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Application of Laser Induced Breakdown Spectroscopy (LIBS) for Environmental, Chemical, and Biological Sensing

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Preface

This study was conducted for the US Army Corps of Engineers under Program Element Number 633734A, Project Number T15, Task 2. The technical monitor was Dr. Jay L. Clausen.

The work was performed by the Biogeochemical Sciences Branch (Mr. David Ringelberg, Acting Chief) of the Research and Engineering Division (Dr. George Calfas, Chief), U.S. Army Engineer Research and Development Center, Cold Regions Research and Engineering Laboratory (ERDC-ITL). At the time of publication, the Deputy Director of ERDC-CRREL was Mr. David B. Ringelberg, and the Director was Dr. Joseph L. Corriveau.

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Application of laser induced breakdown spectroscopy (LIBS) for environmental, chemical, and biological sensing

ABSTRACT

The Army is interested in sensors capable of characterizing/monitoring the environment (battlefield or military training ranges) at proximal distances. Recently, we evaluated laser induced breakdown spectroscopy (LIBS) systems (hand-held, proximal, and bench top) for the characterization of metals (antimony, copper, lead, tungsten, and zinc) in soils obtained from military training ranges. We then compared the results to findings obtained with standard field and laboratory instrumentation for metals analysis - X-ray Fluorescence (XRF) and Inductively Couple Plasma- Optical Emission Spectroscopy (ICP-OES).

ACRONYM LIST

ASI	Applied Spectra Inc.
ASTM	American Society of Testing Materials
CONUS	continental United States
CRREL	Cold Regions Research and Engineering Laboratory
DOD	Department of Defense
ERDC	Engineer Research and Development Center
GC/MS	gas chromatography/mass spectrometry
HPLC	high-performance liquid chromatography
ICP-OES	inductively-coupled plasma-optical emission spectrometry
LC/MS	liquid chromatography mass spectrometry
LIBS	laser-induced breakdown spectroscopy
ng	nanogram
OCONUS	outside continental United States
ppm	parts per million
USACE	U.S. Army Corps of Engineers
XRF	x-ray fluorescence

1. INTRODUCTION

Conventional analytical approaches to metal and organic analysis utilizes lab-based instruments such as X-ray Fluorescence (XRF), inductively coupled plasma- optical emission spectroscopy (ICP-OES), liquid chromatography mass spectrometry (LC/MS), high performance liquid chromatography (HPLC), or gas chromatography mass spectrometry (GC/MS). These methods involve collecting large amounts of sample, shipping the sample to a laboratory, sample preparation involving sieving, grinding, and subsampling for soils, extraction/digestion with an appropriate organic solvent, and analysis. Though high sensitivity and precision can be achieved through use of these instruments, extensive sample preparation is needed prior to analysis and results cannot be acquired in real-time in the field. In addition, prior knowledge about the site or sample is often needed. Samples must also be packaged and shipped back to the laboratory, which results in a much higher analysis cost and lengthier process overall. An emerging technology, laser induced breakdown spectroscopy (LIBS), promises the benefits associated with on-site proximal analysis; including rapid acquisition of sample results.

LIBS as an analytical measurement technology has existed since the beginning of the laser. It was recognized early that laser induced plasma could be used as a spectroscopic source for direct sampling and analysis. Benefits of LIBS include real time, simultaneous, multi-element chemical analysis without sample preparation. The basis of LIBS is ablation of a tiny portion of the sample using a laser beam to produce high temperature luminous plasma. A plasma spectrum consists of narrow atomic, ionic, and molecular lines of emitted light collected using standard optics, a spectrometer, and detector. LIBS is an atomic emission spectroscopic technique allowing for rapid elemental analysis of a wide variety of samples, even in austere environments¹. A variety of optical spectrographs (Echelle, Czerny-Turner, and multi-channel) have been employed with LIBS. Chemometric analysis of the laser ablation spectra of a complex matrix like soil, sediment, or water containing an allogenic contaminant such as an explosive can be used to identify the contaminant from amongst the complex elemental and isotopic spectra of the soil material itself. In addition to elemental, molecular, and isotopic analysis, each LIBS spectrum is a unique spectral signature (equivalent to a barcode) for every material. This signature bears information about the chemical and physical properties of the sample. Although the LIBS spectra comprise mainly atomic emission lines, relative intensities and shapes of these lines depend upon the nature of the sample. Thus, LIBS can discriminate even compositionally similar molecular compounds. The focus to date has been on qualitative assessments to discriminate between different populations of data or to obtain a yes/no presence. Our work has focused on whether the LIBS technology can be utilized in a quantitative manner to determine the concentration of the material of interest.

LIBS instrumentation is relatively inexpensive, has been ruggedized for use in industrial settings and harsh environments, and is adaptable for direct or proximal analysis. The method is straightforward, inherently sensitive (low parts per million [ppm] range), requires little to no sample preparation, consumes only small amounts of sample, nanograms (ng), is capable of stratigraphic profiling, and is amenable to use in the field. LIBS has been successfully applied to the analysis of biomaterials², soil analysis³, explosives⁴, items of forensic interest⁵, and many other materials. A field portable LIBS instrument, CHEMCAM, is currently gathering data at proximal distance of up to 3 m on Mars as part of the instrument suite on the Curiosity Rover⁶.

LIBS is a versatile analytical method applicable to many projects of interest to the DoD because of its potential for use in field operations. It is an advanced analytical measurement technology developed, modified, and refined over the last decade to provide a wide range of analytical capability. LIBS has many advantages over conventional analytical technologies such as XRF, ICP, GC, and HPLC (Table 1)^{7, 8}. One application of interest to the Army is in support of existing countermining sensor detection technologies. Whereas these technologies identify a target based on its shape, LIBS could be used to augment these technologies by providing chemical information, e.g. is there explosive residue on the soil surface associated with a buried object location.

Table 1. LIBS and Comparable Analytical Technologies.

	LIBS	XRF ^a	ICP-OES/MS ^b	GC/MS ^c	HPLC ^d
Field Portable	Yes	Yes	No	Yes	No
Sample Preparation Required	No	No	Yes – 10's min.	Yes – 10's min.	Yes – 10s min.
Hazardous Chemical Usage	No	No	Yes	Yes	Yes
Analysis Time	nano-sec.	min's.	10's min.	10's min.	10's min.
Multi-element	Yes	Yes ¹	Yes ¹	No	No
Molecular Compounds	Yes	No	No	Yes	Yes ²
Isotopic and Speciation Capabilities	Yes	No	Yes	No	No
Depth Profiling Capability	Yes ³	No	No	No	No
O&M Instrument Cost	No	No	Yes	Yes	Yes

¹Not capable of analyzing light elements – H, He, C, N, O

²Limited to energetic compounds

³Soil, biota, and other hard surfaces

^ax-ray fluorescence

^binductively coupled-optical emission spectroscopy/mass spectroscopy

^cgas chromatography/mass spectrometry

^dhigh-performance liquid-chromatography

LIBS analysis systems provide valuable chemical information on almost any type of sample. This is particularly true given the recent advances in laser and spectrometry manufacturing as well as chemometrics. The advent of broadband spectrometers for LIBS has extended applications into the molecular domain and provided enhanced capability by taking the ratio of the elemental peaks. Traditionally, LIBS has been confined to laboratory analysis due to the size and fragility of the instrument. Recent technological advances have focused on ruggedization and miniaturization of system components to bring this technology to the field for near real-time analysis^{7,8}. Consequently, numerous manufacturers have developed commercially available, field-portable, LIBS systems in the past five years. All of these systems are limited to a qualitative output or are focused on matching an unknown material to a material in a reference library. However, the quantification sensitivity of these instruments is unknown and is the objective of this study.

Objectives of study

The goal for this study is to demonstrate the viability of LIBS for in-field analysis of interest to the Army. Ultimately, a methodology for proximal analysis is desired in support of environmental awareness and characterization without the need for prior knowledge of the materials or areas being surveyed. Lowering analytical costs through reduction of sample shipping, sample preparation, reduction in sample production waste, elimination of the need for hazardous chemicals from extraction/digestion are specific objectives to be demonstrated. Success will be based on the ability of the LIBS technology to detect the analytes of interest at the desired sensitivity. The U.S. Department of Defense (DoD) spends tens of millions of dollars on analytical monitoring and characterization activities and the widespread field implementation of LIBS could potentially save DoD millions of dollars in annual monitoring costs. In the current fiscal environment approaches to reduce operational and maintenance costs and investigation costs are extremely important to the sustainable operation of the DoD. We are also introduced in applications to support the warfighter.

2. EXPERIMENTAL APPROACH

Field-portable LIBS instruments underwent extensive laboratory validation and optimization through comparisons with CRRELs fixed-based laboratory J200 LIBS system as well as comparisons with XRF and ICP-OES for metals and HPLC for energetics. Comparisons were performed on soil samples using known analytical standards analyzed in triplicate on all instruments allowing for instrument optimization. Archived soil samples from a variety of military installations across

CONUS and OCONUS, previously analyzed by ERDC with XRF and ICP-OES, will then be analyzed with the field-portable LIBS systems.

Prior to analysis, all soils were air dried, sieved to < 2 m particle size, milled for 5 minutes, and then pressed into pellets. Pellets were made using a die and applying a load of 2 tons for 3 minutes.

2.1. XRF

A subsample was taken from each sample and placed in a clear plastic bag. Samples were then analyzed with an Innov-X alpha series XRF by placing the instrument in direct contact with the sample utilizing a 2 minute counting interval.

2.2. ICP-OES

One gram of each sample was digested with a mixture of 2.5 mL nitric acid and 10 mL hydrochloric acid at 95 °C for 4 hours. Digests were allowed to cool and then diluted with MilliQ water to a final concentration of 2% and 5 % nitric acid and hydrochloric acid respectively. Samples were digested in triplicate. Aliquots from these digestates were then analyzed with a Thermo Scientific iCAP 6000 Series ICP-OES followed US EPA Method 3050 procedures.

2.3. LIBS

Samples analyzed with the Applied Spectra J200 LIBS utilized a 266 nm laser, with a 25 mJ nominal maximum energy output, 250 nanosecond spectrometer delay, 9 integrated shots within a 3 x 3 grid and quantified based on calibration completed with NIST certified reference soils. NIST reference soils of known concentrations were combined with KBr and ground with mortar and pestle to dilute the material to concentrations between 0 and 100,000 ppm. These mixtures were then formed into 6 mm diameter pellets using a die at 2850 psi for 3 minutes. Four standards were used to develop calibration curves for quantification of the LIBS results: antimony, lead, tungsten, and zinc. A single variable linear approach was employed to develop calibration curves for each element from the intensity of the peak at that wavelength. Lead was quantified at the 405.768 nm wavelength, antimony at 276.956 nm, tungsten at 401.648 nm, and zinc at 202.535 nm. Analysis of samples with a hand-held LIBs instrument is yet to commence so the focus of our work to date has been on the performance of the bench top LIBS to conventional detection technologies such as ICP-OES and XRF.

3. RESULTS AND DISCUSSION

Calibration of standard reference soils with the bench top LIBS system was conducted using a single variable linear approach (Figure 1). Four elements were used for the calibration: antimony, lead, zinc, and tungsten. Both lead and tungsten demonstrated a very linear relationship with peak intensity, having correlation coefficients above 0.89, followed by zinc (0.81) and antimony (0.66) respectively. However, the concentrations calculated with these calibration curve were not in good agreement with concentrations found using the more conventional analytical techniques (Tables 2 and A1). Trends varied both between sites as well as among analytes (Table A1). This suggests that a single variable linear approach to calibration may not be as accurate as a multivariate approach to calibration. It has been supported that a multivariate approach that takes into account multiple emission lines for a single element, coupled with chemometric methods of analysis, are more robust⁹. This type of model is currently being developed for the data collected in this study.

Figure 1. Single variable linear calibration of select metals (antimony, lead, tungsten and zinc) with Applied Spectra J200 LIBS bench-top system

Because of the high variability between LIBS systems, the calculated concentrations obtained using the bench top LIBS system were compared with XRF and ICP values for the same samples to determine if a relationship exists between the data sets that could be used to predict a theoretical LIBS value. This theoretical value could then be used to test for accuracy in the experimentally obtained LIBS concentrations. A Spearman correlation was used because the assumption of normality for a Pearson correlation was not met. When comparing LIBS concentrations to ICP values, an exponential function results in a correlation coefficient of 0.35 (Figure 2), which is higher than that obtained using a linear model (0.21). The R^2 value is relatively low between these sets of data due to the large spread within the datasets. A modified exponential function was also used to compare the same LIBS data with XRF concentrations for the soils; resulting in a correlation coefficient of 0.58 (Figure 3). The exponential function provides the same R-square when linear relationship is observed.

Figure 2. Exponential relationship between lead concentrations found with bench top LIBS and ICP systems.

Figure 3. Exponential relationship between lead concentrations found with bench top LIBS and XRF.

From this relationship, an exponential model was generated (Equation 1) that can be used to predict theoretical LIBS concentrations from experimentally obtained ICP or XRF values. This value can then serve as an accepted value to assess accuracy of lab-based results.

Figure 4. Histogram with density plot of for the ICP, LIBS, and XRF concentration values.

$$C_{LIBS} = c + (d - c) \left(1 - e^{-\frac{x}{e}}\right) \quad (\text{Equation 1})$$

where x = XRF/ICP Concentration of a given material
 c = lower limit when LIBS concentration is 0
 d = upper limit
 e = steepness of the increase as x changes

Given that the none of the concentration density values follow a normal distribution (Figure 4), a Spearman Rank Correlation was used to determine if the relationship between ICP and XRF concentrations and LIBS concentrations was statistically significant (Table 2). The variable ρ denotes the spearman rank correlation coefficient with the corresponding P-value of the test. In both cases, the relationship between LIBS and the compared technology were statistically significant at a confidence level or 0.001. This suggests that the model can be used to predict theoretical LIBS concentrations.

Table 2. Spearman Rank Correlation between LIBS and comparable analytical technologies

Concentration values	ρ	P-value
LIBS and ICP	0.72	<0.0001
LIBS and XRF	0.83	<0.0001

4. CONCLUSIONS

LIBS offers several potential advantages over conventional analytical approaches to inorganic analysis for field screening, characterization, and routine monitoring applications. Calibration of standard reference soils for LIBS using a single variable linear approach demonstrated a linear relationship between metal concentration and peak intensity at the chosen wavelength for each analyte. Tungsten showed the most linear relationship, followed by lead, zinc, and antimony.

However, these results did not agree well with the other analysis methods, suggesting low precision in the measurements or calibration technique. There is, however, a relationship between these other techniques and the concentrations obtained using the bench top LIBS system that is best described using an exponential function in both cases. This function can be used to determine theoretical LIBS values from concentrations obtained with ICP or XRF and help to verify the accuracy of LIBS data collected experimentally.

5. ACKNOWLEDGMENTS

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APPENDIX A

Table A1. Concentrations of lead, antimony, tungsten, and zinc in military soils measured using ICP-OES, XRF, and bench top LIBS.

Sample ID	Location	Lead			Tungsten			Antimony			Zinc		
		ICP	XRF	LIBS	ICP	XRF	LIBS	ICP	XRF	LIBS	ICP	XRF	LIBS
B01	Ft. Benning	6056.90	6928.00	84096.30	85.50	-	0.00	97.30	122.00	2080.48	44.20	78.00	0.00
B02	Ft. Benning	18551.50	5188.00	99675.00	92.70	-	0.00	279.70	-	1088.74	70.60	70.00	0.00
B03	Ft. Benning	6335.20	5929.00	134860.20	87.40	-	0.00	113.40	-	1221.89	42.60	78.00	0.00
B04	Ft. Benning	16484.20	3999.00	127985.20	101.00	-	0.00	239.00	-	1336.68	46.90	68.00	0.00
B05	Ft. Benning	15584.90	4887.00	90300.00	116.50	-	0.00	642.40	85.00	69.46	143.50	62.00	0.00
B08	Ft. Benning	5848.70	3710.00	111156.50	120.90	201.00	0.00	77.70	63.00	1740.72	53.70	56.00	0.00
B10	Ft. Benning	3355.00	2008.00	52360.19	85.10	142.00	0.00	45.30	-	2796.73	28.20	45.00	0.00
B11	Ft. Benning	23237.80	1456.00	34975.93	44.00	228.00	0.00	533.80	-	1107.11	153.00	44.00	0.00
B12	Ft. Benning	6530.60	228.00	0.00	36.90	-	0.00	117.70	-	1281.58	12.40	17.00	799.09
B13	Ft. Benning	1532.40	224.00	0.00	-	-	0.00	20.40	-	1561.65	10.80	21.00	0.00
B14	Ft. Benning	6454.70	2751.00	2175.00	110.40	-	0.00	120.60	-	224.39	32.40	53.00	0.00
B15	Ft. Benning	4219.50	2547.00	95300.00	105.90	134.00	0.00	78.90	-	0.00	73.70	42.00	0.00
B16	Ft. Benning	2872.90	1548.00	72545.37	16.60	-	0.00	56.20	-	588.28	23.90	35.00	0.00
B17	Ft. Benning	1891.90	1689.00	0.00	37.00	-	0.00	36.50	-	0.00	25.00	45.00	0.00
B18	Ft. Benning	283.70	614.00	0.00	-	-	0.00	5.00	-	1345.86	19.40	47.00	0.00
B19	Ft. Benning	265.80	473.00	0.00	-	-	0.00	6.60	-	1456.05	22.80	39.00	464.23
B20	Ft. Benning	62.50	85.00	0.00	-	-	0.00	7.70	-	1763.67	29.70	37.00	0.00
B21	Ft. Benning	105.20	119.00	0.00	-	-	0.00	6.10	-	1965.69	16.30	27.00	0.00
B22	Ft. Benning	13044.70	3036.00	78610.19	52.50	-	0.00	266.90	-	1543.29	26.30	47.00	0.00
B23	Ft. Benning	2097.90	2047.00	47059.26	37.60	-	0.00	18.90	-	1249.44	23.70	46.00	0.00
B24	Ft. Benning	3989.00	3034.00	132313.90	47.00	-	0.00	68.60	-	914.27	60.30	51.00	0.00
B25	Ft. Benning	1880.80	3781.00	0.00	41.20	-	0.00	33.30	-	941.82	21.60	65.00	0.00
B26	Ft. Benning	2454.80	2187.00	0.00	77.00	-	0.00	41.20	-	124.55	251.40	42.00	91.32
B27	Ft. Benning	196.90	417.00	0.00	-	-	0.00	-	-	400.04	4.60	17.00	0.00
B28	Ft. Benning	650.60	350.00	0.00	-	-	0.00	5.70	-	693.88	5.40	18.00	0.00

B29	Ft. Benning	3140.40	1341.00	0.00	55.50	-	0.00	37.70	-	1901.41	25.10	28.00	0.00
B30	Ft. Benning	4320.20	1273.00	0.00	111.50	-	0.00	89.00	-	1561.65	21.20	41.00	0.00
B31	Ft. Benning	2245.10	698.00	0.00	-	-	0.00	42.10	-	827.03	4.30	22.00	639.27
B32	Ft. Benning	376.80	689.00	0.00	-	-	0.00	20.00	-	354.12	5.10	14.00	646.88
B33	Ft. Benning	563.30	1472.00	0.00	5.80	-	0.00	7.30	-	2737.04	12.00	39.00	0.00
B34	Ft. Benning	5467.20	3769.00	44258.33	79.20	-	0.00	97.70	83.00	1538.70	29.90	60.00	0.00
B35	Ft. Benning	4201.30	3161.00	34767.59	5.70	-	0.00	32.30	-	1093.33	30.80	41.00	0.00
B36	Ft. Benning	5386.80	666.00	1735.19	54.90	-	0.00	86.50	-	1681.03	24.90	23.00	1118.72
B37	Ft. Benning	989.80	961.00	0.00	12.20	-	0.00	15.60	-	726.02	17.40	28.00	0.00
B38	Ft. Benning	5318.20	2150.00	30925.00	9.60	-	0.00	74.70	71.00	1364.22	127.60	48.00	0.00
B39	Ft. Benning	3034.30	1752.00	21503.70	-	-	0.00	25.80	68.00	721.43	1062.50	44.00	616.44
B40	Ft. Benning	12710.70	2934.00	68911.11	304.60	-	0.00	228.80	-	436.77	34.00	55.00	0.00
B41	Ft. Benning	4090.60	2591.00	10768.430	135.40	-	0.00	71.30	60.00	1524.92	29.70	44.00	251.14
B42	Ft. Benning	2982.10	4602.00	79698.15	18.00	-	0.00	32.40	64.00	1217.30	29.00	64.00	0.00
B43	Ft. Benning	4212.80	2103.00	68702.78	4.40	-	0.00	29.60	-	1084.15	40.40	37.00	0.00
B44	Ft. Benning	2852.70	2524.00	25960.560	167.60	153.00	0.00	53.60	-	2149.35	25.10	39.00	0.00
B45	Ft. Benning	2494.90	1842.00	52591.67	132.70	-	0.00	31.30	-	386.26	33.40	30.00	0.00
B54	Ft. Benning	8360.90	6210.00	30527.690	135.60	-	0.00	145.00	100.00	2374.32	56.60	68.00	0.00
B55	Ft. Benning	11400.10	5720.00	31724.440	132.70	-	0.00	191.80	73.00	973.96	263.30	63.00	0.00
B56	Ft. Benning	5292.20	6618.00	23661.940	69.30	-	0.00	137.60	118.00	680.11	56.40	76.00	0.00
B57	Ft. Benning	8765.10	8011.00	44212.04	18.40	-	0.00	66.40	98.00	335.76	69.80	97.00	1910.20
B58	Ft. Benning	9981.00	8155.00	31655.000	133.00	-	0.00	146.40	117.00	46.50	100.00	97.00	0.00
B59	Ft. Benning	10385.30	6409.00	30900.370	214.30	208.00	0.00	188.30	96.00	1612.16	61.70	76.00	190.26
B60	Ft. Benning	4801.50	2823.00	64142.59	38.30	-	0.00	56.40	-	670.93	31.60	45.00	0.00
B61	Ft. Benning	2942.80	3432.00	67545.37	118.40	126.00	0.00	46.10	-	1580.02	24.00	39.00	0.00
B62	Ft. Benning	8300.30	3320.00	56341.67	131.40	-	0.00	142.00	-	1130.06	131.20	58.00	0.00
B63	Ft. Benning	3600.10	3395.00	16828.610	56.30	-	0.00	54.30	-	225.56	38.70	52.00	182.65
B64	Ft. Benning	2938.80	1652.00	12198.15	91.50	-	0.00	47.30	-	0.00	25.90	38.00	0.00
B65	Ft. Benning	2790.50	1314.00	1480.56	15.90	-	0.00	15.70	-	638.79	32.00	30.00	0.00

B66	Ft. Benning	1043 3.20	1798. 00	27383 .33	28.4 0	-	0.00	281.0 0	-	565. 33	949.2 0	45.00	0.00
B70	Ft. Benning	5234. 30	4987. 00	16307 7.80	91.5 0	-	0.00	78.40	-	1598 .38	48.50	66.00	0.00
B71	Ft. Benning	5516. 00	5528. 00	19062 4.10	98.7 0	-	0.00	70.80	62.00	748. 98	46.80	72.00	0.00
B74	Ft. Benning	329.9 0	526.0 0	0.00	-	-	0.00	-	-	299. 03	17.90	37.00	0.00
B75	Ft. Benning	314.7 0	689.0 0	0.00	-	-	0.00	-	-	459. 72	19.70	39.00	0.00
B76	Ft. Benning	3141. 80	3476. 00	59813 .89	83.8 0	-	0.00	34.50	-	2048 .34	30.80	56.00	0.00
B77	Ft. Benning	5748. 40	3601. 00	20437 4.10	65.5 0	-	0.00	70.30	-	1942 .74	54.00	58.00	0.00
B78	Ft. Benning	1039. 10	947.0 0	36897 .22	13.8 0	-	0.00	14.60	-	813. 26	11.60	22.00	0.00
B79	Ft. Benning	613.3 0	1081. 00	0.00	40.0 0	-	0.00	9.50	-	1997 .83	9.50	27.00	0.00
B80	Ft. Benning	202.7 0	368.0 0	0.00	-	-	0.00	-	-	1134 .66	71.20	12.00	0.00
B81	Ft. Benning	3564. 50	5606. 00	10583 2.40	20.2 0	-	0.00	48.60	83.00	1906 .01	30.40	73.00	0.00
B82	Ft. Benning	1104. 90	1687. 00	35137 .96	-	-	0.00	8.00	-	960. 18	12.90	38.00	0.00
B83	Ft. Benning	85.60	126.0 0	0.00	-	-	0.00	-	-	468. 91	9.60	18.00	0.00
B84	Ft. Benning	51.80	92.00	0.00	2.40	-	0.00	4.20	-	491. 86	8.40	32.00	0.00
B85	Ft. Benning	96.00	116.0 0	0.00	3.70	-	0.00	9.20	-	2553 .39	14.80	27.00	1621. 01
B86	Ft. Benning	81.50	106.0 0	0.00	4.20	-	0.00	7.40	-	2911 .51	12.10	27.00	570.7 8
B87	Ft. Benning	1217. 60	907.0 0	11758 .33	102. 70	175.0 0	0.00	15.00	-	400. 04	21.10	29.00	0.00
B88	Ft. Benning	102.7 0	106.0 0	0.00	-	-	0.00	6.50	-	2980 .39	15.40	22.00	1118. 72
B89	Ft. Benning	51.00	52.00	0.00	14.9 0	-	0.00	14.90	-	3499 .21	19.60	29.00	418.5 7
B90	Ft. Benning	43.80	42.00	0.00	24.3 0	-	0.00	19.50	-	4729 .70	35.30	37.00	0.00
B91	Ft. Benning	41.90	47.00	45577 .78	42.4 0	-	0.00	18.20	-	703. 07	13.10	29.00	1537. 29
B92	Ft. Benning	71.30	77.00	0.00	40.1 0	-	0.00	23.50	-	4109 .86	17.40	32.00	410.9 6
B95	Ft. Benning	9.60	81.00	0.00	-	-	0.00	-	-	253. 11	30.50	134.0 0	0.00
B96	Ft. Benning	12.00	77.00	0.00	-	-	0.00	-	-	0.00	24.50	178.0 0	669.7 1
FE D 01	Ft. Eustis	235.1 0	581.0 0	0.00	-	-	0.00	-	-	1428 .50	18.90	41.00	0.00
FE D 02	Ft. Eustis	2571. 50	1572. 00	0.00	-	-	0.00	396.3 0	-	0.00	20.90	61.00	190.2 6
FE D 03	Ft. Eustis	158.9 0	358.0 0	0.00	-	-	0.00	-	-	1791 .22	16.60	40.00	0.00
FE D 04	Ft. Eustis	156.5 0	365.0 0	0.00	-	-	0.00	-	-	592. 87	20.30	52.00	0.00
FE D 05	Ft. Eustis	199.0 0	480.0 0	0.00	-	-	0.00	-	-	1896 .82	19.20	51.00	0.00

FE D 06	Ft. Eustis	197.9 0	616.0 0	0.00	-	-	0.00	-	-	712. 25	20.90	58.00	0.00
FE D 07	Ft. Eustis	47.30	181.0 0	0.00	-	-	0.00	-	-	1515 .74	8.50	31.00	0.00
FE D 08	Ft. Eustis	55.60	169.0 0	0.00	-	-	0.00	-	-	1777 .45	10.30	38.00	0.00
FE D 09	Ft. Eustis	17.90	78.00	0.00	-	-	0.00	-	-	0.00	21.30	82.00	106.5 4
FE D 10	Ft. Eustis	3.00	38.00	0.00	-	-	0.00	-	-	2374 .32	19.50	58.00	0.00
FE D 11	Ft. Eustis	40.40	103.0 0	0.00	-	-	0.00	-	-	1391 .77	20.10	50.00	593.6 1
FE D 12	Ft. Eustis	2955. 90	2626. 00	0.00	-	-	0.00	-	-	1410 .14	22.70	50.00	15.22
FE D 13	Ft. Eustis	176.2 0	537.0 0	0.00	-	-	0.00	-	-	1272 .40	16.10	41.00	0.00
FE D 14	Ft. Eustis	157.9 0	347.0 0	0.00	-	-	0.00	-	-	951. 00	14.70	34.00	0.00
FE D 16	Ft. Eustis	235.1 0	754.0 0	0.00	-	-	0.00	-	-	1189 .75	15.20	48.00	0.00
FE D 17	Ft. Eustis	352.9 0	940.0 0	0.00	-	-	0.00	-	-	1249 .44	15.10	47.00	0.00
FE D 18	Ft. Eustis	63.60	187.0 0	0.00	-	-	0.00	-	-	546. 96	14.80	48.00	0.00
FE D 19	Ft. Eustis	29.00	100.0 0	0.00	-	-	0.00	-	-	859. 17	15.90	51.00	0.00
FE D 20	Ft. Eustis	31.90	89.00	0.00	-	-	0.00	-	-	951. 00	16.50	51.00	0.00
FE D 21	Ft. Eustis	8.70	41.00	0.00	-	-	0.00	-	-	1887 .64	18.30	54.00	0.00
FE D 22	Ft. Eustis	40.70	102.0 0	0.00	-	-	0.00	-	-	758. 16	23.40	56.00	30.44
FE D 23	Ft. Eustis	63.10	207.0 0	0.00	-	-	0.00	-	-	335. 76	31.40	81.00	0.00
FE D 24	Ft. Eustis	39.30	138.0 0	0.00	-	-	0.00	-	-	946. 41	22.30	101.0 0	0.00
FE D 25	Ft. Eustis	33.70	78.00	0.00	-	-	0.00	-	-	1483 .60	14.30	43.00	258.7 5
FE D 26	Ft. Eustis	28.50	80.00	0.00	-	-	0.00	-	-	156. 69	14.40	30.00	0.00
FE D 27	Ft. Eustis	17.10	83.00	0.00	-	-	0.00	-	-	0.00	11.70	55.00	0.00
FE D 28	Ft. Eustis	23.70	82.00	0.00	-	-	0.00	-	-	804. 08	12.10	42.00	0.00
FE D 29	Ft. Eustis	10.90	52.00	0.00	-	-	0.00	-	-	849. 99	11.00	38.00	0.00
FE D 30	Ft. Eustis	-	35.00	0.00	-	-	0.00	-	-	1387 .18	11.20	45.00	273.9 7
FE D 31	Ft. Eustis	20.50	122.0 0	0.00	-	-	0.00	-	-	1212 .71	9.70	50.00	0.00
FE D 32	Ft. Eustis	-	32.00	0.00	-	-	0.00	-	-	1855 .50	12.90	47.00	0.00
FE D 33	Ft. Eustis	-	33.00	0.00	-	-	0.00	-	-	1111 .70	10.90	50.00	0.00
FE MI-01	Ft. Eustis	183.0 0	482.0 0	22059 .26	-	-	0.00	-	-	1728 .09	14.40	41.00	0.00
FE MI-02	Ft. Eustis	232.5 0	571.0 0	0.00	-	-	0.00	-	-	1429 .65	14.20	45.00	0.00

FE MI-03	Ft. Eustis	237.9 0	568.0 0	0.00	-	-	0.00	-	-	1089 .89	15.10	42.00	0.00
FE MI-04	Ft. Eustis	357.5 0	860.0 0	0.00	-	-	0.00	-	-	162. 43	17.00	52.00	0.00
FE MI-05	Ft. Eustis	713.8 0	1389. 00	0.00	-	-	0.00	7.80	-	534. 33	18.30	46.00	22.83
FE MI-06	Ft. Eustis	360.5 0	762.0 0	3355. 56	-	-	0.00	-	-	75.2 0	17.00	43.00	0.00
FE MI-07	Ft. Eustis	475.8 0	1121. 00	7776. 85	-	-	0.00	3.30	-	1369 .96	17.50	38.00	441.4 0
FE MI-08	Ft. Eustis	643.0 0	1288. 00	0.00	-	-	0.00	3.40	-	1227 .63	16.50	46.00	144.6 0
FE MI-09	Ft. Eustis	432.0 0	986.0 0	0.00	-	-	0.00	-	-	1062 .34	15.50	43.00	0.00
FE MI-10	Ft. Eustis	388.2 0	770.0 0	9698. 15	-	-	0.00	4.20	-	323. 13	16.40	40.00	220.7 0
FE MI-11	Ft. Eustis	382.2 0	671.0 0	0.00	-	-	0.00	-	-	217. 53	17.40	42.00	2640. 79
FE MI-12	Ft. Eustis	244.8 0	572.0 0	0.00	-	-	0.00	-	-	144. 07	17.50	44.00	1270. 93
FE MI-13	Ft. Eustis	564.5 0	1041. 00	0.00	-	-	0.00	2.40	-	355. 27	17.50	45.00	0.00
FE MI-14	Ft. Eustis	562.5 0	1123. 00	0.00	-	-	0.00	7.90	-	102. 75	16.90	39.00	449.0 1
FE MI-15	Ft. Eustis	501.9 0	996.0 0	0.00	-	-	0.00	-	-	84.3 8	16.60	45.00	0.00
FE MI-16	Ft. Eustis	565.2 0	1253. 00	0.00	-	-	0.00	2.40	-	240. 49	20.70	46.00	0.00
FE MI-17	Ft. Eustis	822.5 0	1649. 00	0.00	-	-	0.00	7.00	-	672. 08	21.00	45.00	0.00
FE MI-18	Ft. Eustis	501.1 0	990.0 0	0.00	-	-	0.00	-	-	621. 57	18.10	38.00	0.00
FE MI-19	Ft. Eustis	75.00	213.0 0	0.00	-	-	0.00	-	-	727. 17	14.10	37.00	0.00
FE MI-20	Ft. Eustis	118.2 0	321.0 0	0.00	-	-	0.00	-	-	1291 .91	13.20	39.00	258.7 5
FE MI-21	Ft. Eustis	76.50	222.0 0	0.00	-	-	0.00	-	-	1539 .84	13.40	38.00	395.7 4
FE MI-22	Ft. Eustis	620.3 0	1245. 00	14883 .33	-	-	0.00	-	-	695. 03	16.10	45.00	0.00
FE MI-23	Ft. Eustis	588.4 0	1083. 00	0.00	4.80	-	0.00	20.70	-	561. 88	17.40	47.00	1035. 01
FE MI-24	Ft. Eustis	623.5 0	1199. 00	0.00	-	-	0.00	-	-	414. 96	15.30	45.00	707.7 6
FE MI-25	Ft. Eustis	599.5 0	1112. 00	0.00	-	-	0.00	-	-	0.00	17.20	44.00	601.2 2
FE MI-26	Ft. Eustis	478.3 0	944.0 0	0.00	-	-	0.00	-	-	451. 69	16.30	36.00	0.00
FE MI-27	Ft. Eustis	672.4 0	1145. 00	7128. 70	-	-	0.00	3.20	-	759. 31	16.60	36.00	0.00
FL 01	Ft. Lewis	30.70	107.0 0	0.00	-	-	0.00	-	-	1244 .85	19.60	56.00	0.00
FL 02	Ft. Lewis	28.80	95.00	0.00	-	-	0.00	-	-	1915 .19	19.10	54.00	388.1 3
FL 03	Ft. Lewis	78.60	279.0 0	0.00	-	-	0.00	-	-	1217 .30	17.20	153.0 0	0.00
FL 04	Ft. Lewis	130.4 0	194.0 0	0.00	-	-	0.00	-	-	2310 .05	18.40	47.00	175.0 4

FL 05	Ft. Lewis	7539. 50	1096 3.00	10379 5.40	130. 30	-	0.00	245.0 0	219.0 0	2153 .94	133.4 0	171.0 0	0.00
FL 08	Ft. Lewis	2274 3.40	2594 6.00	39386 4.80	981. 50	2276. 00	0.00	867.1 0	366.0 0	1368 .82	181.9 0	400.0 0	494.6 7
FL 09	Ft. Lewis	2315 8.10	2376 0.00	31270 7.40	986. 50	2274. 00	0.00	546.6 0	261.0 0	1506 .56	815.0 0	444.0 0	0.00
FL 20	Ft. Lewis	2119 0.70	4001 8.00	54002 2.20	563. 80	1605. 00	0.00	1024. 80	578.0 0	2856 .42	644.2 0	586.0 0	761.0 4
FL 21	Ft. Lewis	2421 5.50	6366 6.00	10885 18.00	763. 20	2199. 00	0.00	582.9 0	685.0 0	1837 .13	1247. 90	807.0 0	30.44
FL 22	Ft. Lewis	2281 6.70	4535 4.00	70323 9.80	529. 40	1350. 00	0.00	731.5 0	567.0 0	3724 .19	616.5 0	620.0 0	0.00
FL 23	Ft. Lewis	2590 5.60	4358 3.00	72293 8.90	417. 00	-	0.00	1818. 90	576.0 0	1685 .62	160.5 0	573.0 0	0.00
FL 24	Ft. Lewis	2306 9.40	5279 1.00	60798 5.20	849. 00	1686. 00	0.00	935.6 0	609.0 0	1837 .13	221.6 0	718.0 0	121.7 7
FL 25	Ft. Lewis	2379 6.10	4369 4.00	61367 9.60	782. 30	1788. 00	0.00	801.2 0	540.0 0	1878 .46	283.3 0	660.0 0	0.00
FL 26	Ft. Lewis	2178 2.00	4364 5.00	62270 7.40	331. 90	-	0.00	876.1 0	642.0 0	905. 09	528.1 0	470.0 0	0.00
FL 27	Ft. Lewis	1800 2.00	3541 8.00	68361 0.20	173. 00	-	0.00	341.2 0	502.0 0	2071 .29	103.9 0	494.0 0	0.00
FL 28	Ft. Lewis	2035 4.60	3164 1.00	94384 1.70	394. 70	1638. 00	0.00	850.0 0	497.0 0	3939 .98	389.9 0	570.0 0	859.9 7
FL 29	Ft. Lewis	2461 7.70	4517 3.00	70094 8.10	1155 .90	-	0.00	798.4 0	657.0 0	2796 .73	258.9 0	597.0 0	0.00
FL 30	Ft. Lewis	2750 6.10	4172 0.00	73865 6.50	430. 30	737.0 0	0.00	732.5 0	403.0 0	2998 .75	1200. 70	599.0 0	0.00
FL 31	Ft. Lewis	1394 5.00	3936 6.00	39944 3.50	39.6 0	-	0.00	440.1 0	448.0 0	321. 98	93.00	334.0 0	0.00
FL 36	Ft. Lewis	2056 5.40	5581 4.00	60495 2.80	248. 20	-	0.00	621.4 0	645.0 0	2714 .09	626.2 0	620.0 0	0.00
FL 37	Ft. Lewis	1953 0.80	5944 4.00	58050 8.30	352. 60	-	0.00	1470. 80	700.0 0	1713 .17	496.2 0	634.0 0	0.00
FL 38	Ft. Lewis	1832 9.30	8731 5.00	72203 6.10	1021 .40	2507. 00	0.00	690.8 0	641.0 0	2677 .35	944.8 0	935.0 0	0.00
FL 39	Ft. Lewis	- 2920. 60	3999 5.00	74215 1.90	- 136. 50	1202. 00	0.00	- 106.5 0	305.0 0	2957 .43	- 123.8 0	619.0 0	0.00
FL 40	Ft. Lewis	2185 5.00	5655 0.00	68286 9.40	116. 50	-	0.00	1047. 30	683.0 0	1534 .10	897.8 0	471.0 0	0.00
FL 41	Ft. Lewis	5626. 70	8807. 00	38722 1.30	-	-	0.00	112.0 0	93.00	2571 .75	109.7 0	172.0 0	334.8 6
FL 42	Ft. Lewis	1071 3.10	2068 4.00	36650 3.70	6.60	-	0.00	250.6 0	323.0 0	1295 .35	317.0 0	287.0 0	0.00
FL 43	Ft. Lewis	1899 3.20	4777 0.00	70499 9.10	203. 80	-	0.00	1304. 80	834.0 0	1093 .33	128.6 0	496.0 0	0.00
FL 44	Ft. Lewis	2203 7.30	7936 2.00	72270 7.40	377. 30	-	0.00	1115. 10	1195. 00	1681 .03	469.5 0	652.0 0	403.3 5
FL 45	Ft. Lewis	2014 6.50	4881 8.00	53583 2.40	384. 80	819.0 0	0.00	594.6 0	311.0 0	905. 09	657.6 0	734.0 0	0.00
FL 46	Ft. Lewis	2206 6.50	5648 7.00	20367 9.60	343. 00	1943. 00	0.00	433.7 0	332.0 0	450. 54	1594. 50	810.0 0	0.00
FL 47	Ft. Lewis	3704. 30	8741. 00	58332 .41	15.9 0	-	0.00	148.9 0	100.0 0	1033 .65	79.00	252.0 0	0.00
FL 48	Ft. Lewis	3250. 70	7413. 00	25462 .04	68.2 0	225.0 0	0.00	48.40	118.0 0	1029 .05	64.10	220.0 0	0.00

FL 49	Ft. Lewis	8778.20	24153.00	211087.00	220.40	-	0.00	279.40	475.00	1644.30	217.00	494.00	1971.08
FL 50	Ft. Lewis	7478.70	22770.00	119003.70	105.70	-	0.00	216.80	384.00	0.00	44.40	210.00	0.00
FL 51	Ft. Lewis	199.70	868.00	0.00	-	-	0.00	-	-	303.62	23.50	74.00	0.00
FL 52	Ft. Lewis	314.20	667.00	0.00	-	-	0.00	-	-	3260.46	20.30	65.00	433.79
FL 53	Ft. Lewis	83.10	262.00	68540.74	-	-	0.00	-	-	932.63	24.80	66.00	167.43
FL 54	Ft. Lewis	105.10	227.00	0.00	-	-	0.00	-	-	1722.35	27.70	67.00	426.18
FL 55	Ft. Lewis	64.60	135.00	120948.10	-	-	0.00	-	-	0.00	48.30	95.00	0.00
FL 56	Ft. Lewis	53.70	119.00	54721.30	-	-	0.00	-	-	110.78	45.60	80.00	0.00
FL 58	Ft. Lewis	18668.70	67387.00	543494.40	409.30	848.00	0.00	532.90	669.00	1800.40	267.60	778.00	0.00
FL 59	Ft. Lewis	19498.60	65544.00	85647.22	485.50	980.00	0.00	861.00	723.00	276.07	812.60	688.00	0.00
FL 60	Ft. Lewis	20184.30	71133.00	638170.40	559.70	1110.00	0.00	1096.30	756.00	2521.25	1210.10	844.00	799.09
FL 61	Ft. Lewis	16755.30	70196.00	653749.10	493.80	835.00	0.00	832.90	892.00	1814.18	1183.70	793.00	776.26
FL 64	Ft. Lewis	4649.70	6802.00	208471.30	6.80	-	0.00	79.00	125.00	1405.55	63.90	186.00	0.00
FL 65	Ft. Lewis	19599.30	63032.00	574559.30	244.30	-	0.00	1255.10	884.00	1304.54	492.90	578.00	1240.49
FL 68	Ft. Lewis	20385.40	70321.00	727915.70	671.10	1384.00	0.00	852.40	755.00	1671.85	322.00	833.00	2404.87
FL 70	Ft. Lewis	20562.30	71327.00	645300.00	419.50	-	0.00	1314.10	1221.00	1437.69	182.10	751.00	0.00
FTWW B09a	Ft. Wainwright	-	10.00	0.00	-	-	0.00	-	-	3889.48	19.00	59.00	159.82
FTWW B09b	Ft. Wainwright	3.70	15.00	0.00	-	-	0.00	-	-	2452.38	22.90	65.00	0.00
FTWW B09c	Ft. Wainwright	70.00	19.00	0.00	-	-	0.00	-	-	3090.58	24.20	64.00	0.00
FTWW B10a	Ft. Wainwright	642.00	709.00	0.00	-	-	0.00	8.90	-	2539.61	29.00	76.00	0.00
FTWW B10b	Ft. Wainwright	1832.90	1017.00	85855.56	-	-	0.00	3.40	-	2851.83	59.30	77.00	38.05
FTWW B10c	Ft. Wainwright	36.40	94.00	0.00	-	-	0.00	-	-	1428.50	24.80	61.00	0.00
FTWW B11a	Ft. Wainwright	41.00	70.00	0.00	-	-	0.00	-	-	1524.92	26.10	51.00	129.38
FTWW B11b	Ft. Wainwright	20.00	45.00	0.00	-	-	0.00	-	-	1524.92	25.50	111.00	129.38
FTWW B11c	Ft. Wainwright	142.60	332.00	0.00	-	-	0.00	-	-	4940.90	27.30	65.00	0.00
FTWW B12a	Ft. Wainwright	67.90	148.00	0.00	-	-	0.00	-	-	4288.93	29.00	60.00	0.00
FTWW B12b	Ft. Wainwright	130.50	61.00	0.00	-	-	0.00	-	-	2966.61	27.20	61.00	0.00
FTWW B12c	Ft. Wainwright	21.70	136.00	0.00	-	-	0.00	-	-	3007.93	26.70	51.00	0.00
FTWW B13a	Ft. Wainwright	1589.20	184.00	0.00	-	-	0.00	2.30	-	3379.83	29.00	70.00	0.00

FTWW B13b	Ft. Wainwright	13.80	120.0 0	0.00	-	-	0.00	-	-	2732 .45	4.40	52.00	0.00
FTWW B13c	Ft. Wainwright	45.20	75.00	0.00	-	-	0.00	-	-	3324 .74	27.80	57.00	350.0 8
FTWW B14a	Ft. Wainwright	22.40	158.0 0	0.00	-	-	0.00	-	-	1965 .69	23.60	60.00	0.00
FTWW B14b	Ft. Wainwright	7.80	40.00	0.00	-	-	0.00	-	-	1561 .65	26.10	80.00	0.00
FTWW B14c	Ft. Wainwright	21.20	73.00	0.00	-	-	0.00	-	-	1378 .00	25.00	62.00	0.00
FTWW B15a	Ft. Wainwright	149.8 0	115.0 0	0.00	-	-	0.00	-	-	2075 .89	28.00	74.00	0.00
FTWW B15b	Ft. Wainwright	-	26.00	0.00	-	-	0.00	-	-	1074 .97	26.50	61.00	0.00
FTWW B15c	Ft. Wainwright	394.2 0	568.0 0	26387 .96	-	-	0.00	-	-	1309 .13	25.30	63.00	0.00
FTWW B16a	Ft. Wainwright	3.90	22.00	0.00	-	-	0.00	-	-	1318 .31	24.20	59.00	0.00
FTWW B16b	Ft. Wainwright	16.10	30.00	0.00	-	-	0.00	-	-	4114 .45	26.80	58.00	0.00
FTWW B16c	Ft. Wainwright	29.20	82.00	0.00	-	-	0.00	-	-	2052 .93	25.90	59.00	0.00
FTWW BCK 1a	Ft. Wainwright	137.5 0	233.0 0	0.00	-	-	0.00	-	-	1175 .98	41.70	90.00	951.2 9
FTWW Bck 1c	Ft. Wainwright	173.1 0	484.0 0	0.00	-	-	0.00	-	-	0.00	43.20	94.00	799.0 9
FTWW MI-01	Ft. Wainwright	207.4 0	422.0 0	0.00	-	-	0.00	-	-	2149 .35	41.60	68.00	0.00
FTWW MI-02	Ft. Wainwright	263.3 0	275.0 0	0.00	-	-	0.00	-	-	3255 .87	29.30	52.00	0.00
FTWW MI-03	Ft. Wainwright	216.8 0	760.0 0	0.00	-	-	0.00	-	-	2500 .59	28.80	62.00	0.00
FTWW MI-04	Ft. Wainwright	401.6 0	287.0 0	0.00	-	-	0.00	3.60	-	1726 .94	28.00	66.00	0.00
FTWW MI-05	Ft. Wainwright	235.6 0	299.0 0	0.00	-	-	0.00	-	-	3187 .00	41.20	71.00	68.49
FTWW MI-06	Ft. Wainwright	192.6 0	278.0 0	0.00	-	-	0.00	-	-	4265 .97	28.50	72.00	0.00
FTWW MI-15	Ft. Wainwright	167.6 0	343.0 0	0.00	-	-	0.00	-	-	2231 .99	39.40	66.00	0.00
FTWW MI-17	Ft. Wainwright	209.9 0	605.0 0	0.00	-	-	0.00	-	-	3205 .36	29.00	63.00	0.00
FTWW MI-18	Ft. Wainwright	396.3 0	365.0 0	0.00	-	-	0.00	3.00	-	3343 .10	27.90	56.00	0.00
FTWW MI-19	Ft. Wainwright	248.0 0	771.0 0	0.00	-	-	0.00	-	69.00	3017 .12	33.80	160.0 0	0.00
FTWW MI-20	Ft. Wainwright	544.5 0	455.0 0	0.00	-	-	0.00	5.80	-	1974 .88	35.10	92.00	68.49
FTWW MI-21	Ft. Wainwright	364.4 0	721.0 0	0.00	-	-	0.00	-	-	3512 .98	32.50	77.00	0.00
FTWW MI-22	Ft. Wainwright	432.1 0	550.0 0	0.00	-	-	0.00	3.80	-	1446 .87	36.90	58.00	281.5 8
FTWW MI-23	Ft. Wainwright	331.3 0	838.0 0	0.00	-	-	0.00	-	-	2760 .00	32.10	66.00	0.00
FTWW MI-24	Ft. Wainwright	561.1 0	413.0 0	0.00	-	-	0.00	5.90	-	3779 .28	31.70	59.00	395.7 4
FTWW MI-25	Ft. Wainwright	298.5 0	598.0 0	8124. 07	-	-	0.00	2.10	-	1699 .39	30.20	69.00	1027. 40

FTWW MI-27	Ft. Wainwright	458.4 0	325.0 0	0.00	-	-	0.00	4.70	-	4059 .36	37.20	71.00	0.00
FTWW MI-28	Ft. Wainwright	218.0 0	695.0 0	5392. 59	-	-	0.00	-	-	2333 .00	27.80	79.00	0.00
FTWW MI-29	Ft. Wainwright	418.4 0	371.0 0	0.00	-	-	0.00	4.60	-	2668 .17	27.50	63.00	0.00
FTWW MI-30	Ft. Wainwright	253.7 0	600.0 0	0.00	-	-	0.00	-	-	2075 .89	31.60	68.00	403.3 5
FTWW MI-30	Ft. Wainwright	376.6 0	410.0 0	0.00	-	-	0.00	3.50	-	2493 .70	27.60	62.00	0.00
FTWW MI-31	Ft. Wainwright	230.3 0	755.0 0	0.00	-	-	0.00	-	-	3040 .07	31.20	71.00	106.5 4
FTWW MI-32	Ft. Wainwright	886.3 0	369.0 0	0.00	-	-	0.00	12.70	-	3912 .43	34.50	66.00	0.00
FTWW MI-33	Ft. Wainwright	332.0 0	552.0 0	0.00	-	-	0.00	-	-	3343 .10	30.70	63.00	0.00
FTWW MI-34	Ft. Wainwright	327.0 0	476.0 0	0.00	-	-	0.00	2.80	-	3673 .68	39.40	61.00	0.00
FTWW MI-35	Ft. Wainwright	276.2 0	544.0 0	0.00	-	-	0.00	-	-	3017 .12	36.00	66.00	1126. 33
FTWW MI-36	Ft. Wainwright	207.8 0	350.0 0	0.00	-	-	0.00	-	-	2199 .85	29.80	58.00	479.4 5
FTWW MI-37	Ft. Wainwright	436.7 0	633.0 0	0.00	-	-	0.00	4.10	72.00	4224 .65	33.00	63.00	0.00
FTWW MI-38	Ft. Wainwright	380.3 0	439.0 0	0.00	-	-	0.00	3.00	-	2911 .51	30.30	68.00	182.6 5
FTWW MI-39	Ft. Wainwright	438.8 0	503.0 0	0.00	-	-	0.00	4.10	-	2833 .46	56.10	71.00	0.00
FTWW MIFP01	Ft. Wainwright	389.6 0	68.00	0.00	-	-	0.00	3.70	-	2429 .42	47.90	87.00	624.0 5
FTWW MIFP02	Ft. Wainwright	19.40	58.00	0.00	-	-	0.00	3.30	-	4784 .79	37.30	69.00	0.00
FTWW MIFP03	Ft. Wainwright	17.70	63.00	0.00	-	-	0.00	2.80	-	2810 .50	34.00	80.00	0.00
FTWW MIFP04	Ft. Wainwright	18.70	51.00	0.00	-	-	0.00	3.60	-	2594 .71	39.70	74.00	0.00
FTWW MIFP05	Ft. Wainwright	16.30	52.00	0.00	-	-	0.00	3.80	-	1602 .97	35.60	80.00	0.00
FTWW MIFP06	Ft. Wainwright	14.50	50.00	0.00	-	-	0.00	2.60	-	2975 .79	32.10	77.00	487.0 6
FTWW MIFP07	Ft. Wainwright	15.90	92.00	0.00	-	-	0.00	3.40	-	2773 .77	36.30	88.00	197.8 7
FTWW MIFP08	Ft. Wainwright	31.10	89.00	0.00	-	-	0.00	9.30	-	2218 .22	41.90	83.00	996.9 6
FTWW MIFP09	Ft. Wainwright	29.20	83.00	0.00	-	-	0.00	9.30	-	2153 .94	40.50	85.00	327.2 5
FTWW MIFP10	Ft. Wainwright	30.20	80.00	0.00	-	-	0.00	9.10	-	3310 .96	39.30	80.00	0.00
FTWW MIFP11	Ft. Wainwright	27.50	75.00	0.00	-	-	0.00	8.60	-	3090 .58	38.90	84.00	0.00
FTWW MIFP12	Ft. Wainwright	26.40	69.00	0.00	-	-	0.00	7.60	-	2273 .31	39.50	82.00	0.00
FTWW MIFP13	Ft. Wainwright	22.80	83.00	0.00	-	-	0.00	6.30	-	2218 .22	38.90	100.0 0	0.00
FTWW MIFP14	Ft. Wainwright	27.10	68.00	0.00	-	-	0.00	8.30	-	3379 .83	42.40	75.00	38.05
FTWW MIFP15	Ft. Wainwright	23.10	93.00	0.00	-	-	0.00	6.70	-	3021 .71	38.10	89.00	0.00

FTWW BCK 1b	Ft. Wainwright	28.10	318.0 0	0.00	-	-	0.00	-	-	854. 58	38.20	89.00	0.00
KTS 01	Kimama	34.40	93.00	0.00	-	-	0.00	-	-	2034 .56	28.50	58.00	0.00
KTS 02	Kimama	844.4 0	1357. 00	0.00	-	-	0.00	-	-	1047 .42	52.70	67.00	905.6 3
KTS 03	Kimama	956.6 0	1577. 00	14790 .74	-	-	0.00	-	-	638. 79	34.10	74.00	0.00
KTS 04	Kimama	481.5 0	606.0 0	0.00	-	-	0.00	-	-	0.00	27.80	52.00	0.00
KTS 05	Kimama	489.2 0	674.0 0	0.00	-	-	0.00	-	54.00	0.00	29.20	61.00	684.9 3
KTS 06	Kimama	162.5 0	118.0 0	0.00	-	-	0.00	-	-	1699 .39	28.60	48.00	1712. 33
KTS 07	Kimama	53.50	73.00	0.00	-	-	0.00	-	-	1460 .64	24.00	45.00	0.00
KTS 08	Kimama	36.80	286.0 0	0.00	-	-	0.00	-	-	1024 .46	23.40	50.00	0.00
KTS 09	Kimama	30.80	81.00	0.00	-	-	0.00	-	-	1024 .46	25.00	52.00	799.0 9
KTS 10	Kimama	128.7 0	52.00	0.00	-	-	0.00	-	-	1281 .58	22.70	43.00	0.00
KTS 11	Kimama	13.10	62.00	0.00	-	-	0.00	-	-	1612 .16	26.20	59.00	0.00
KTS 12	Kimama	494.8 0	248.0 0	0.00	-	-	0.00	-	-	0.00	26.40	61.00	0.00
KTS 13	Kimama	84.80	149.0 0	0.00	-	-	0.00	-	-	781. 12	27.40	50.00	0.00
KTS 14	Kimama	127.1 0	226.0 0	0.00	-	-	0.00	-	-	643. 38	26.50	54.00	0.00
KTS 15	Kimama	1083. 60	716.0 0	0.00	-	-	0.00	4.20	-	1616 .75	28.00	66.00	0.00
KTS 16	Kimama	124.1 0	237.0 0	0.00	-	-	0.00	-	-	0.00	25.80	51.00	0.00
KTS 17	Kimama	171.5 0	226.0 0	0.00	-	-	0.00	-	-	0.00	25.40	54.00	601.2 2
KTS 18	Kimama	24.90	40.00	0.00	-	-	0.00	-	-	2562 .57	22.20	53.00	296.8 0
KTS 19	Kimama	9.40	71.00	0.00	-	-	0.00	-	-	1460 .64	24.30	42.00	0.00
KTS 20	Kimama	6.10	35.00	0.00	-	-	0.00	-	-	308. 21	24.40	48.00	0.00
KTS 21	Kimama	-	26.00	0.00	-	-	0.00	-	-	2002 .42	25.30	53.00	0.00
KTS 22	Kimama	3.90	37.00	0.00	-	-	0.00	-	-	1837 .13	26.00	48.00	45.66
KTS 23	Kimama	9.50	38.00	0.00	-	-	0.00	-	-	0.00	23.00	48.00	0.00
KTS 24	Kimama	7.80	43.00	0.00	-	-	0.00	-	-	2576 .34	26.10	49.00	0.00
KTS 25	Kimama	143.3 0	108.0 0	0.00	-	-	0.00	-	-	1157 .61	22.80	51.00	0.00
KTS 26	Kimama	106.5 0	285.0 0	0.00	-	-	0.00	-	-	790. 30	24.50	50.00	0.00
KTS 27	Kimama	4.90	32.00	0.00	-	-	0.00	-	-	987. 73	22.30	51.00	0.00
KTS 28	Kimama	486.1 0	72.00	0.00	-	-	0.00	-	-	1497 .37	25.20	51.00	0.00

KTS 29	Kimama	2.10	34.00	0.00	-	-	6324 1.67	-	-	0.00	21.30	47.00	0.00
KTS 30	Kimama	-	23.00	0.00	-	-	0.00	-	-	2050 .05	23.00	47.00	190.2 6
KTS 31	Kimama	265.4 0	494.0 0	0.00	-	-	0.00	-	-	2677 .35	23.90	53.00	0.00
KTS 32	Kimama	187.5 0	471.0 0	0.00	-	-	0.00	-	-	1630 .52	24.90	58.00	936.0 7
KTS 33	Kimama	293.3 0	352.0 0	0.00	-	-	0.00	-	-	7.33	25.00	51.00	0.00
KTS 34	Kimama	283.3 0	315.0 0	0.00	-	-	0.00	-	-	3485 .44	39.10	55.00	0.00
KTS 35	Kimama	245.4 0	339.0 0	0.00	-	-	0.00	-	-	3646 .13	29.70	60.00	0.00
KTS 36	Kimama	274.7 0	380.0 0	0.00	-	-	0.00	-	-	978. 55	26.00	63.00	0.00
KTS 37	Kimama	262.5 0	455.0 0	0.00	-	-	0.00	-	-	1772 .86	23.20	53.00	0.00
KTS 38	Kimama	291.0 0	405.0 0	0.00	-	-	0.00	-	-	1736 .12	22.90	58.00	0.00
KTS 39	Kimama	162.4 0	297.0 0	0.00	-	-	0.00	-	-	1479 .01	22.10	62.00	327.2 5
KTS 40	Kimama	374.2 0	696.0 0	0.00	-	-	0.00	-	-	877. 54	25.80	59.00	1567. 73
KTS 41	Kimama	259.1 0	378.0 0	0.00	-	-	0.00	-	-	1745 .31	24.30	57.00	631.6 6
KTS 42	Kimama	222.2 0	603.0 0	0.00	-	-	0.00	-	-	928. 04	24.60	59.00	1339. 42
KTS 43	Kimama	313.6 0	394.0 0	0.00	-	-	0.00	-	-	1437 .69	25.10	62.00	0.00
KTS 44	Kimama	263.9 0	346.0 0	0.00	-	-	0.00	-	-	2355 .96	25.40	52.00	0.00
KTS 45	Kimama	252.3 0	434.0 0	0.00	-	-	0.00	-	-	1529 .51	23.50	56.00	0.00
KTS 46	Kimama	-	22.00	0.00	-	-	0.00	-	-	859. 17	25.20	60.00	0.00
KTS 47	Kimama	-	22.00	0.00	-	-	0.00	-	-	1373 .41	24.10	50.00	0.00
KTS 48	Kimama	-	26.00	0.00	-	-	0.00	-	-	1566 .24	24.60	56.00	426.1 8
MMR BBG045 S	MMR	11.80	31.00	0.00	-	-	0.00	-	-	0.00	8.10	15.00	0.00
MMR BFP1A	MMR	19.20	41.00	0.00	-	-	0.00	-	-	1740 .72	10.70	19.00	0.00
MMR BFP1B	MMR	38.90	70.00	0.00	-	-	0.00	-	-	0.00	9.40	19.00	213.0 9
MMR BFP1C	MMR	27.40	69.00	0.00	-	-	0.00	-	-	450. 54	9.60	13.00	433.7 9
MMR BFP2A	MMR	13.70	35.00	0.00	-	-	0.00	-	-	0.00	9.50	27.00	974.1 2
MMR BFP2B	MMR	26.80	37.00	0.00	-	-	0.00	-	-	519. 41	10.30	22.00	0.00
MMR BFP2C	MMR	15.70	44.00	0.00	-	-	0.00	-	-	744. 39	8.90	23.00	0.00
MMR BFP3A	MMR	12.10	35.00	0.00	-	-	0.00	-	-	0.00	9.90	22.00	0.00

MMR BFP3B	MMR	17.50	40.00	0.00	-	-	0.00	-	-	611. 24	10.50	21.00	0.00
MMR BFP3C	MMR	14.10	35.00	0.00	-	-	0.00	-	-	1676 .44	10.50	19.00	0.00
MMR BFP4A	MMR	34.10	46.00	0.00	-	-	0.00	-	-	0.00	8.80	22.00	38.05
MMR BFP4B	MMR	25.90	46.00	0.00	-	-	0.00	-	-	909. 68	10.60	19.00	220.7 0
MMR BFP4C	MMR	22.50	49.00	0.00	-	-	0.00	-	-	854. 58	10.10	20.00	0.00
MMR BFP5A	MMR	22.80	42.00	0.00	-	-	0.00	-	-	367. 90	12.20	20.00	0.00
MMR BFP5B	MMR	16.50	33.00	0.00	-	-	0.00	-	-	216. 38	12.60	18.00	273.9 7
MMR BFP5C	MMR	12.10	32.00	0.00	-	-	0.00	-	-	1276 .99	11.60	27.00	0.00
MMR BLB024 S1	MMR	274.9 0	227.0 0	0.00	402. 90	1157. 00	0.00	5.80	-	1231 .07	28.30	61.00	0.00
MMR BLB027 S1	MMR	272.2 0	227.0 0	0.00	487. 60	779.0 0	0.00	7.40	-	1451 .46	29.10	56.00	700.1 5
MMR BLB038 S	MMR	189.0 0	330.0 0	0.00	43.5 0	-	0.00	-	-	170. 47	14.10	39.00	989.3 5
MMR BLB043 S	MMR	1852. 80	187.0 0	0.00	297. 10	686.0 0	0.00	21.20	-	0.00	37.20	41.00	0.00
MMR BLB047 S	MMR	104.2 0	256.0 0	0.00	93.0 0	285.0 0	0.00	-	-	0.00	13.80	53.00	0.00
MMR BMB02 2S1	MMR	573.3 0	648.0 0	0.00	1020 .30	2150. 00	0.00	16.70	-	1474 .42	33.40	103.0 0	0.00
MMR BMB04 2S	MMR	290.4 0	342.0 0	0.00	155. 60	308.0 0	0.00	-	-	0.00	17.10	42.00	0.00
MMR BMB04 4S	MMR	1173. 30	197.0 0	0.00	466. 70	1238. 00	0.00	17.80	-	248. 52	19.00	77.00	365.3 0
MMR BMB04 6S	MMR	131.6 0	287.0 0	0.00	367. 70	1237. 00	0.00	2.50	-	0.00	20.40	78.00	0.00
MMR BMB08 2S	MMR	179.4 0	373.0 0	0.00	421. 90	1030. 00	0.00	3.80	-	211. 79	26.20	73.00	0.00
MMR BRF009 S2	MMR	91.40	91.00	0.00	81.9 0	-	0.00	16.50	-	308. 21	17.40	36.00	0.00
MMR BRF012 3S2	MMR	88.90	186.0 0	0.00	-	-	0.00	-	-	1786 .63	14.60	36.00	0.00
MMR BRF012 S1	MMR	96.60	180.0 0	0.00	2.30	-	0.00	-	-	0.00	19.30	45.00	0.00
MMR BTA020 S	MMR	154.8 0	313.0 0	0.00	-	-	0.00	-	-	0.00	12.00	30.00	0.00

MMR BTR033 S1	MMR	221.2 0	340.0 0	0.00	478. 00	1210. 00	0.00	5.80	-	1254 .03	25.00	59.00	0.00
MMR BTR034 S2	MMR	279.5 0	515.0 0	0.00	483. 30	2126. 00	0.00	6.30	-	445. 95	24.50	120.0 0	2115. 68
MMR BTR035 S3	MMR	215.4 0	401.0 0	0.00	510. 60	1734. 00	0.00	5.80	-	0.00	25.70	106.0 0	0.00
MMR BTR037 Sd	MMR	272.4 0	516.0 0	0.00	266. 10	626.0 0	0.00	2.80	-	1162 .20	24.20	64.00	0.00
MMR BTR037 Se	MMR	475.4 0	546.0 0	0.00	360. 10	618.0 0	0.00	5.40	-	1474 .42	26.60	64.00	0.00
MMR BTR037 Sf	MMR	305.0 0	551.0 0	0.00	277. 90	737.0 0	0.00	2.80	-	831. 62	25.50	63.00	1659. 06
MMR BTR039 S	MMR	182.5 0	483.0 0	0.00	9.70	-	0.00	-	-	1400 .95	15.80	34.00	0.00
MMR BTR049 B	MMR	256.3 0	417.0 0	96551 .85	112. 90	258.0 0	0.00	2.70	-	303. 62	15.20	33.00	0.00
MMR BTR050 B	MMR	215.0 0	353.0 0	0.00	66.9 0	128.0 0	0.00	-	-	0.00	13.60	36.00	0.00
MMR BUB078 B	MMR	106.7 0	55.00	0.00	18.8 0	-	0.00	-	-	0.00	3.60	-	1019. 79
MMR BUB079 B	MMR	16.40	14.00	0.00	7.70	-	0.00	-	-	257. 70	3.40	-	0.00
MMR BUB080 B	MMR	28.80	25.00	0.00	14.1 0	-	0.00	-	-	0.00	2.80	15.00	0.00
MMR BUB081 B	MMR	28.50	45.00	0.00	6.20	-	0.00	-	-	1301 .09	4.10	-	616.4 4
MMR CMB00 9S2	MMR	340.9 0	412.0 0	0.00	346. 70	1010. 00	0.00	4.70	-	1080 .71	26.80	111.0 0	0.00
MMR CMB01 1S3	MMR	359.0 0	353.0 0	0.00	399. 00	830.0 0	0.00	5.90	-	823. 59	28.60	73.00	0.00
MMR CMB03 3B	MMR	308.6 0	325.0 0	0.00	171. 90	364.0 0	0.00	2.90	-	2003 .57	17.70	40.00	129.3 8
MMR CMB03 4B	MMR	185.8 0	508.0 0	0.00	62.8 0	131.0 0	0.00	2.50	-	0.00	14.00	27.00	0.00
MMR CMB03 5B	MMR	154.0 0	220.0 0	0.00	7.00	-	0.00	-	-	910. 83	12.40	23.00	235.9 2
MMR CMB03 8B	MMR	269.4 0	424.0 0	0.00	-	-	0.00	2.90	-	199. 16	8.90	25.00	601.2 2

MMR CTR003 S1	MMR	247.1 0	831.0 0	0.00	116. 20	1051. 00	0.00	-	-	447. 10	18.20	98.00	0.00
MMR CTR010 S3	MMR	300.7 0	574.0 0	0.00	189. 60	697.0 0	0.00	-	-	1521 .48	23.00	76.00	0.00
MMR CTR012 B	MMR	321.2 0	570.0 0	0.00	65.3 0	188.0 0	0.00	-	-	0.00	18.90	46.00	0.00
MMR CTR013 B	MMR	189.5 0	344.0 0	0.00	11.1 0	-	0.00	-	-	0.00	11.20	24.00	0.00
MMR CTR014 B	MMR	269.7 0	268.0 0	0.00	-	-	0.00	-	-	506. 79	7.50	15.00	0.00
MMR CTR015 B	MMR	45.50	50.00	0.00	-	-	0.00	-	-	988. 88	4.10	10.00	0.00
MMR CTR017 B	MMR	5.20	16.00	could not make pellet	-	-		-	-		3.40	-	
MMR CUB019 S1	MMR	824.1 0	323.0 0	0.00	168. 60	446.0 0	0.00	9.10	-	773. 09	17.20	51.00	0.00
MMR CUB020 S2	MMR	245.3 0	515.0 0	0.00	114. 40	352.0 0	0.00	-	-	38.4 7	16.30	46.00	0.00
MMR E1LBFP	MMR	41.90	70.00	0.00	-	-	0.00	-	-	878. 69	10.50	20.00	0.00
MMR E2	MMR	6.90	18.00	0.00	-	-	0.00	-	-	167. 02	10.30	17.00	0.00
MMR E3	MMR	17.30	35.00	0.00	-	-	0.00	-	-	134. 89	6.90	19.00	0.00
MMR E4	MMR	-	8.00	0.00	-	-	0.00	-	-	0.00	7.30	14.00	0.00
MMR E5	MMR	-	-	0.00	-	-	0.00	-	-	378. 23	7.60	10.00	768.6 5
MMR IBB004 S1	MMR	1038. 70	560.0 0	0.00	67.0 0	826.0 0	0.00	9.90	-	0.00	33.90	130.0 0	0.00
MMR IBB018 S2	MMR	515.3 0	1212. 00	15624 .07	223. 70	203.0 0	0.00	3.60	-	56.8 3	21.60	54.00	0.00
MMR IFP- TA001S 1	MMR	102.3 0	151.0 0	sampl e not found	-	-		-	-		13.60	26.00	
MMR IFP- TA014S 2	MMR	305.5 0	348.0 0	0.00	-	-	0.00	-	-	157. 84	13.80	23.00	0.00
MMR ILB003S 3	MMR	108.5 0	108.0 0	0.00	285. 30	509.0 0	0.00	5.90	-	1434 .24	985.8 0	49.00	0.00
MMR ITR002S 1	MMR	341.9 0	469.0 0	0.00	97.4 0	632.0 0	0.00	-	-	456. 28	19.60	62.00	0.00

MMR ITR009S 2	MMR	632.3 0	442.0 0	0.00	106. 30	504.0 0	0.00	4.00	-	0.00	14.20	60.00	0.00
MMR ITR013S 3	MMR	328.6 0	444.0 0	0.00	86.7 0	684.0 0	0.00	2.00	-	0.00	16.60	79.00	0.00
MMR IUB010 S1	MMR	395.7 0	213.0 0	0.00	3.30	-	0.00	-	-	111. 93	14.00	35.00	0.00
MMR IUB014 B	MMR	36.00	87.00	0.00	19.7 0	-	0.00	-	-	1117 .44	7.40	18.00	0.00
MMR IUB015 B	MMR	30.20	30.00	0.00	3.80	-	0.00	-	-	1590 .35	9.30	12.00	0.00
MMR IUB017 B	MMR	186.6 0	230.0 0	0.00	-	-	0.00	-	-	437. 92	7.10	14.00	410.9 6
MMR J1	MMR	34.90	96.00	0.00	-	-	0.00	-	-	24.6 9	31.60	76.00	0.00
MMR J3	MMR	3.00	13.00	0.00	-	-	0.00	-	-	29.2 8	22.80	35.00	0.00
MMR J4	MMR	-	17.00	0.00	-	-	0.00	-	-	1897 .97	12.70	30.00	0.00
MMR J6	MMR	84.40	124.0 0	0.00	-	-	0.00	-	-	819. 00	11.90	25.00	958.9 0
MMR K2RBFP	MMR	12.30	31.00	0.00	-	-	0.00	-	-	1608 .71	16.30	33.00	0.00
MMR K2RBFP	MMR	11.70	35.00	0.00	-	-	0.00	-	-	1608 .71	17.00	42.00	0.00
MMR K3	MMR	-	22.00	0.00	-	-	0.00	-	-	2416 .80	11.30	26.00	0.00
MMR K5	MMR	-	20.00	0.00	-	-	0.00	-	-	819. 00	9.60	26.00	0.00
MMR KILBFP	MMR	1938. 70	55.00	0.00	412. 80	-	0.00	18.50	-	29.2 8	17.30	62.00	0.00

- Denotes that the concentration is below detection limit of the instrument

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14. ABSTRACT The Army is interested in sensors capable of characterizing/monitoring the environment (battlefield or military training ranges) at proximal distances. Recently, we evaluated laser induced breakdown spectroscopy (LIBS) systems (hand-held, proximal, and bench top) for the characterization of metals (antimony, copper, lead, tungsten, and zinc) in soils obtained from military training ranges. We then compared the results to findings obtained with standard field and laboratory instrumentation for metals analysis - X-ray Fluorescence (XRF) and Inductively Couple Plasma- Optical Emission Spectroscopy (ICP-OES).					
15. SUBJECT TERMS Laser induced breakdown spectroscopy (LIBS), inductively coupled plasma- optical emission spectroscopy (ICP-OES), X-ray fluorescence (XRF)					
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