Hyperspectral remote sensing is the acquisition of electromagnetic data from an aerial platform, which goes beyond the wave-lengths of visible light, for the application of isolating certain target features on the Earth’s surface. Essentially, it is a remote (usually airborne) survey of electromagnetic energy from the Earth, which can be used to identify environmental features and pollutants. Historically, the application of hyperspectral remote sensing techniques in South Africa has been limited; partially due to the fact that the science is relatively new, and the data sets are massive requiring advanced processing power.

The advantages of using this technology for environmental analyses are numerous; it offers scientifically defensible analyses, at a snap-shot in time (providing historical proof). It can deliver results analysing large tracts which would be difficult to cover accurately via fieldwork, and with a lower relative cost implication. Hyperspectral remote sensing is a rapid method to assess many aspects of the natural environment and can be used over longer periods of time to identify environmental changes in natural ecosystems and man-made systems, based on visual, chemical and mineral aspects. It can be successfully utilised by organisations to help meet their environmental legislative requirements, reduce overall environmental liability and save costs.

The technology was used for an environmental application in coal mining in South Africa in 2011 by Digby Wells Environmental and Southern Mapping (in partnership with SpecTIR) for Xstrata Coal, when a hyperspectral remote sensing pilot project was carried out on a portion of Xstrata’s operations near Emalahleni. The pilot project was deemed an overall success; thus, a comprehensive hyperspectral remote sensing project for all of the collective Xstrata operations in the Emalahleni area was initiated in 2012. The aim of this comprehensive project was to utilise state-of-the-art hyperspectral remote sensing technology to detect aspects and capture data pertaining to: hydrocarbon spillages at the mine operations; alien vegetation including blue gum and black wattle; and to establish vegetation health responses on rehabilitated areas.

Methodology
An aerial survey was conducted between 15 and 17 November 2012 by Digby Wells Environmental and Southern Mapping (in partnership with SpecTIR) which entailed the acquisition of 360 bands of electromagnetic energy in the near-infrared (NIR) and short wave infrared (SWIR) portions of the electromagnetic spectrum (450 nm – 2500 nm). The data collected were orthorectified and output into a hyperspectral “data cube”. The hyperspectral data cube essentially contains an image layer per wave length band at nominal 5 nm intervals making up a total of 360 suitable bands for analysis. Image pixels were
extracted from the data cube using spectral signatures collected in situ with a handheld spectrometer. The extracted data was then interrogated in a GIS (geographic information system) environment. Once the hyperspectral data had been interrogated and interesting patterns or anomalies observed; two field visits were carried out in order to verify and further investigate the hyperspectral findings.

Findings and applications

Alien vegetation

The alien vegetation data that was acquired using hyperspectral remote sensing techniques proved to be very useful as an indicator tool to identify eucalyptus spp. (blue gum) and acacia mearnsii spp. (black wattle) stands. Stands of blue gum and black wattle were successfully recorded, while single trees were slightly more inconspicuous within the hyperspectral data. There were only two cases of false positive classification of alien vegetation within the hyperspectral data; these cases occurred due to the presence of tracts of wet ground that confounded the hyperspectral signature for black wattle. Omitting the lack of sufficient signal from the hyperspectral data for single trees or exposed tree canopies smaller than 7m², the hyperspectral data was estimated to have a mapping accuracy of 95% after ground truthing activities were translated into a standard error matrix. An example of alien vegetation distribution mapping is shown in Fig. 1.

The intermittent mapping of vegetation species of interest using hyperspectral remote sensing can serve as a useful tool to visualise spatial-temporal relationships. Fig. 2 shows the comparison of a particular stand of blue gum that was mapped during the 2011 Hyperspectral Remote Sensing Project to the very same stand that was mapped in 2012. The aerial photographs show how the extent of the stand has decreased from one year to the next. The two hyperspectral data layers (2011 and 2012) for blue gum correlate with their relevant aerial images; there are fewer features (polygons) for that particular stand within the 2012 blue gum data set than there are in the 2011 blue gum data set due to the active alien vegetation clearing program at the site. This application illustrates how alien eradication programs’ effectiveness can be measured over time.

Since the hyperspectral data products are output in a GIS format, the alien vegetation areas can be further measured and compared. Such statistics, which are measured over such a large area of land, would be difficult to determine in the same time frames without the application of hyperspectral remote sensing. Alien eradication and management plans can be formulated implemented and monitored, targeting those areas or operations that have a higher infestation of alien vegetation.

Hydrocarbons analysis

The hydrocarbon analysis focussed on the search for hydrocarbon spills (oil and diesel). The results of the hydrocarbon analysis were stratified into low probability, medium probability and high probability classes. "False positives" were identified within the hydrocarbons layer due to the fact that hydrocarbon signatures are the same for oil, petroleum, and derivatives of these materials such as plastics and oil based paints. These "false positives" included plastic water tanks, construction plastic and oil-based paint

Fig. 2: Temporal change of a blue gum stand (decrease over time).

Fig. 3: Hydrocarbon Occurrence Probability Map.
that is used on vehicles and on roof tops. Where obvious, the pseudo “false positives” (building roofs and cars) were manually removed from the final output hydrocarbons vector layer so as to report a more accurate estimate on hydrocarbon spillage areas. The final layer is however likely to include plastic wastes and can therefore be used as an indicator tool to locate areas where oil spills have occurred or where oil is being stored or disposed of in a concerning manner, and also to pinpoint areas that might require other forms of simpler clean-up; such as collecting and disposing of plastic litter.

A typical hydrocarbons probability map is shown in Fig. 3.

Once again, these statistics cannot be perceived as the absolute truth, but give an indication as to where hydrocarbon spill and waste clean-up management efforts need to be directed over a large piece of land.

**Normalized Difference Vegetation Index**

A Normalized Difference Vegetation Index (NDVI) essentially exploits the fact that the more chlorophyll in the leaves of plants the higher the infrared reflectance and the higher the productivity of the plant. Derived from the red and infrared wavelength bands, the NDVI layer is a coarse index which can be quickly and usefully applied as a tool for assessing the relative health responses of the rehabilitated mining areas. An example of an NDVI map is illustrated in Fig. 4.

The NDVI layer is not only effective for monitoring the progress of rehabilitated areas over time, but is also beneficial when anomalies are observed within the layer. An example of this application was noted when a ground-truthing timeline transect was conducted from the south-western to the north-eastern corner of a rehabilitated mining area, which effectively allowed three consecutive years of rehabilitation to be assessed from 2009-2011. One would expect a steadily decreasing NDVI through the rehabilitation timeline since the vegetation in the areas that were rehabilitated earlier in the timeline have had more time to establish itself in terms of building biomass. However, the area that was rehabilitated in 2009 proves to have the lowest NDVI out of all three of the sequentially rehabilitated areas, as seen in the Fig. 5. This anomaly can be explored further to determine the cause of this trend; the rehabilitation methods, maintenance protocols or seed mixes used might have varied between years, resulting in the variation in rehabilitation effectiveness. There are a number of factors that could be explored further, but hyperspectral remote sensing has shown that the rehabilitation efforts from 2009 are not as effective as those of 2010.

**Lessons learnt and way forward**

Although the results, in their rawest form, were presented as findings of the study, in order to experience the maximum benefits of applying hyperspectral remote sensing techniques, this data needs to be interrogated further and exploited by the relevant environmental officers. Interesting patterns, such as the success and failure of rehabilitated areas throughout the timeline will be analysed in the form of follow-on studies.

The application of this science is relatively novel and it is important to document the lessons learnt from each project in an attempt to adapt and refine the process. It is important to note that the entire process, from data acquisition to mapping of results, takes a period of time, dependant on the size of the area analysed. It is also important to remember that
the data, once it has been processed, might need to be refined and checked to display practical results that are relevant and specific to the project. Since hyperspectral remote sensing techniques are effective for assessing or monitoring spatial-temporal environmental patterns, it is important to carry out data acquisition processes at the same seasonal time each year (or monitoring period) when aspects such as relative NDVI are of interest. If data is acquired at different times of the year, the changes in the NDVI layer might simply be mapping changes in vegetation health due to seasonal variations. There is still a fair amount to learn about the application of hyperspectral remote sensing techniques for environmental monitoring. Those organisations that are willing to explore and apply progressive techniques, such as hyperspectral remote sensing, are being recognised for their innovation in the field of environmental monitoring and planning. Xstrata Coal Group Services has been recognised as an industry leader in utilising this technology for environmental monitoring, and has been in receipt of numerous environmental awards for their efforts.

In a world where scientific research is being revolutionised on an almost constant basis, it is important to apply this research in real-world and practical situations. In doing so, failures and successes are documented and techniques are adapted and refined to close the daunting gap between scientific research and implementation.

Acknowledgements
We would like to thank Xstrata Coal for permission to use project material in this case study.

Contact Bradly Thornton, Digby Wells Environmental, Tel 011 789-9495, bradly.thornton@digbywells.com or Alex Fortescue, Southern Mapping Company, Tel 011 467-2609, alex@southernmapping.com.