The use of hyperspectral remote sensing to monitor landfills areas of remediated sites in the 0.35 to 14 micron spectral range

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INTRODUCTION

Laboratory spectral measurements were conducted to evaluate the potential of hyperspectral technologies, both reflective and emissive, to detect contaminants in remediated sites of the Distant Early Warning (DEW) line. A SVC-HR1024, an ASD (.35 to 2.5 micron) and a FSR (1.6 to 12 micron) spectrometers were used to measure the reflectance of contaminated soil.

Table 1 shows the list of contaminants under investigation with the maximum allowed concentrations when available. In addition, iron was also investigated because of its potential to mobilize heavy metals.

Table 1.

Contaminant	Concentration		Contaminant	Concentration
Arsenic	30 ppm		Lead	500 ppm
Cadmium	5 ppm		Mercury	2 ppm
Chromium	250 ppm		Nickel	100 ppm
Copper	100 ppm		Zinc	500 ppm
HC	NA		PCBs	5 ppm

Our assessment is based on past DRDC work, literature survey, on site measurements at the DYE-Main site and laboratory measurement of DEW line sites soil samples with known concentrations stored at the Royal Military College (RMC) in Kingston ON.

LABORATORY AND FIELD MEASUREMENTS RESULTS

Hydrocarbons (HC)

VNIR/SWIR: a unique spectral absorption feature of HC in the vicinity of 1.73 micron can be used to perform a direct detection of HC in the soil [1,2,3]. The lab spectra show a relationship with the depth of the 1.73 band and the concentration of HC in the sample ($r = 0.6$ with the HC = 0 ppm samples, and $r = 0.75$ when 0 ppm samples are removed). A map of the depth of this feature can be produced from an airborne sensor providing that the soil is exposed to the surface.

MWIR/LWIR: there is a unique absorption feature of HC at 3.3 micron, which can be used to perform a direct detection of HC presence. Analysis of soil samples for Dye-Main site showed HC features to be present in some samples containing at least 1300 ppm of total HC. It is expected that the detection of HC at the soil surface could be performed with high confidence from airborne and ground-based sensors operating in the MWIR band.

Iron (Fe)

VNIR/SWIR: soil transition iron ions (Fe^{++} and Fe^{+++}) are readily detectable in the VNIR bands (0.35 to 1 micron). Iron oxides can migrate through the leaching solution and mobilize heavy metals such as lead

and zinc. The presence of certain iron oxides and iron sulfates are also indicator of an acidic or stable soil environment, acidity being a major factor controlling heavy metals mobility in the soils. Thus, mapping iron oxides could be used as an indicator of contaminated soil and potential acidic drainage [4].

MWIR/LWIR: metallic iron cannot be detected directly, however, iron oxides do exhibit features in the 12 micron region. They are probably too weak and too close to atmospheric water vapor bands for detection from an airborne platform, but they may be detectable from ground-based instrumentation.

Lead (Pb) – Zinc (Zn) – Cadmium (Cd)

VNIR/SWIR: unlike Fe and HC, heavy metals do not exhibit any spectral feature in the VNIR/SWIR that could be diagnostic of their presence [5]. However, indirect detection of soil heavy metal content can be achieved using the spectral features of minerals capable of binding with heavy metals. This is the case with soil clay minerals; the binding of heavy metals to the surface of the clay minerals results in a decrease of the clay spectral absorption band depth at 2.2 micron (negative correlation).

The RMC soil samples heavy metals form two groups with highly correlated concentrations: the Pb-Zn-Cd group and the Ni-Cu-Cr-As group. Thus, the detection of one member of a group implies the detection of the other members. RMC had a limited number of samples that were tested for lead. Among these samples, only two exceeded the 500 ppm concentration that is deemed acceptable (Table 1). Clay content was not available but because of the sticky nature of clay a simple hand test was performed to determine and confirmed the presence of clay in the samples. There was an r = -0.43 correlation between the band depth of the clay feature and the concentration of Pb-Zn-Cd in the RMC samples. The confidence level for the detection of these elements from the ground is considered low and is not recommended from an airborne platform.

MWIR/LWIR: metallic lead cannot be detected directly. However, lead oxides do exhibit spectral features near 10 micron that could be used for indirect detection from both ground-based and airborne platforms. The RMC samples containing high amounts of lead, and therefore possibly lead oxide, exhibited no features related to the latter. The confidence of such measurements, particularly from an airborne system, would be expected to be low.

Nickel (Ni) – Copper (Cu) – Chromium (Cr) – Arsenic (As)

VNIR/SWIR: Among this group of elements, samples with high Ni-Cu-Cr concentration were found to have an absorption feature centered at 1.22 micron. This feature is not documented in the literature in relation to heavy metals. There were only two samples at RMC with high concentrations of the three elements Ni-Cu-Cr-As (560 ppm to 900 ppm). All the other samples had values close to or below the background limit (Table 1). Only the samples with the two highest concentrations show the absorption feature at 1.2 micron. It is possible that this feature at 1.2 micron is related to Cr^{++} ions and that it is only detectable at very high concentrations. However, this could only be confirmed if samples of concentrations between the lowest and highest are included in the analysis.

MWIR/LWIR: chromium metal does not exhibit absorption bands in the LWIR/MWIR region. We have not been able to test oxides of chromium as a way of indirectly measuring the metal. Nickel metal (or perhaps its oxide) appears to exhibit an absorption feature at 9.5 micron, which may provide a means for detecting nickel with low confidence from airborne and ground-based systems. The feature was not present in any of the RMC samples containing high nickel amounts.

PCB

Considering the low concentrations of PCB in the RMC soil samples and the small amount of samples available, it is difficult to conclude on the potential of detecting PCBs using hyperspectral reflective remote sensing. In the LWIR/MWIR it is expected that PCBs will have strong absorption features based on their principle components.

DISCUSSIONS AND RECOMMENDATIONS

A summary of the results obtained thus far and the probability of ground and airborne detection is shown in Table 2. Based on results available we can make the following comments and recommendations:

1- Heavy metals, except for iron-bearing minerals, do not exhibit any diagnostic spectral feature in the VNIR/SWIR (0.35 to 2.5 micron). For this reason they can only be detected in an indirect manner in association with iron or clay minerals. The latter are readily detectable when present in the soil. Similarly, in the LWIR/MWIR bands, generally only the oxides of metals exhibit spectral features which may provide an indirect detection method for heavy metals.
2- Direct detection in VNIR/SWIR bands can be performed for hydrocarbons and iron rich soil. The MWIR band also can be used for direct detection of hydrocarbons.
3- We have not found any relevant papers about the detection of PCBs by airborne hyperspectral sensors in the open literature. Further investigation will follow.

Table 2.

		Direct detection	*Indirect detection*	*Ground*	*Airborne (1)*
VNIR/SWIR	HC	X	X	high	med
	Fe	X	X	high	med
	Pb-Zn-Cd	no	X	low (2)	not recommended
	Ni-Cu-Cr-As	no	X	low	not recommended
	PCB	n/a	n/a	n/a	n/a
MWIR/LWIR	HC	X	no	high	high
	Fe	no	X (3)	low	not recommended
	Pb	no	X (4)	low	not recommended
	Cr	no	tbd	tbd	tbd
	Ni	X	no	low	not recommended
	PCB	X	no	high (5)	high (5)

(1) providing that the soil is exposed to the surface

(2) only if clay is present in the soil

(3) via iron oxide

(4) via lead oxide

(5) expected high confidence based on molecular structure, to be confirmed through further laboratory measurements

REFERENCE

[1] C. Scott Allena and Melvin B. Satterwhite, *Reflectance spectra of three liquid hydrocarbons on a common sand type*, Proc. of SPIE Vol. 6233, 2006

[2] Kuhn, F. Opperman, K., Horig, B. *Hydrocarbon Index – An Algorithm for Hyperspectral Detection of Hydrocarbons.* Int. J. Remote Sensing, 20 June, 2004, vol. 25, no. 12, 2467-2473.

[3] Magnus Wettle, Paul J. Daniel, Graham A. Logan , Medhavy Thankappan. Assessing the effect of hydrocarbon oil type and thickness on a remote sensing signal: A sensitivity study based on the optical properties of two different oil types and the HYMAP and Quickbird sensors. Remote Sensing of Environment 113 (2009) 2000–2010

[4] Eunyoung Choe, Freek van der Meer, Frank van Ruitenbeek, Harald van der Werff, , Boudewijn de Smeth, Kyoung-Woong Kim, *Mapping of heavy metal pollution in stream sediments using combined geochemistry, field spectroscopy, and hyperspectral remote sensing: A case study of the Rodalquilar mining area, SE Spain*, Remote Sensing of Environment 112 (2008) 3222–3233

[5] Xia Zhang, Jianting Wen, Dong Zhao, *Band Selection Method for Retrieving Soil Lead Content with Hyperspectral Remote Sensing Data*, Proc. of SPIE Vol. 7831, 2010

[6] Guy Schwartz, Gil Eshel and Eyal Ben-Dor, Reflectance Spectroscopy as a Tool for Monitoring Contaminated Soils, Chapter 4 in Earth and Planetary Sciences, book edited by Simone Pascucci, ISBN 978-953-307-647-8, Published: September 12, 2011.