

Temporal trends in reclamation assessed with airborne multispectral remote sensing¹

Leslie Brown, Gary Borstad, Mar Martínez, Randy Kerr, Peter Willis
G. A. Borstad Associates Ltd., Sidney British Columbia

Mark Richards and Peter Witt
Highland Valley Copper, Logan Lake, British Columbia

Airborne multispectral imagery of Highland Valley Copper Mine, near Kamloops BC was acquired in July 2005, the fourth in a series of airborne remote sensing campaigns. A quantitative index of vegetation biomass (Normalized Difference Vegetation Index or NDVI) and multispectral classifications are now available for 2001, 2002, 2003 and 2005 for reclamation sites at Bethlehem, Trojan, Heustis and Highmont Tailings areas. Temporal trends can now be examined.

The remote sensing data show that 2005 was a “green” year. Most vegetation, whether dense, moderate or sparse, was actively growing and green at the time of imaging. This is in contrast to 2003, which was unusually dry. The four-year time series indicates an overall increase in vegetation density and greenness since 2001, with the drought of 2003 having clear, short-term impacts on the vegetation.

On a more local scale, the area along Trojan Dam and the area to the north and west of Bethlehem Tailings showed dramatic increases in vegetation in 2005.

Local analyses of reclamation sites at Bethlehem Northeast and Heustis demonstrate the usefulness of imagery to supplement ground evaluation of individual sites. With boundary vectors for all reclamation sites, these analyses could be extended throughout the mine to assist in reclamation assessment.

¹ Presented at the 30th British Columbia Mine Reclamation Symposium, Smithers, British Columbia, June, 2006

INTRODUCTION

Highland Valley Copper is a large open pit copper mining complex, situated between 1200 and 1600 m above sea level on the Thompson Plateau, near the town of Logan Lake British Columbia (BC), 220 Km northeast of Vancouver and 55 Km southwest of Kamloops (Figure 1).

Highland Valley Copper consists of four mining operations: Lornex, Valley, Bethlehem and Highmont. Since the beginning of 2004, the mine is almost 100% owned by Teck Cominco. Operations at the latter two were discontinued in the mid-1980s, and decommissioning begun. Production is currently planned to cease in early-2009 but may be extended to 2013 pending approval of a new plan. The total disturbed area is currently 6200 ha.

Reclamation is an integral part of production and decommissioning. Reclamation monitoring programs are conducted annually to assess the progress toward achieving the end land use objectives, and to determine when individual sites achieve a self-sustaining state. Beginning in 2001, remote sensing has been evaluated as a way of improving the efficiency and effectiveness of the monitoring program (Richards *et al.*, 2003; Richards *et al.*, 2004; Borstad *et al.*, 2005).

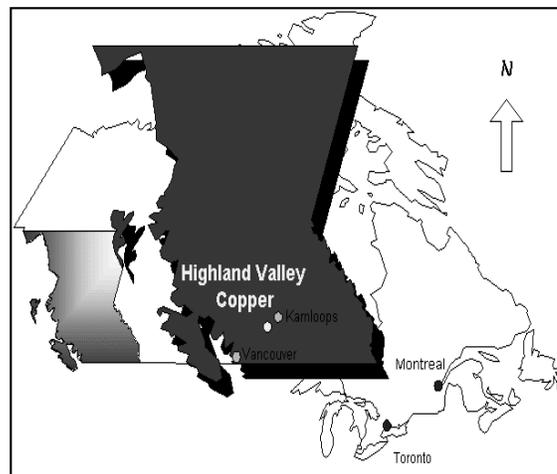


Figure 1: Location Map of Highland Valley Copper

We present here examples of analysis of temporal trends of vegetation biomass at reclamation sites at the Bethlehem Northeast, and Heustis areas at Highland Valley Copper, as determined from airborne multispectral imagery acquired in July 2001, 2002, 2003 and 2005.

METHODS

Airborne and Ground Data

The data and methods have been previously described (Richards *et al.*, 2003; 2004; Borstad *et al.*, 2005) and will not be repeated in detail here. In all years, airborne multispectral imagery was acquired using a Compact Airborne Spectrographic Imager (CASI), configured to acquire imagery in 9 spectral bands, and with 2.5m ground sampling distance. The imagery is radiometrically calibrated and mapped to Mine Units with an estimated geographic accuracy of +/-10m.

Ground observations and measurements available from conventional field surveys made for Highland Valley Copper by C. E. Jones & Associates Ltd. were used for calibration and validation of the CASI imagery.

Airborne Data Analysis

Analysis of the airborne data proceeded along two lines: the estimation of vegetation biomass using the Normalized Difference Vegetation Index (NDVI), and vegetation classification using multispectral analytical techniques. The analysis was restricted to those areas of interest for the reclamation program, corresponding roughly to those seeded with forage species and excluding areas dominated by trees and shrubs. Aquatic areas are not discussed here.

The commonly used NDVI (Normalized Difference Vegetation Index) was correlated with ground survey measurements of biomass ($r^2 \sim 0.7$). NDVI is calculated as follows:

$$\text{NDVI} = (R_{776} - R_{665}) / (R_{776} + R_{665})$$

where R_λ = at-sensor radiance at wavelength λ (in nanometres).

For the temporal analysis that is the subject of this paper, NDVI images calculated for all four years were compiled into a single, 4-channel data file, so that for any location in the imagery NDVI values for all four years (*i.e.*, temporal profiles) could be easily extracted as a 'time profile' (Figure 2).

Comparisons were also made between the image-based vegetation indices and the ground measurements of biomass and vegetation coverage. The vegetation coverage used in these comparisons was expressed as total vegetation presence along 5 m transects disregarding species composition.

Vegetation classification was performed using the Spectral Angle Mapper (SAM). This is a supervised technique in which type spectra (called 'endmembers') are defined for each vegetation class to be mapped, and each image pixel is evaluated based on its similarity to the type or reference spectra. Each pixel in the is classified according to its mathematical similarity to the endmember spectra.

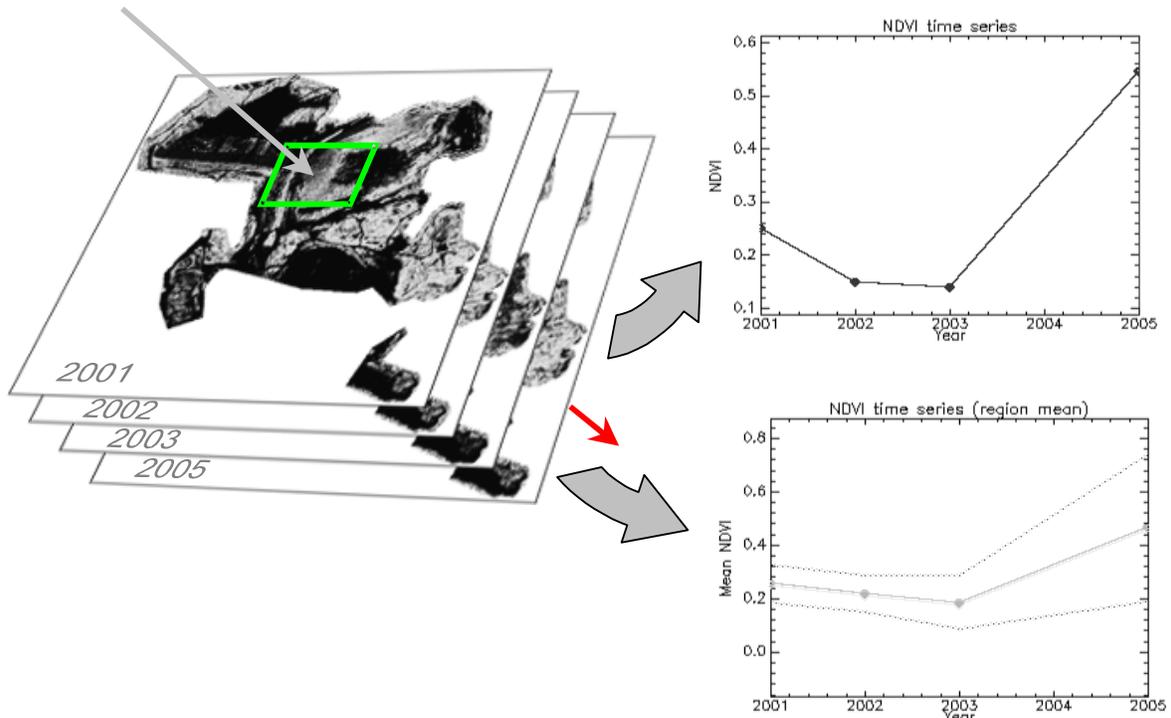


Figure 2. Overview of the method: An NDVI time series for the years 2001-2005 allows temporal extracts for a single point (red) or a user-defined area (green, with ± 1 standard deviation bounds also shown).

RESULTS AND DISCUSSION

Figure 3 is a map of NDVI for Bethlehem, Trojan, and Heustis, for all four imaged years. The grey-scale legends for all maps are the same, so that direct comparisons among years can be made. In each case, the areal coverage has been edited to include only those areas evaluated in all four years. In these grey scale NDVI images, water and bare ground appear black. Very green areas with high vegetative biomass appear white. The image has been cropped to the approximate boundaries of the reclaimed areas.

In general we see that, the vegetation on lower, flatter areas near the ponds tends to be greener (higher NDVI) than that on high, more exposed areas and on slopes. Among the recent changes at Bethlehem we see:

- an overall increase in vegetation greenness in 2005 over 2003 (2005 image is brighter overall),
- growth of new green vegetation along Trojan Dam in 2005,
- increased vegetation over the entire area surrounding Bethlehem Tailings pond in 2005
- low NDVI values (due to drought) in 2003, except for areas to the north and west of Trojan Pond and certain areas near Bethlehem Tailings pond, which managed to stay relatively green despite the dry weather.

- an increase in greenness at Bethlehem Northeast (box) in 2005 apparently representing a recovery to the levels present in 2001 and 2002, after the dry year in 2003

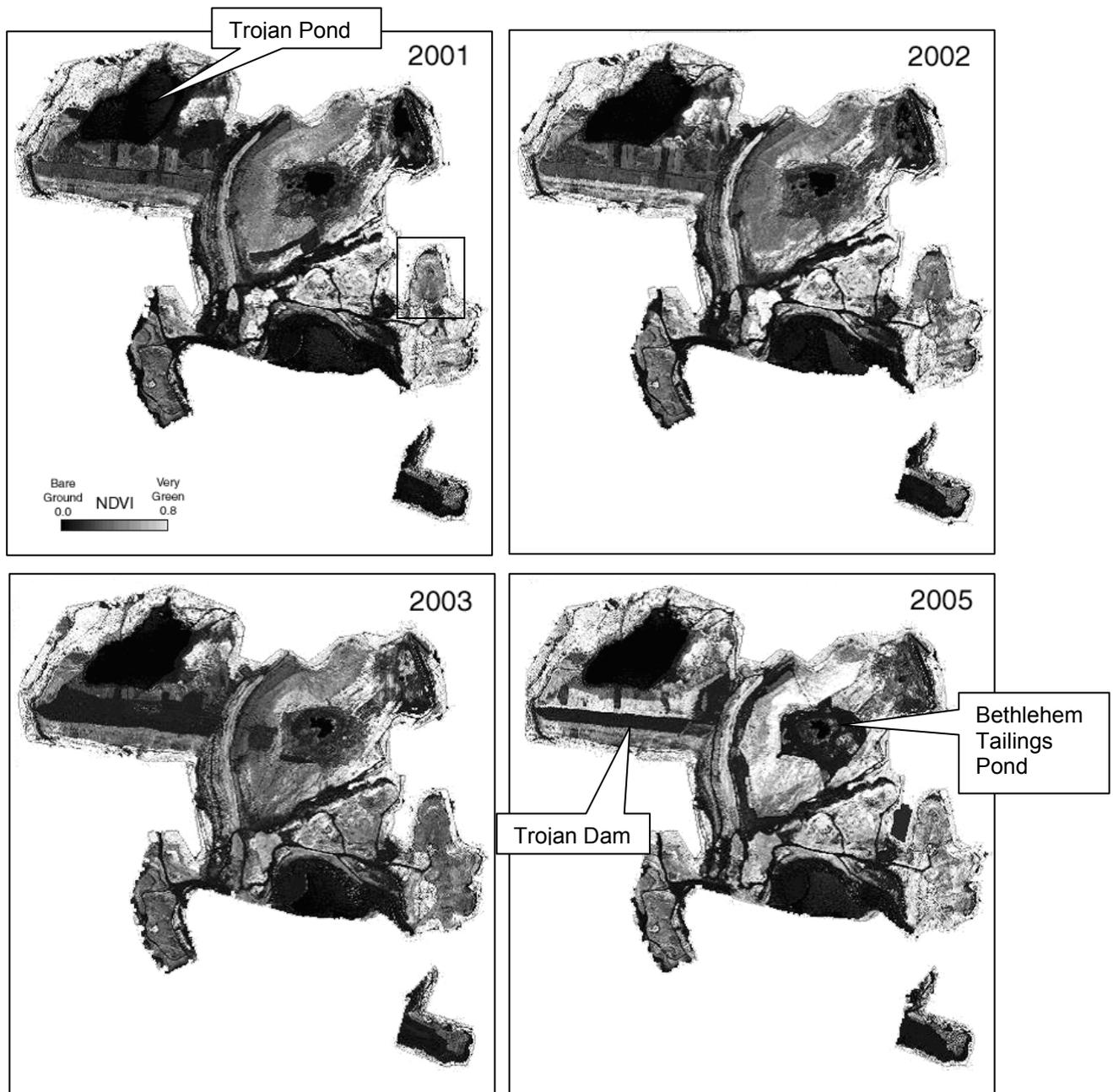


Figure 3. NDVI images for Bethlehem-Trojan-Heustis for 2001-2005. Box and letters are areas referred to in the text.

Many of these differences between 2003 and 2005 can be attributed to the timing and amount of precipitation in these two years. The summer of 2003 was unusually dry, particularly in the interval immediately preceding CASI image acquisition, whereas the corresponding period in 2005 was wetter. Other changes are likely responses to reclamation activities such as seeding and fertilization.

Local Analysis - Bethlehem Northeast

Bethlehem Northeast is a steep site capped with overburden that was originally seeded in 1991 and later top-dressed with biosolids in 1998 after a decrease in biomass production had been observed. Ground observations in 2000 and 2004 showed a decrease in agronomic cover between these two years, suggesting that the site was not self-sustaining. Similarly, the image data in Figure 4 show a decrease in NDVI between 2001 and 2003 (we do not have data for 2004), but an increase in 2005. The classification statistics and maps also show a decrease in density between 2001 and 2002, followed by drying over most of the site in 2003. 2005 shows recovery of the vegetation, though from ground observations this may consist of forbs rather than agronomic species. The fact that the vegetation over most of the site (except a small area at the north end) dried in 2003 suggests that water retention is a problem here – an observation consistent with the steepness of the site.

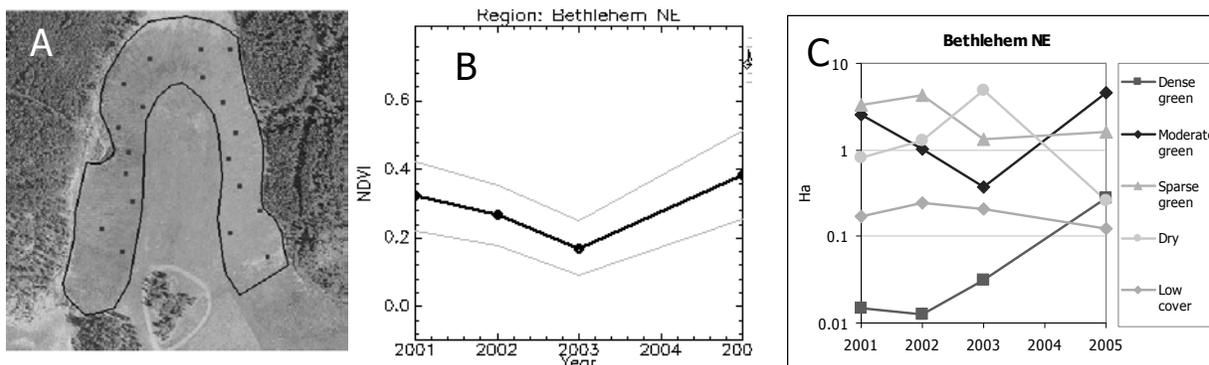


Figure 4. NDVI and classification details for Bethlehem Northeast (topdressed biosolids, seeded 1991). A, site limits, and ground sampling plots. B, change in mean NDVI for the site for 2001-2005 (± 1 standard deviation). C, changes in SAM class areas (hectares) for 2001-2005.

Local Analysis - Heustis

Heustis is an area of waste rock that was seeded in 1998 following biosolids incorporation in 1997 (Figure 5A). Ground assessments in 2000 and 2004 showed mild decreases in biomass and more significant decreases in vegetation cover between these two years. We see that in 2001 the overall vegetation coverage was low, but that between 2001 and 2002 there was some increase in NDVI, concomitant with increases in 'moderate' and 'sparse' green vegetation classes and a decrease in 'low cover' (Figure 5C, D). In 2003 there was a drop in NDVI. The classification data shows that this was mostly due to the dryness of much of the vegetation, and in fact the 'low cover' class was smaller than in previous years. In 2005 we see an increase in NDVI and all green vegetation classes, and a further decrease in 'low cover'. Despite these increases the overall level of cover remains low, with a mean NDVI of 0.25 in 2005 (recall that an NDVI value of 0 indicates no vegetation, and 1 indicates dense green vegetation). Close examination of the spatial distribution of NDVI in figure 3 show that most of the vegetation development is at the north end of the Heustis site, and that much of the remaining area remains 'sparse' or 'low cover'. As at Bethlehem Northeast, water availability may be a factor here, since the north end, which is lower in elevation than the rest of the site and close to Heustis Pond, did not dry in 2003 and showed a more or less steady increase in vegetation coverage from 2001 to 2005.

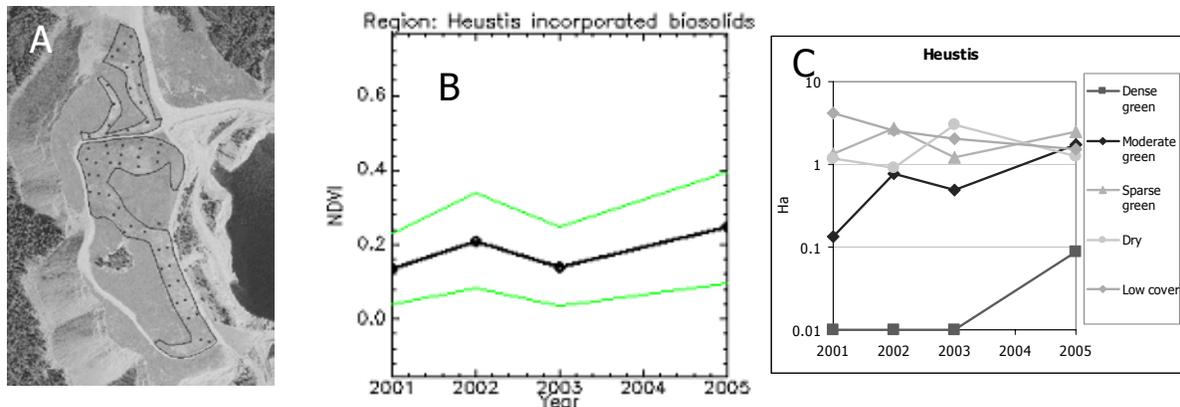


Figure 5. NDVI and classification details for Heustis (incorporated biosolids, seeded 1998). A, site limits and plot locations. B, change in mean NDVI for the site for 2001-2005 (green shows ± 1 standard deviation). C, changes in SAM class areas (ha) for 2001-2005.

The fact that the Heustis site showed marked decreases in vegetation coverage between 2000 and 2004 in ground data but not in the image data suggests that much of the decrease occurred in the first year (2000 to 2001). Ground observations indicate dense vegetation at 52% of the plots in 2000, whereas in 2001 the image data shows low cover or sparse vegetation over most of the site.

CONCLUSIONS

The remote sensing data show that 2005 was a “green” year, in that, whether dense, moderate or sparse, most of the vegetation at Bethlehem, Trojan, and Heustis was actively growing and green at the time of imaging (July 21st). Time series of NDVI show a slow increase in overall vegetation density and greenness in both areas since 2001 (the year of the first airborne survey). At Bethlehem, the overall NDVI dropped in 2003, but recovered in 2005, indicating a temporary drying likely related to the low precipitation that year in the weeks preceding image acquisition. Similarly, the multispectral classifications show a gradual increase in dense and moderately vegetated area, and a decrease in sparsely vegetated and low cover areas over the four-year period. In addition, similar to NDVI, the classifications show a peak in dry vegetation area in 2003 followed by a recovery in 2005, indicating that 2003 was likely a temporary, precipitation-related decrease in greenness and not a permanent loss of vegetation.

On a more local scale, the area to the north and west of Bethlehem Tailings Pond showed dramatic increases in vegetation in 2005², as did the area along Trojan Dam.

With four years of imagery, we can begin to provide temporal as well as spatial context and continuity for the ground-sampling program. While the remote sensing data cannot provide the level of detail provided by the ground sampling, it does supply full spatial coverage that the ground sampling cannot replicate. In addition, the imagery is acquired within a few hours in each year, thus valid comparisons may be made between widely spaced areas of the mine, a feature that is not easily replicated in ground surveys.

The strength of ground surveys lies in its level of detail. The strength of the airborne surveys lies in its synoptic coverage of the entire mine site. We believe that the two methods complement each other, and that a very effective monitoring program can be

² As observed during Borstad’s visit in 2003: Biosolids were applied in 2003, and area had been reseeded.

devised utilizing a combination of the two methods. To take full advantage of the airborne data, we suggest the following steps be incorporated into the program:

- use of the airborne imagery to aid in the selection of sampling plots for new treatment sites, and
- extraction of statistics similar to those presented in section for all ground treatment sites.

The first of these strategies will help to ensure representative sampling at each site, and may permit a decrease in number of ground samples to ensure good coverage of important sites. More importantly, the second will assist in the interpretation of ground data by providing temporal continuity for the entire mine, showing the trends in vegetation even at sites during the years when sampling was not conducted. It will also supplement the ground data in the evaluation of reclamation treatments.

Finally, the airborne data could be used as a basis upon which to build a GIS-like database incorporating both air and ground data. Such a database would provide a useful tool in reclamation management. If required, the time series could be extended to earlier years using Landsat imagery. Landsat TM has an archive extending back to 1984 and Landsat MSS to 1972 for Highland Valley Copper. The spatial resolution of these sensors is less than our airborne imagery, and the spectral bands are more limited, but our analysis (Borstad Associates Ltd. 2005) suggests they are adequate for vegetation assessment.

REFERENCES

- Borstad, G. A., M. Martínez, H. Larratt, M. Richards, L. Brown, R. Kerr and P. Willis. 2005. Using multispectral remote sensing to monitor aquatic vegetation at a reclaimed mine site. Presented at the 29th British Columbia Mine Reclamation Symposium, Abbotsford, BC.
- G.A. Borstad Associates Ltd., 2005, "Multispectral mapping of reclaimed areas: extended analysis of the 2003 imagery", Highland Valley Copper 2004 Annual Reclamation Report, Vol. II Rep. 8.
- Richards, M., M. Martínez de Saavedra Álvarez, and G. A. Borstad, 2003. The use of Multispectral Remote Sensing to Map Reclaimed Areas at Highland Valley Copper," Presented at the 105th CIM Annual General Meeting, Montreal, QC, 2003.
- Richards, M., G. A. Borstad, and M. Martínez de Saavedra Álvarez, 2004. Use Multispectral Remote Sensing to Monitor Reclamation at Highland Valley Copper," Presented at the 28th British Columbia Mine Reclamation Symposium, Cranbrook, BC.