

# USE OF GIS AND MULTITEMPORAL IMAGING SPECTROMETER DATA FOR MODELLING AND MAPPING ENVIRONMENTAL CHANGES IN MINING AREAS

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## ABSTRACT:

Deep hard coal mining activities lead to land subsidence, resulting in infrastructural influences and hydrological changes. In the case of underground mining, a dislocation zone which transforms in the upward direction into flexure of the strata occurs directly above the mined area. A depression is formed on the surface. The shape of this depression depends on the structure of the deposit, mining parameters and the overlaying geology. Spatial and temporal influences of the environment result from the amount of subsidence, the local ground-water situation and actual land-cover and land-use. An important factor is the intensity of impairment regulated by properties of the local soil and vegetation data. To estimate changes of the dynamic system "subsidence-ground-water-vegetation", ground-water recharge rate and isobars of the ground-water table were calculated in detail for a small-parcelled area of 110 sqkm using a GIS. Because of the large extent of the area to be monitored, airborne surveys were done in August 1998 and in August 2000, using the HYMAP™ imaging spectrometer to detect affected vegetation stands.

## KURZFASSUNG:

Untertägiger Steinkohlenbergbau führt zu Bodenbewegungen an der Tagesoberfläche. Diese führen zu Beeinflussungen der Infrastruktur und zu Veränderungen der hydrologischen Situation. Durch die großen Teufen, in denen der Abbau stattfindet, erstrecken sich die Gebirgsbewegungen innerhalb bestimmter Grenzwinkel trogförmig über weite Bereiche an der Tagesoberfläche oberhalb des Abbaus und es bildet sich eine Senkungsmulde. Die Ausprägung ist abhängig von der Lagerstätte, Abbauparametern und der lokalen Geologie. Eine räumliche und zeitliche Beeinflussung der natürlichen Umwelt erfolgt aufgrund der auftretenden Senkungsbeträge, der lokalen Grundwassersituation und der aktuellen Landnutzung und Landbedeckung. Die Intensität der auftretenden Beeinflussung an einem Standort wird durch Parameter des Bodens und der Vegetation gesteuert. Um bergbaubedingte Veränderungen in dem dynamischen System „Senkung-Grundwasser-Vegetation“ erfassen zu können, wurden für ein 110 km<sup>2</sup> großes Untersuchungsgebiet GIS-gestützt die Grundwasserneubildungsrate und die Grundwasserflurabstände berechnet. Aufgrund der Größe des Untersuchungsgebietes wurden im August 1998 und 2000 Befliegungen mit dem bildgebenden Spektrometer HYMAP™ durchgeführt, um Veränderungen der Vegetation zu erfassen.

## 1. INTRODUCTION

Underground mining activities lead to subsidence and ground movements at the topographic surface. The present and future modifications of the topographic situation lead impairments of the infrastructure and to a permanent influence of the technical infrastructure as well as changes of hydrological and ecological parameters.

The management of mining activities has to be done in a dynamic way, due to be bound to deposit structures and geological structures. Present procedures for environmental monitoring are based by predeterminations of rock mechanics of the overlaying strata, topographic measurements done with photogrammetric measurement techniques and upon calculations of three-dimensional stationary ground-water models. Since these different data layer are present only to discrete times and in different scales, a consistent description of the effects and the prognosis of future modifications are severely limited.

Therefore space and time-variant models are necessary, which can describe measured variables and resulting influences related to the considered geo-system. This is the prerequisite to detect relevant ecologically effects and to control and simulate administrative measures. Because of the large extent of the affected area and the small-parcelled landscape structure, only a detailed

monitoring concept together with GIS modelling techniques and high resolution imaging spectrometer data permit an appropriate way to update the large GIS database and to fulfill legal demands.

## 2. MINING IMPACTS

In the case of underground mining, a dislocation zone which transforms in the upward direction into flexure of the strata occurs directly above the mined area. A depression is formed on the surface. The shape of this depression depends on the structure of the deposit, mining parameters and the overlaying geology. Depending on the thickness of the overburden and the extent of the mined area, the surface impacts start to occur after around six months. At the end of approximately two years, around 80 % of the maximum anticipated depression has occurred, and the final condition is achieved after more or less five years.

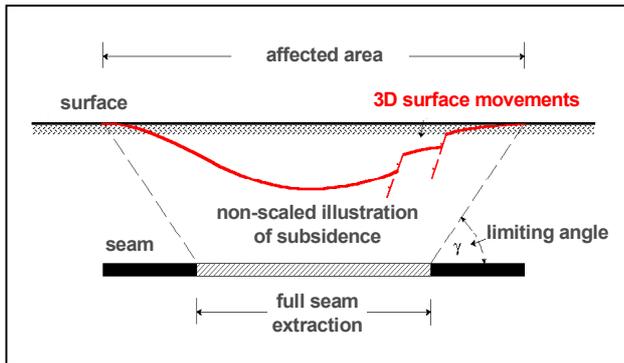


Figure 1: 3D-movements caused by mining activities

### 2.1 Surface Movements and Hydrological Parameter

The consequences of the extensive depression are changes in hydrological and associated ecological parameters. Such changes include alterations in the surface and underground catchment areas of individual watercourses and also in their geometry. The resultant changes affect the runoff, sedimentation and erosion conditions in watercourses. The impacts on the groundwater produce an extensive alteration in the spatial location and deformation of the groundwater-conducting strata ("aquifers"), and thus changes in the groundwater divides, as well as in directions and rates of flow. Locally, new isobars of the ground-water tables can occur. Changes to watercourses can be adjusted locally by means of constructional provisions, whereas the registration and evaluation of extensive changes in the groundwater situation is possible only by GIS-related modelling techniques based on accurate digital terrain models and ground-water models in particular. The intensity of the influence of a regarded surface is steered by its position in the relief and by the local characteristics of soil and vegetation (Drecker, et. al., 1995).

### 2.2 Monitoring

Depending on the mine site situation these investigations may cover an area of nearly 100 sqkm. Together with calculated and predicted surface movement data, resting upon current extraction plans, this information is of fundamental need for the individual monitoring concept for each mine site. During the mining process, extraction plan data and predicted surface movements have to be updated at several times. Therefore even the calculations of the resulting influences have to be updated. Considering the character of the effect forecast as a whole, the complete assessment area of the environmental compatibility survey must be monitored over a period of at least 20 years in order to verify determined forecasts.

The monitoring of terrestrial areas normally takes place at 2- to 5-year intervals. For this characteristic test sites were chosen, which describe the natural diversity of the area under investigation. Based on parameters derived from soil samples and different vegetation parameter an individual code is defined, which describe the ecological situation found on different areas. On these long-term monitored test sites, the biotope will be mapped regularly to determine the extent of the areas with undergoing change.

## 3. GIS Modelling

To monitor predicted movements high resolution digital terrain models (DTM) are generated at regular intervals based on photogrammetric surveys. A two-stage procedure was developed in respect to the accuracy of the DTM. The first step is to measure a regular grid, whereby the mesh size depends on the exactness of the approximation of the terrain. This DTM, initially roughly structured, is suitable for a first calibration of the ground water model. In order to reproduce the morphology of the terrain surface, the next stage involved the measurement of additional stations along breaklines. This results in a detailed DTM covering the whole area.

The description of the ground-water flow for these areas can only be described with the help of numeric ground water models (GWM). To consider the pre-calculated amounts of subsidence in the GWM, the DTM updated by the subsidence values is used. This procedure leads to a direct entry of the influences caused by subsidence on the hydrologic parameters and enables the calculation of modifications of the ground-water situation. An important factor is the intensity of impairment regulated by properties of the local soil and vegetation data. To estimate changes of the dynamic system "subsidence-ground-water-vegetation", the ground-water recharge rate and isobars of the ground-water table are calculated in detail for a small-parcelled area of 110 sqkm. This was done for 1993, referring as a starting point of influence and for 2004 as a prediction. Additional data based on a current excavation plan with resulting subsidence data for 1998 and for 2000 were considered.

## 4. HYPERSPECTRAL SURVEY

Because of the large extent of the area which has to be monitored, actual research focuses on digital image processing techniques to derive information of the actual land-use and land-cover. Therefore, airborne data recording was done in August 1998 using the HYMAP™ imaging spectrometer. A second airborne survey was done in 2000 again with the HYMAP™. At the same time, detailed field surveys were carried out. Field measurements included spectroradiometrical data needed for the atmospheric correction of the hyperspectral data. Additional measurements of the leaf-area-index of specific plants were done in several subareas. The main emphasis of these investigations is the connection of calculated changes in periled areas and hyperspectral data features.

### 4.1 HYMAP™ Technical Parameter

The imaging spectrometer HYMAP™ has been developed for geological remote sensing applications. The system is built up in a modular manner which can be used in the most different fields of application. During the two flight campaigns in 1998 a subset of approx. 56 sqkm and in 2000 the whole area of 120 sqkm was recorded. The ground instantaneous field of view (GIFOV) was 7m in 1998 and a 5m in 2000 respectively. The Table 1 below shows the general features of the HYMAP™ system (Cocks, et. al., 1999, Integrated Spectronics, Pty. Ltd. 2002).

|   |   |
|---|---|
| <b>spectral range</b>                       | visible, near infrared, middle infrared |
| <b>number of channels</b>                   | 100 - 200                               |
| <b>spectral resolution</b>                  | 10 - 20 nm                              |
| <b>GIFOV</b>                                | 2 - 10 m                                |
| <b>aperture angle</b>                       | 60 - 70°                                |
| <b>signal to noise ratio</b>                | > 500:1                                 |
| <b>operation altitude (above sea level)</b> | 6.000 - 15.000 ft.                      |

Table 1: HYMAP™ technical features

## 4.2 Ground Reflectance Measurements

During the HYMAP™ data acquisition field spectra from selected representative targets were taken. Therefore a FieldSpec Pro FR from ASD Inc., operated by the GeoForschungsZentrum Potsdam (GFZ) was used. Additionally a Mark V from GER Inc., operated by the Federal Institute for Geosciences and Natural Resources (BGR) was used during the flight campaign in 2000.

|                     | <b>ASD FieldSpec FR</b>                | <b>GER Mark V</b>  |
|---------------------|--|--|
| Spectral range      | 350 - 2500 nm                          | 385 - 2548 nm  |
| Spectral resolution | 1,4 nm@350-1050nm<br>2 nm@1000-2500 nm | 4 nm@385-1050nm<br>14 nm@1050-1785nm<br>23 nm@1785-2548 nm |
| scan time           | 0.1 seconds                            | 60 seconds.  |

Table 2: Technical parameter of the ASD and GER portable field spectrometer

## 5. IMAGE PROCESSING

### 5.1 Preprocessing

The signal recorded by an airborne optical sensor is influenced by several components during the radiation's way from the sun to the ground and back to the sensor. The main influences include varying atmospheric conditions and variations of the sun-sensor-geometry. This modifies the reflectance values of the observed ground features. Especially for quantitative analyses and change detection applications with images from different times and sensors the atmospheric correction is an essential part of preprocessing and a prerequisite for the derivation of products needed for the subsequent image processing and analysis steps.

Atmospheric correction was done using the ATCOR-A and the newer version ATCOR-4 software package (Richter, 1996; Richter, 1997), which is commercially available. To model different atmospheric conditions it uses the look-up tables from MODTRAN (Berk, et. al., 2000). The atmosphere is modeled thereby a number of layers, whose layer boundaries can be parameterized. Standard atmosphere profiles describe different atmospheric conditions for different climate zones and seasons. The given values for a parameterization of different atmosphere layer (pressure, temperature, water vapor content) can be replaced by measured values. Additionally different aerosol models can be selected. Apart from a consideration of the spatial variability of atmospheric conditions differences in illumination within a scan line can be considered. Figure 2 shows the result of corrected spectra from the data flown in 2000 using AT-

COR4. Darker columns show wavelengths which are strongly affected by absorption of atmospheric water vapor and CO<sub>2</sub>.

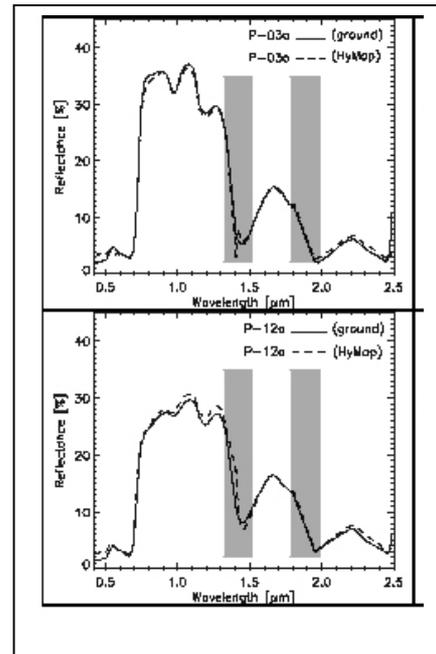


Figure 2: Comparison of ground reflectance spectra and corrected HyMap™ spectra.

The deviation of ground measured reflectance and retrieved reflectance is less than 3% in our case (Figure 2), except for the few HYMAP™ channels with noise problems and the regions of strong water vapour absorption.

### 5.2 Vegetation Analysis

First image processing steps of the HYMAP™ data lead to the detection of open water pits at different locations within the flown area. These locations occurred at places where ground-water table changes were calculated (Figure 3 at point 6.)

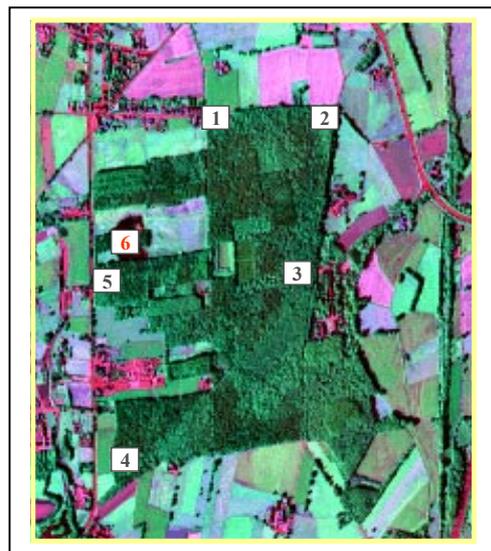


Figure 3: Subset with open water logging, point 6

This location is stocked with beech and oak. This mixed forest stand is represented with approximately 3% at the entire forest and tree species in the investigation area. On similar stands at different locations spectra were entered and compared with a representative spectrum of the influenced stand. To derive first qualitative information following parameters were calculated to compare forests stands on different locations.

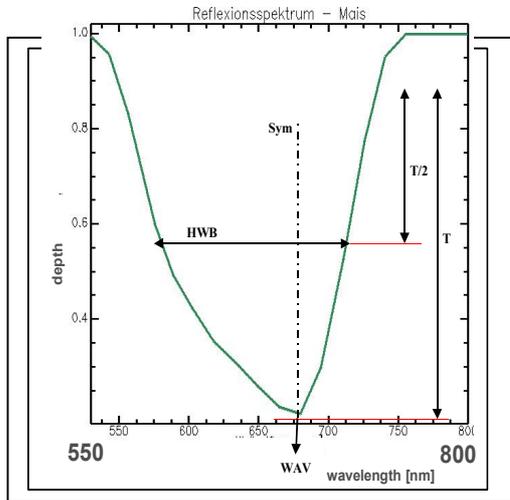


Figure 4: Schematic illustration of different parameter from normalized reflection spectra in the range between 550 and 800 nm.

This procedure was applied by Singhroy & Kruse (1991) to analyses reflection curves of different vegetation stocks and local mineralogical conditions. On the basis of laboratory analyses a connection between chlorophyll content of the plants and different concentration of different metal ions at the locations could be calculated. Further investigations (Clark, et. al., 1995; Koklay, et. al., 1999) improved these investigations and show that these analyses allow the discrimination of individual stands in terms of vitality. Table 3 shows the results for the affected location no. 6.

|            | loc 5  | loc 6  | Change      |
|------------|--------|--------|-------------|
| <b>HWB</b> | 167.0  | 136.88 | <b>20 %</b> |
| <b>T</b>   | 0.98   | 0.89   | <b>10 %</b> |
| <b>WAV</b> | 679.88 | 665.0  | <b>3 %</b>  |
| <b>Sym</b> | 0.38   | 0.27   | <b>30 %</b> |

Table 3: Calculated Reflectance parameter from different locations

In a further step, it was verified if effects could also be detect on locations affected by a modification of the local soil water situation. The analyses are based upon different corn parcels mapped in the area under investigation, for which reference data were raised. This procedure was selected, since this type of vegetation was regarded as homogeneous, so that occurring modifications are not due to the natural variability, as for example with mixed woodland. Therefore a spectral library of different endmember associated with different stages of vitality of the corn fields was set up. Spectral unmixing procedures in conjunction with a subpixel analysis led to a significant improvement of the correlation between features of the hyperspectral data and the raised reference data. On the base of the correlation between derived endmember and measured leaf-area-index

values (LAI) determinations of the LAI values for all corn fields were possible. The following Figures 5 and 6 show the calculated correlation between endmember values and LAI values measured within the field survey.

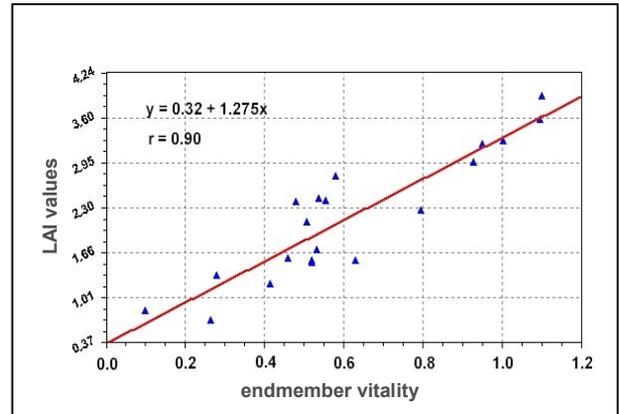


Figure 5: Relationship between measured LAI and derived endmember describing vital vegetation

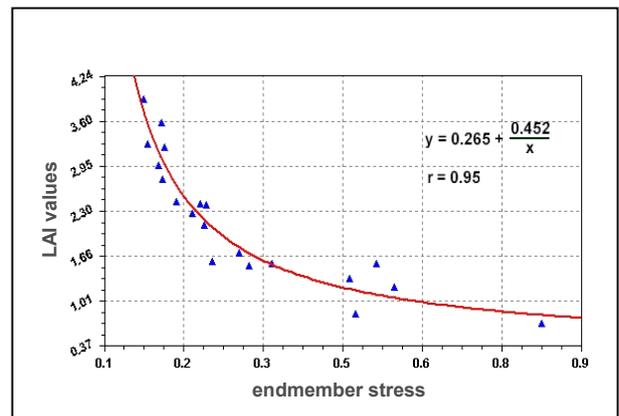


Figure 6: Relationship between measured LAI and derived endmember describing stressed vegetation

## 6. CONCLUSIONS

The high geometrical and spectral resolution of the data allows the detection of locations with mining affected changes of hydrological parameter and corresponding influences of different vegetations stands. At present there these investigations seem to be a methodological alternative to large scale field mapping procedures, which has a comparably potential of automation. Since the presented procedures for the analysis are based on derived parameters of the reflection signatures, the development of change detection routines for time series analyses are plausibly feasible. This is a crucial step to develop methods for efficient long-term monitoring procedures that become part of the GIS.

## 7. RESEARCH

Ongoing research is actually done within two projects:

- “Monitoring and assessment in the environmental Impact of mining in Europe using advanced Earth Observation techniques” (MINEO). This project is financed by the EU Commission, DG XIII-B4, reference-no.: IST-1999-10337, term: 01/2000-12/2002, (<http://www.brgm.fr/MINEO>).
- “Development and application of geoinformation to analyse impacts, predictions and management of anthropogenic influenced processes in geosystems“ – sub-project: “Analyses of landscape-ecological changes caused by dynamic surface movements resulting from mining activities”, DFG-ID: BU 1283/3.

This project is part of an interdisciplinary research project, carried out together with the Institute of Computer Science of the University of Hamburg and is supported by the German Research Foundation (Deutsche Forschungsgemeinschaft, DFG). The focus of this project is to model the dynamic impacts of the hydrological balance caused by subsidence within an object-oriented database. This database will be the core of a time- and scale-dependent simulation tool. The aim is the development of a 4D software environment.

## REFERENCES

- Berk, A. et al., 2000. Modtran 4 User Manual, Air Force Research Laboratory, Hanscom, MA, USA.
- Clark, R., et al., 1995. Initial vegetation species and senescence/stress mapping in the San Louis Valley, Colorado using imaging spectrometry data. In: Posey, H. H.; e.a. (Ed.): Proceedings of the Summitville Forum '95. Colorado Geological Survey, Special Publication No. 38. Boulder, pp. 59-63.
- Cocks, T., et al., 1999. The HYMAP™ Airborne Hyperspectral Sensor: the system, calibration and performance. In: Schaepmann, M., e.a. (Ed.): *1<sup>st</sup> EARSeL Workshop on Imaging Spectroscopy*, 6<sup>th</sup>–8<sup>th</sup> Oct. 1998, Zürich, pp. 37-45.
- Drecker, P., et al., 1995. Subsidence and wetland development in the Ruhr district of Germany. In: Barends, F.; e.a. (Ed.): *Land Subsidence*. Proceedings of the 5<sup>th</sup> Int. Symp. on Land Subsidence, The Hague, Oct. 1995, IAHS Publications No. 234, pp. 413–421.
- HYMAP™ 2002: Integrated Spectronics Pty. Ltd., <http://www.intspec.com> (accessed 12. March 2002).
- Koklay, R.; Clark, N., 1999. Spectroscopic Determination of Leaf Biochemistry Using Band-Depth Analysis of Absorption Features and Stepwise Linear Regression. In: *Remote Sensing of Environment*, 67(1), pp. 267–287.
- Richter, R., 1996. A Spatially-Adaptive Fast Atmospheric Correction Algorithm. In: *International Journal of Remote Sensing*, 17(6), pp. 1201-1214.
- Richter, R., 1997. Correction of atmospheric and topographic effects for high spatial resolution satellite imagery. In: *International Journal of Remote Sensing*, 18(5), pp. 1099- 1111.
- Singhroy, V. H.; Kruse, F., 1991: Detection of metal stress in boreal forest species using the 0,67 µm chlorophyll absorption Band. In: *Proc. 8th Thematic Conference on Geologic Remote Sensing, Exploration, Engineering and Environment*, Denver, 29 April – 2 May 1991, pp. 361-372.

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