Remote Surveillance of Mineral Extraction Discharges

National Centre for Environmental Data and Surveillance

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Statement of use
This report concludes that a combination of airborne spectrographic imaging and photography can identify surface water, treatment processes and discharges to water courses in open cast coal workings.

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EXECUTIVE SUMMARY

The application of remote surveillance to the identification of polluted discharges to controlled waters arising from major civil engineering works was investigated in this scoping study. A combination of spectral imaging and aerial photography was able to identify water treatment processes and discharges to watercourses to a similar degree of effectiveness to personal inspection, but could not improve on it. The technique would therefore be most appropriate to overview large sites that are not routinely audited by ground-level inspection. This may limit its usefulness to some extent but it nonetheless can perform well in this overview role. Remote surveillance mapping of stressed vegetation was shown to be a useful adjunct to the identification of contaminated land and, by implication, the extent of contamination of its associated surface water. The study indicated that a more intensive interpretation of remote imaging spectra together with the use of other GIS-based techniques may further improve the potential of remote surveillance to detect contaminated land, and this approach is recommended for further investigation.

ACKNOWLEDGEMENTS

The evaluation and interpretation of surveillance data by site inspection officers was an important contribution to this project, and the assistance of the inspection staff at Orgreave and Ffos Las is gratefully acknowledged.

1. INTRODUCTION

Civil engineering projects that involve redistribution of large quantities of soil and rock can give rise to new and transient discharges to controlled waters. These transient discharges are prone to contain suspended solids which may be contaminated by adsorbed pollutants or dissolved pollutants arising from the large scale earth moving processes. The settlement of suspended solids on river beds can have a significant impact on fish spawning grounds, and sediment deposition in rivers can lead to silted watercourses with increased concentrations of any adsorbed pollutants. Consequently, where large earth moving processes are planned, the potential discharges need to be identified and programmes set up to uprate the water quality through settlement and appropriate treatment. If entering controlled waters the discharges will need to be consented with an associated programme of regular inspection and monitoring. Audit of these large and rapidly changing construction sites requires a significant level of highly experienced inspection staff resource.

Remote surveillance using airborne imaging equipment can provide information on broad areas of land, and the spectral data comprising the images can be processed to highlight surface water, to estimate suspended solid pollution in surface water, and to identify some forms of land contamination as an indicator of the likelihood of dissolved pollutants in the water. Although remote surveillance has no previous history of being used to inspect transient discharges to watercourses it may have potential to provide a broad synoptic overview, not as a replacement for personal site inspection, but to provide information to assist staff in planning an inspectorate strategy for a particular site by, for example, enabling key discharge routes to be more effectively targeted and scrutinised.

The purpose of this project is to scope the potential of remote surveillance to overview problems that large earth moving activities place on watercourses, and provide a set of tools that inspection staff can use as appropriate to manage their audit activities more effectively.

2. PROJECT DESIGN

Three sites involving large earth moving operations were chosen for study; Orgreave open cast coal mine in South Yorkshire, Ffos Las open cast coal mine in South Wales and the Newbury by-pass road construction in Berkshire. Of these, Orgreave was by far the largest excavation. Each site was overflown once with remote surveillance equipment during March 1997. This time schedule was determined by the overall project plan to give a high likelihood of high rainfall and consequently high discharge to watercourses; although the month was in fact characterised by low rainfall, particularly in Berkshire.

Three types of surveillance imaging equipment were used, visible and near infrared spectral data, thermal imagery and aerial photography. These were selected as a result of a literature review of remote surveillance publications, which indicated that vegetation stress (and by implication pollutants that may give rise to vegetation stress) can be inferred from CASI imagery, landfill leachate "hot spots" may be thermally imaged because of their higher temperature, and aerial photography to provide ground cover detail. Environment Agency inspection staff for the sites evaluated the remote surveillance information in context of their specialist local knowledge. From these evaluations, judgments were made on the effectiveness of remote surveillance to identify the discharges, the extent of treatment processes provided (ie settling tanks, lagoons, channels etc) and the likelihood of contamination in the surface water.

3. REMOTE SURVEILLANCE TECHNIQUES

The three different imaging sensors used in one aircraft comprised of a CASI (Compact Airborne Spectrographic Imager) which captured electromagnetic radiation in the visible to near infra-red spectrum as separate wavebands, a digital thermal sensor which recorded emitted far infra-red radiation as a broad waveband and a Hassleblad aerial camera which took high resolution, true colour photographs.

The spectral data from the CASI and digital thermal sensors were both corrected for first order distortions such as aircraft roll using the onboard gyroscope information. GPS data collected every second enabled the images to be fully georeferenced and orientated to the British National Grid. For further spatial analysis the image data could then be imported and manipulated as an additional layer within a Geographical Information System.

These three sensors provide different but complementary data on the physical state of the land around and within the sites, and the CASI spectral data in particular could be processed in a number of ways to provide information on the chemical composition of the surface layer and some indication of the composition of the sub-surface. Details on the sensing techniques are given below.

3.1 Compact Airborne Spectrographic Imager

The CASI data used in this project were configured as 15 channels of radiance recorded in a selection of wavelengths between 420-920 nm. Overview flight lines over the works areas were flown at 10,000ft with a narrow width lens giving a spatial resolution of 5m. Lower altitude flights over the mine sites gave more detailed 1m resolution data.

True colour CASI composites were generated by combining channels from the blue, green and red visible wavelengths in the blue, green and red display to give images which were as close to the colours seen by the human eye as possible. However, the range of wavelengths comprising these visible images contain a wealth of information on the composition of the land surface and the condition of the vegetation growing on it, and the true potential of the system is seen when these hidden trends are visualised in false colour or selectively enhanced using channel ratios. For example, vegetation can be highlighted on the composite image in shades of red by using a near infra-red band in the red display and red and green visible wavebands in the green and blue display. Procedures for highlighting two land characteristics of particular relevance to this study, surface water and contaminated land inferred from stressed vegetation, are given below.

These examples illustrate that although reflected light forming the image only penetrates the outer atomic layers of the ground surface, to two nanometres depth at the most, interpretation of the characteristic reflectance of different wavelengths of light can sometimes provide information on the composition of the material a metre below the surface.

3.1.1 Identification of Surface Water

The characteristic spectral profile of water (see diagram 1) is a moderate radiance in the visible blue/green wavelengths and a very low near infra-red radiance. Wavelengths above 700nm are generally absorbed unless there is reflectance from suspended sediment or the bottom surface, both of which tend to increase radiance in the near infra-red and visible wavelengths. In order to selectively highlight areas of water in an image a ratio of green to near infra-red wavelengths can be used:

(Green / NIR) *n

where n is an empirical multiplicand for appropriate colour scale

This ratio identifies clear water pixels in an image by their very high values, shallow water or turbid water would have less high values whereas terrestrial cover would have clearly separated moderate to low values. An empirically selected ratio can thus enable the image to be thresholded to separate land from water, and the water areas can be assigned a false red colour for easy visual identification.

Water containing sediment has increased blue, red and NIR radiance (see diagram 1) as well as a prominent peak in the 550 nm region. These other wavelength absorptions could be exploited to develop algorithms to assess the suspended solids content of the water, but the opportunity to evaluate this aspect did not arise in this study because no suitable discharges to watercourses with ancillary turbidity analytical data were found.

3.1.2 Identification of Contaminated Land

Areas of land which are contaminated can sometimes be identified by looking at the health and density of the vegetation cover. Pollutants within the soil and ground water will affect vegetation in a number of ways; stunted growth and decreased vigour, chlorosis of leaves, reduction in species and the presence of plant species adapted to grow on polluted land (1,2)

The spectrum of healthy, green vegetation is characterised by a low reflection in the visible blue and red wavelengths and a higher green reflection. In the near infra-red wavelengths the reflectance is significantly higher. When vegetation becomes stressed or senescent reflectance increases in the visible wavelengths and near infra-red reflectance decreases.

The reasons for these characteristic spectral differences are a consequence of the leaf structure as shown in Figure 1 below.

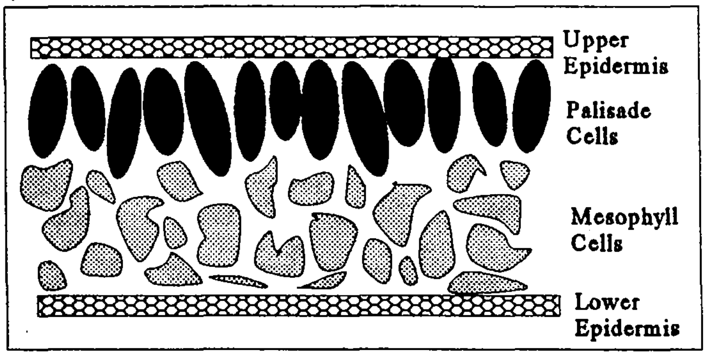

Fig. 1 Cross section of a typical leaf

A typical leaf has a top layer of cells called the epidermis which allows diffusion of much visible light through it. Below this layer are the long, narrow palisade cells containing chlorophyll pigments. These absorb visible light which results in the low reflectance of vegetation in the 350 - 700 nm region An increased reflectance at 550 nm due to chlorophyll causes healthy leaves to appear green. Underneath the palisade cells are the mesophyll cells which reflect around half of the incoming near infrared radiation. An increase in the number of air spaces within this layer results in an increased reflectance in the 700 - 1350 nm region due to multiple scattering within the layer. When the vegetation becomes stressed or senescent a decrease in chlorophyll results in a the green colour becoming masked by blue and red increase. The spongy mesophyll layer also contracts causing the number of air spaces to decrease and near infra-red reflectance by scatter is reduced (3). These changes are shown in diagram 2.

A commonly used procedure for visualising stressed vegetation uses a false colour composite with an infra-red wavelength in the red display. This enhances healthy vegetation in red and sparse/senescent/unhealthy vegetation in oranges and yellows. Another procedure uses a band radio known as the NDVI (Normalized Difference Vegetation Index) to intensify the difference in reflectance between the NIR and red parts of the spectrum:

$$NDVI = (NIR - Red) / (NIR + Red)*n$$

where n is an empirical factor for appropriate colour scale

This results in a single band image where healthy, green vegetation is given high digital numbers (white) and bare ground low digital numbers (black). A pseudo colour table can then be applied to the ratio image, to assign each grey level to colours of increasing spectral wavelength and intensity. This results in areas of bare ground and water being shown in blue and healthy vegetation in red/pink.

3.2 Thermal Sensor

This sensor measures emitted infra-red radiation from the land or water surface as a broad band in the 1000-1200nm range. The system senses relative change in temperature and must be calibrated with reference to an external thermometer, when it is possible to determine temperature variations with a 0.1°C accuracy. In imaging terms white indicates the warmest areas and black the coldest.

The technique has a proven history of visualising discharge plumes to rivers because of their thermal differences to the receiving water, and has reported application to identification of leachate hot spots in landfill sites.

3.3 Aerial Photography

A 70 mm medium format Hassleblad camera fitted with a 50 mm focal length lens was used to provide spatially high resolution photographs of the works areas to complement CASI's high spectral resolution. The camera was controlled by a software system to produce images of known overlap with spectral imagery. The reason for including photography in the array of surveillance techniques is to provide a high degree of surface detail which cannot be achieved by the relatively low spatial resolution of spectral and thermal imaging equipment.

4 ORGREAVE SITE SURVEILLANCE

4.1 Introduction

The Orgreave site is an open cast coal mine located on the outskirts of Sheffield and is shown in overview in Plate 1, together with a location map. The site previously housed a conventional colliery and a coking and gas works. An area of highly contaminated soil around the old gas works site is currently being removed and will be secured in a high density polyethylene containment cell to the west of the works. Contaminated surface water will be treated in an aeration tank containing activated sludge from a sewage works that receives coking/gas works runoff and discharged into the River Rother. Tip washing lagoons in the southerly part of the present workings are used for reprocessing spoil heaps to recover coal.

Coal is extracted by removal of the south east face of the void and backfilling the north west face, thus effectively moving the void to the south east. The remediated land will be then be of high value for development. The site is being redeveloped by R J Budge Mining Ltd and is monitored extensively by Environment Agency water and waste inspectors. Plate 2 shows ground level views of (a) the activated sludge lagoon and (b) construction of the lined contaminated landfill site, to illustrate the scale of the operation.

The site is downstream from the Pithouse West open cast coal site (no longer operated). Further upstream lie the River Rother Woodhouse washland, a sewage works and the Rother Valley Country Park, an amenity area reclaimed from old coal mining and waste sites. The entire area contains many active and old waste sites. The River Rother is extensively canalised with an ox-bow lake (Treeton Dyke) remaining from the old river course now used by the South Yorkshire Boat and Ski Club for watersports.

4.2 Surveillance of Surface Water

Plate 3 shows the site overview imaged at 10000 feet with all areas of surface water identified in red by infra red /visible ratio as described in section 3.1.1 above. Plates 4 to 11 are close up views of the site overflown at 2000 feet. Of particular note are Plate 4 where the sewage works area is expanded to maximum magnification to identify the effluent discharge point, and Plates 9 and 10 which shown the contaminated surface water treatment process and sites of the old gas holders.

Plate 4 illustrates the limitations of resolution when magnifying CASI images, with the "pixilated" appearance of the magnified CASI image clearly shown. Plate 12 is an enlarged photograph of the sewage effluent discharge and clearly illustrates the discharge plume's tendency to follow the east bank of the Rother, possibly as a consequence of the
culvert discharge from the west bank (the report reproduction is less clear than the original photograph). Plates 13 and 14 are photographic views of two features in the water treatment process, the surface water aeration tank and an enlargement of a discharge point (not actually discharging) to the River Rother.

4.3 Surveillance of Contaminated Land

It is not an objective of this project to develop methods of identifying contaminated land per-se, but the identification of contaminated land is a useful adjunct to deciding whether water on *it is* likely to be contaminated. A record of landfill sites was supplied by the Area Hydrogeologist.

Plate 15 is an overview of the Orgreave site with stressed vegetation identified by infra red absorption as described in section 3.1.2 above, with the registered landfill sites superimposed. Plate 16 is the site overview with stressed vegetation identified as an NDVI black and white image, and Plate 17 is the same NDVI image with pseudo colours added as described in section 3.1.2 above.

Plate 18 is the thermal image of the site, with the area presently being worked expanded.

4.4 Evaluation of Surveillance Information by Site Inspectors

The images with surface water highlighted (Plates 3-11) were evaluated by the site's Environmental Protection Officer, Mr J Meynell (4). His opinions were:

(i) all the watercourses and treatment processes have been identified, including the aeration tank to remediate contaminated surface water from the old coking works area;

(ii) there were no discharges to the Rother on the date of overflying and the surveillance report of no identified discharges was therefore correct; and

(iii) the sensitivity of the photographic images in Plates 13 and 14 would be sufficiently discriminating to identify any discharges from the site to the Rother.

Notwithstanding these encouraging results in complete identification of the surface water systems, Mr Meynell wished to emphasise that it showed nothing additional to his present knowledge of the site.

Three imaging techniques were used for contaminated land identification: vegetation stress by near infra-red (Plate 15), vegetation stress by NDVI (Plate 16), vegetation stress by NDVI with false colour enhancement (Plate 17), and thermal imaging (Plate 18). A preliminary comparison with landfill site records established that the thermal images showed no consistent correlation with contaminated land and evaluation of thermal imagery was discontinued. However, it should be borne in mind that leachate visualisation by thermal imagery is best carried out at night, when maximum temperature differential would be expected. Both the near infra-red and NDVI images with colour enhancement showed similar good correlation with landfill site records and, of the two techniques, the near infra-red image was used for detailed evaluation by the site inspector because of its greater similarity to visual appearance.

The near infra-red vegetation stress images were examined with reference to landfill site and contaminated land information by the Agency's Hydrogeologist, Mr F Lowe (5). The interpretation of the images' value for contaminated land application was:

(i) Site No. 1 (in Plate 15) fell within a larger area of disturbed ground. The identified contaminated land had very little vegetation cover giving an overall stressed appearance.

(ii) Site No 2. was an area of reclaimed colliery waste. Where there was vegetation cover it appeared stressed due to the low density of growth.

(iii) Sites Nos. 3 - 6 were old landfill sites and fell within a stressed vegetation boundary.

(iv) Site 7 was a metalliferous waste site from a previous steel works. It was sharply delineated by a sparse vegetation area with a stressed appearance.

(v) Site 8 was an old colliery site containing non-hazardous waste tips. The site was sharply delineated by a lack of healthy vegetation. The landfills within the area were not identified.

(vi) Sites 9 and 10 fell within an overall stressed vegetation area but were not specifically identified within that area.

(vii) Site 11 alone was a landfill site that was covered by healthy rather than stressed vegetation. It was licensed for soil and sub-soil deposition and was closed and covered in the late 80's. It would not be unreasonable for it to show healthy vegetation now.

Mr Lowe's overall opinion was that stressed vegetation imagery was a valuable adjunct to the identification of contaminated land but that it alone does not provide a complete picture of land condition.

There was one apparently stressed vegetation site that could not be correlated with known contaminated land records, the washlands (ie an area designated for winter flooding) to the south of the open cast workings. The history of this location was investigated by Mr Meynell, who established that the area flooded severely in 1958 and a regulator gate was installed, and before that there were small steelworks and fabricators on the land. Since 1958 there have been major flooding events in 1982 and 1986, when the Rother was known to be contaminated. It is possible, therefore, that the washlands area may be contaminated, and the presence of stressed vegetation may well have a contamination cause. The time schedule and budget of this project precluded sampling and analysis of the washland area to clarify this aspect.

One final feature of the vegetation stress imagery was an unusual area in the River Rother Country Park, consisting of a semi-circular stressed vegetation sector bisected by a healthy vegetation strip. A site examination showed the strip to be a grass "ski" slope surrounded by a semi-circle planted with bushes and low trees. Possible explanations for the stressed signal may possibly be either late leaf formation at the date of overflying (on 16 March) or deeper roots of the trees penetrating the cap into the colliery tip material.

5 FFOS LAS SITE SURVEILLANCE

5.1 Introduction

The Ffos Las site is an open cast coal mine to the North West of Llanelli in South Wales, and is shown in overview in Plate 19. A small watercourse has been re-routed around the site and the minewater discharges to the watercourse are identified.

5.2 Surveillance of Surface Water

Plate 20 shows the site overview imaged at 10,000 feet with areas of surface water identified by infra red/visible spectral ratio as described in Section 3.1.1 above. Plates 21 to 24 are close up views of the site overflown at 2000 feet. Plate 25 is an enlargement of discharge points C and G. The images clearly illustrate the difficulty in resolving small discharge streams using CASI imagery. Plate 26 is notable in that it shows an apparent stepwise decrease in suspended solids content in an array of water treatment settling tanks.

5.3 Surveillance of Contaminated Land by Site Inspectors

Plate 27 is an overview of the site with stressed vegetation identified by infra-red absorption as described in Section 3.1.2 above. From the findings of the Orgreave site exercise, NDVI stressed vegetation and thermal imagery were not considered in the Ffos Las site study. Plate 27 indicated a general stressed vegetation appearance in the surrounding countryside, with some evidence of clustering immediately east and west of the site.

5.4 Evaluation of Surveillance Information

The images of Ffos Las were examined by Messrs N Reynolds, A Jones and C Bolton of the Swansea Pollution Control function (6). Their opinions were as follows:

(i) all the water treatment features were identified, but small watercourses were not. There would not be sufficient resolution in CASI imagery to identify illegal discharges, and therefore it could not replace site visits;

(ii) identification of major water treatment features would be of value for sites for which there was limited knowledge, but this information added nothing to present knowledge of Ffos Las;

(iii) the apparently stressed vegetation areas are not recorded as contaminated land, although the east area is a restored open cast working and the west area is proposed for further open cast development and therefore (possibly) may have minerals close to the surface;

(iv) the surrounding countryside is graded as poor agricultural land, providing some support for the overall appearance of vegetation stress; and

(v) the site staff expressed an interest in applying vegetation stress imagery to other stretches in the Area which have a historical association with mineral and metal working.

6 NEWBURY BY-PASS SURVEILLANCE

This area was examined to investigate whether construction sites pose different surveillance problems to open cast workings. However, as shown in Plates 28 and 29, in March 1997 when this work was undertaken the abnormally low rainfall precluded the possibility of transient stream formation. Regrettably, this surveillance application had to be abandoned.

7 DISCUSSION OF RESULTS

7.1 Surface Water Surveillance

Feedback from the site inspection officers for Orgreave and Ffos Las was consistent and can be summarised as follows:

(i) surface water treatment processes can be identified satisfactorily by remote surveillance;

(ii) imaging may indicate the amount of suspended material in water, but the opportunity to confirm this did not arise;

(iii) surface water imaging is most appropriate for an unknown site but adds no additional information to that from ground inspection for a site that is regularly audited;

(iv) remote surveillance imaging does not have sufficient resolution to identify discharges to watercourses although low altitude imagery picked out the larger Orgreave sewage discharge ; and

(v) the resolution of aerial photography is good enough to visualise small discharges and can show up riverine discharge plumes.

7.2 Contaminated Land Surveillance

Agency inspectors' views can be summarised as follows:

(i) stressed vegetation as identified by remote surveillance was highly correlated with known contaminated land sites, with nine of the eleven sites in the Orgreave area falling within stressed vegetation areas;

(ii) only one known waste site was not identified by stressed vegetation, and its remediation is long established with healthy grass cover;

(iii) one stressed vegetation area has no waste tip record, but is a flood area and is likely to be contaminated;

(iv) stressed vegetation areas generally were larger than known waste sites and, with present knowledge, are not in themselves sufficiently selective to conclusively identify contaminated land; and

(v) identification of contaminated land was considered to be a more useful application of remote surveillance than identification of water treatment and discharge problems.

8 CONCLUSIONS

(i) Remote surveillance using a combination of CASI imaging and photography can identify surface water, treatment processes and discharges to watercourses in major civil engineering excavations. However, remote surveillance cannot add anything extra to the knowledge acquired from regular ground based inspection. The implication is that this application of remote surveillance is best suited to the examination of unknown or infrequently monitored sites, rather than regularly audited locations.

(ii) From the limited work carried out in this project, CASI imaging of vegetation stress is strongly indicative of contaminated land, but it is not exclusively co-incidental with known contaminated land areas. The technique would be more useful to site inspectors if it could be reinforced with other supporting techniques for inferring contamination, to reduce the uncertainty of identification. Possible reinforcing techniques may be historical mapping information (of previous industrial workings etc) on a common GIS basis, or characterisation of specific contaminants by a detailed spectral signature of the vegetation.

(iii) Thermal imaging had no application to contaminated land identification in this study. Night time thermal imaging would be more appropriate but was outside the budget of this scoping study.

9 RECOMMENDATIONS

(i) The benefits and limitations of remote surveillance to the inspection of water treatment and discharge control for major civil engineering sites have been established in this study and there is sufficient information for users to judge whether it has application to particular situations. No further development work is necessary to clarify this application.

(ii) The imaging of stressed vegetation has considerable application to identifying contaminated land. This important application does not have a wide range of alternative techniques and the stressed vegetation approach should therefore be developed further by investigating additional remote surveillance techniques to reinforce its selectivity of identification. Overlaying the imagery with historical mapping information, and correlation of multi-spectral imaging or enhanced spectral narrow band imaging with different contaminants are suggested as promising reinforcing techniques.

(iii) The extent to which remote surveillance can estimate suspended solids concentrations in inland waters could not be evaluated in this study. This relatively small scale investigation can be incorporated in the next suitable remote surveillance project.

REFERENCES

1 Lyon, J G. Use of Maps, Aerial Photographs and Other Remote Sensor Data for Practical Evaluations of Hazardous Waste Sites. Photogrammetric Engineering and Remote Sensing. Vol 53, No 5, May 1987 pp 515-519.

2 Murtha, P A. Remote Sensing and Vegetation Damage: A Theory for Detection and Assessment. Symposium on Remote Sensing for Vegetation Damage Assessment, Seattle, Washington, Feb 14 15 1978. Published by the American Society for Photogrammetry.

3 Harris, R. Satellite Remote Sensing, An Introduction. Pub: Routlege and Kegan, London, 1987.

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