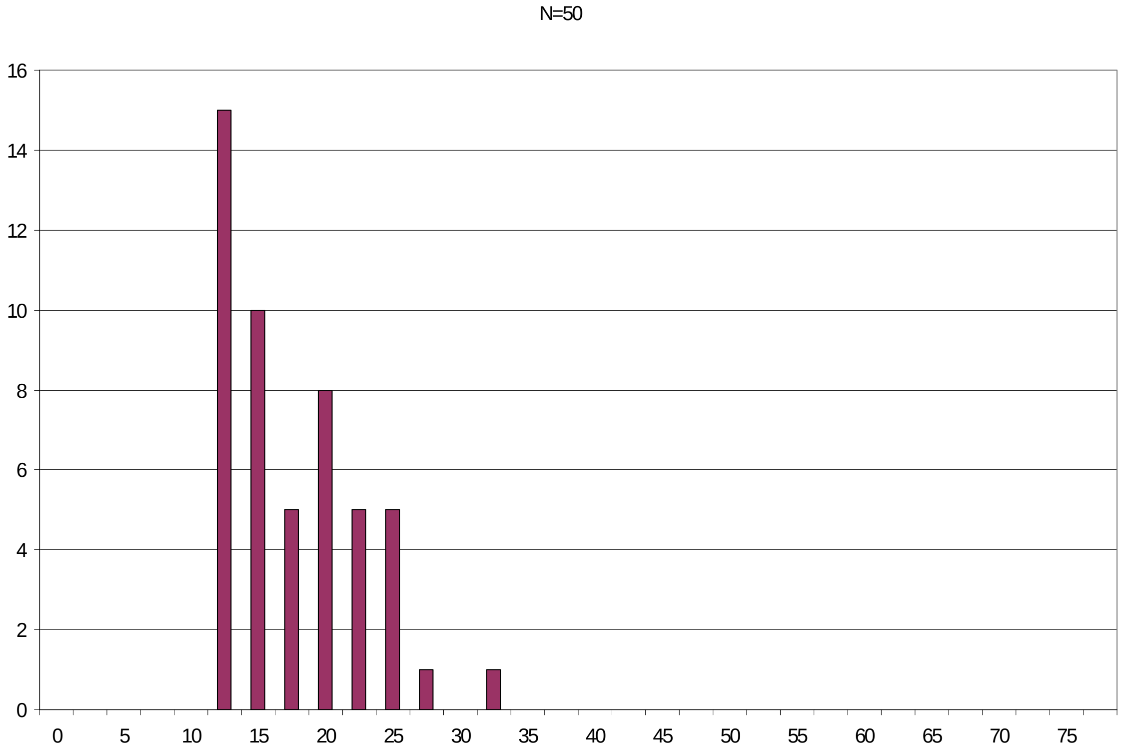

Figure 23: Histogram of TNT Concentrations Distribution Using n = 50

Figure 24: Wooden Target in the Middle of Remote Area C-314

Figure 25: Wooden Target in the Middle of Remote Area A-387

Figure 26: Debris in Remote Area F-332

Figure 27: High Vegetation in Remote Area E-301

Appendix A

MAP OF CLAWR

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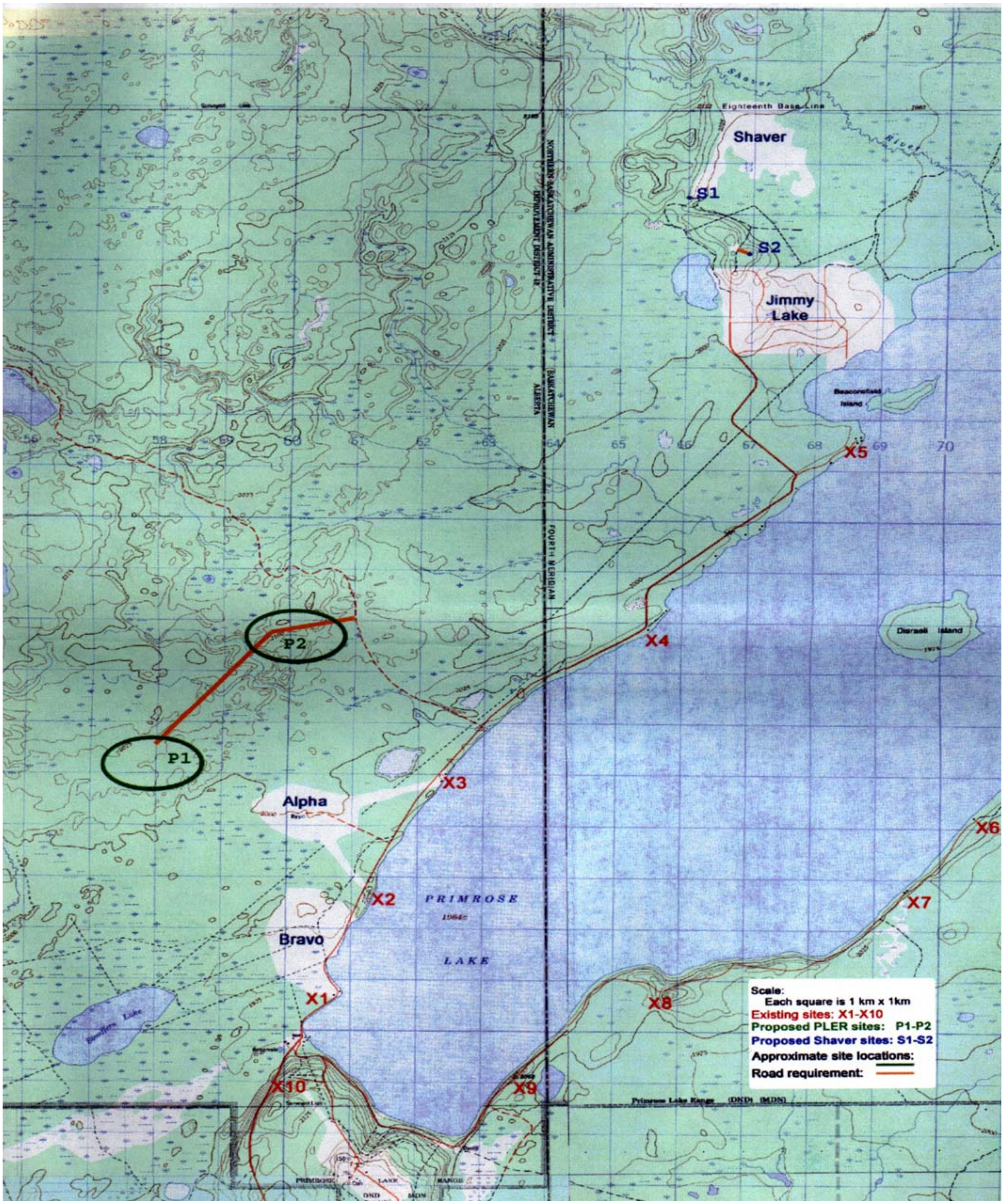
Eighteenth Base Line
Shaver River
Shaver
S1
S2
Jimmy Lake
Beaconsfield Island
NORTHERN SASKATCHEWAN ADMINISTRATIVE DISTRICT
IMPROVEMENT DISTRICT 18
SASKATCHEWAN
ALBERTA
FOURTH MERIDIAN
56
57
58
59
60
61
62
63
64
65
66
67
68
69
70
X5
P2
P1
X4
Disraeli Island
X3
Alpha
Bravo
X2
PRIMROSE
1964±
LAKE
X6
X7
X1
X8
X10
X9
Primrose Lake Range (DND) (MDN)
Scale:
Each square is 1 km x 1km
Existing sites: X1-X10
Proposed PLER sites: P1-P2
Proposed Shaver sites: S1-S2
Approximate site locations:
Road requirement:

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This work describes the evaluation of the impacts of the live firing training activities in Cold Lake Air Weapons Range (CLAWR) in Alberta performed during August 03 (Phase II). The study was conducted by DRDC Valcartier in collaboration with the U.S. Army Engineer Research and Development Center (ERDC), Cold Regions Research Engineering Laboratory (CRREL), Hanover, NH, and the ERDC Environmental Laboratory (EL), Vicksburg, MS to complete the first evaluation performed during Phase I. Four ranges on the site were re-visited during August 2003. More precisely, in Alpha and Bravo, more biomass and background samples were collected for metal analyses while for Jimmy Lake and Shaver River, more sampling was done to ascertain the metal and explosive concentrations. Surface water and sediments were also evaluated in Jimmy Lake and Primerose Lake. The circular sampling strategy was achieved in Jimmy Lake and Shaver River ranges. The linear transect strategy was applied to Alpha and Jimmy Lake ranges. In Shaver River range, another strategy consisting in collecting 100 discrete samples was accomplished in front of the target. In total, 324 soil samples, 69 biomass samples, 19 surface water and 28 sediments samples were collected during phase II. Metal analyses were done using Inductively Coupled Plasma /Mass spectrometer (ICP/MS) and explosives concentrations were deternined using the High Pressure Liquid Chromatography (HPLC) method EPA 8330. Results showed that the quality of soil, biomass, surface water and sediments is excellent with exception in Jimmy Lake range where high levels of cadmium and copper were again found. This report describes the approaches and strategies used and the results obtained during this study.

Ce travail décrit l'évaluation de l'impact des activités d'entraînement par tir réel faites au secteur d'entraînement des forces de l'air à Cold Lake (CLAWR) en Alberta effectuée en août 2003 (Phase II). Cette étude a été dirigée par RDDC Valcartier en collaboration avec l'US Army Research and Development Center (ERDC), Cold Regions Research Engineering Laboratory (CRREL), Hanover, NH, et l'ERDC Environmental Laboratory (EL) Vicksburg, MS pour compléter la première évaluation faite durant la phase I. Quatre champs de tir du secteur ont été visités en août 2003. Plus précisément, dans Alpha et Bravo, plus de biomasse et d'échantillons témoins ont été ramassés pour l'analyse des métaux pendant que pour Jimmy Lake et Shaver River, plus d'échantillonage fût fait pour évaluer les concentrations de métaux et d'explosifs. L'eau de surface et des sédiments ont aussi été évalués dans Jimmy Lake et Primerose Lake. La stratégie d'échantillonnage circulaire a été réalisée dans les sites de Jimmy Lake et de Shaver River. La stratégie d'échantillonnage par section transversale linéaire a été appliquée aux sites Alpha et Jimmy Lake. Dans Shaver River, une autre strategie qui a consisté à prendre 100 échantillons discrets en face de la cible a été accomplie. Au total, 324 échantillons de sol, 69 de biomasse, 19 d'eaux de surface et 28 de sédiments ont été recueillis durant la phase II. Les analyses de métaux ont été effectuées par plasma inductif couplé/spectrométrie de masse (PIC/SM) et les concentrations d'explosifs ont été déterminées par la méthode de chromatographie liquide haute pression (CLHP) EPA 8330. Les résultats ont montré que la qualité des sols, de la biomasse, de l'eau de surface et des sédiments est excellente à l'exception des échantillons du site de Jimmy Lake où de hautes concentrations de cadmium et de cuivre ont été à nouveau trouvées. Ce rapport décrit les approches et stratégies utilisées ainsi que les résultats obtenus durant cette étude.

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