The National Centre for Environmental Data and Surveillance

USE OF AIRBORNE REMOTE SENSING TO ASSIST WITH INDUSTRIAL SITE MONITORING RISK ASSESSMENT AND DETECTION OF CHANGE

ENVIRONMENT AGENCY

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National Centre for Environmental Data and Surveillance

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EXECUTIVE SUMMARY

The Environment Agency has a duty to assess industrial sites in terms of their environmental risks for planning purposes and rapid response in emergency situations. To date these assessments have taken the form of ground based surveys. There is a potential for greater information gain by the use of aerial survey techniques.

This report outlines the collection of aerial survey data of various industrial sites in England and Wales using the National Centre for Environmental Data and Surveillance survey equipment.

From the imagery gathered over these industrial sites the following potential environmental impacts were noted:

- signs of vegetation stress associated both with reclaimed land over old industrial sites and possible air pollution close to nuclear power stations
- signs of enhanced vegetation growth close to coal fired power stations
- enhanced algal growth on mudflats close to discharges of warm water from nuclear power stations and oil refinery processes
- warmer ground around reclaimed land fill sites

The report concludes that aerial surveillance allows an overview of an industrial area to be collected, indicating potential environmental impacts. Further work would be required in order to develop a full strategy for the implementation of such techniques in routine risk analysis studies. A more detailed investigation specifically into the remote sensing of land contamination has been initiated under R&D Project E1C(97)2.

1 INTRODUCTION

The Environment Agency is responsible for assessing industrial sites in terms of their environmental risks for planning purposes and rapid response in emergency situations. In 1997, a series of major pollution incidents by the petrochemical company ICI resulted in high level prosecutions by the Environment Agency. As a result of these the Agency required the production of risk assessments of environmental damage from the two industrial sites involved at Runcorn and Teesside, carried out under the supervision of the National Centre for Risk Assessment and Options Appraisal (NCRAOA). The industrial sites were satisfactorily regulated in the standard assessment. However, it was considered that further information on areas of damage might be gathered using an aerial assessment of the region around the industrial site.

The National Centre for Environmental Data and Surveillance (NCEDS) has developed a range of surveillance capabilities using, amongst others, airborne remote sensing techniques. It was decided that these techniques should be implemented around the two sites in question - Teesside and Runcorn in order to assess any environmental damage. Additionally a number of further industrial sites were identified which had potential environmental impact and imagery of these collected on an *ad hoc* basis as part of the NCEDS routine surveillance.

It was anticipated that environments downwind of the industrial complexes, or downstream in estuarine or coastal environments, might be impacted upon, showing signs of vegetation stress or growth enhancement. Additionally, sediments downstream may show signs of staining due to chemicals within the discharge.

This report outlines the collection of aerial imagery from the NCEDS survey equipment of these sites. Preliminary interpretation of the imagery is then described, resulting in an assessment of the current capabilities, before suggesting avenues for further development of the techniques discussed.

2 DATA COLLECTION

A wide number of sites were selected for investigation with data being gathered on an *ad hoc* basis as part of the NCEDS flight program in addition to the re-investigation of data gathered for earlier projects. The data may be broadly divided into the following: the ICI sites initially investigated; energy production sites including oil refineries, open cast mining, power station fuel production and redevelopment of existing land fill sites. A full list of the sites flown is included in Appendix I.

The aerial surveillance system used in this surveillance study is an integrated system consisting of a Compact Airborne Spectrographic Imager (CASI) and a digital thermal scanner. Data from these two sensors are integrated with data from a global positioning system to allow positioning of the aerial data.

The CASI is an imaging spectrometer which records the upwelling signal from the surface in a number of wavelengths from 420 to 920 nm. The CASI may be operated in a number of modes.

- Spatial mode: up to 19 spectral channels over 512 spatial pixels
- Spectral mode: 288 spectral channels over 39 spatial pixels
- Enhanced spectral mode: 72 spectral channels over 300 spatial pixels

In this project the CASI was operated in spatial mode with a 15 channel band set. The channel wavelengths have been selected to show variations in vegetation and water quality parameters. The two main display mechanisms used were the true colour composite image and the false colour composite image.

The true colour composite image displays three spectral channels representing red, green and blue wavelengths on the red, green and blue channels of the display. This gives a near real colour representation, similar to a photograph. The advantage of the digital system over photography is the ability to further enhance the data to extract more information.

The false colour composite image displays a near-infrared channel on the red gun of the display, with green and blue channels being displayed on the green and blue guns. This display allows the clear differentiation of vegetation which has a characteristic near-infrared signal. Different tones of red represent different vegetation types, or the health and density of the vegetation based on the amount of photosynthetic activity.

The CASI data might be expected to show stress in the surface vegetation down wind of power stations and major industrial sites caused by release of potentially harmful substances into the environment. 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 (Lyon, 1987, Murtha, 1978).

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.

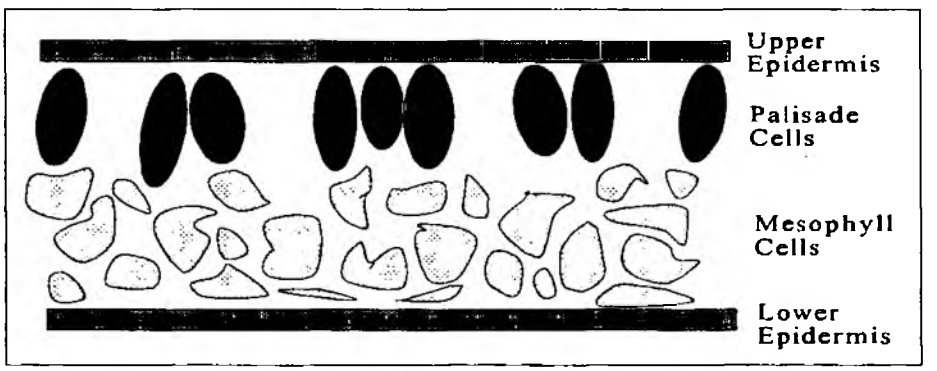

Fig. 1 Cross section of a typical leaf

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 (Harris, 1987).

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 (Normalised 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 is given 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.

The thermal sensor operates in the 10-12 μm range measuring the radiation emitted from the very top of the land or sea surface. This information is displayed as a grey scale image. The digital number of the image may be used to determine variation in the temperature across an image, showing relative change. In order to calculate absolute temperature a calibration must be made against *in-situ* temperature measurements.

The thermal data may be used to identify the presence of plumes of warmer than ambient temperature water associated with, for example, the outfalls of nuclear power stations. The release of warmer water from cooling water systems may enhance primary production. This may result in the presence of phytoplankton blooms in the water column which would be shown in the CASI data. The use of remote sensing in the detection of algal blooms relies on two optical characteristics of chlorophyll-*a*. Early work concentrated on the differential reflectance of green light over blue due to absorption by chlorophyll-*a*, with the development of the technique for calibration of chlorophyll-*a* concentration known as the blue/green ratio method (Gordon *et al.* 1980, Moore and Aiken, 1990). Subsequently, an algorithm has been developed which relies on the fluorescent emission of chlorophyll-*a* at red wavelengths (Neville and Gower, 1977, Gower and Borstad, 1981).

The NCEDS has carried out investigations into the calibration of CASI imagery for chlorophyll-*a* concentration (Environment Agency 1997*a*) and the subsequent use of this imagery in the detection of algal blooms (Environment Agency 1997*b*). This work illustrated the ability of CASI data to accurately map chlorophyll-a concentration with adequate *in-situ* calibration data, but noted the difficulty in using CASI data as a surveillance technique for bloom detection. On the scale required here, however, the presence of a bloom would be readily apparent in the imagery collected.

A further manifestation of enhanced productivity would be the presence of increased density of macro-algae on mudflats and shores in the vicinity of plumes. The NCEDS has used digital classification of the CASI imagery to allow differentiation of these algae (Environment Agency 1997*c*). The thermal data may also be used in association with the CASI data when investigating landfill sites under redevelopment as the presence of harmful gases might result in the warming of land adjacent to the site.

3 RESULTS

3.1 ICI Industrial Sites

There was no successful data collection from the ICI Runcorn site due to poor weather conditions. Imagery was however collected from the lower Tees estuary, including the ICI Wilton site. This imagery (Plate 1) clearly shows the presence of the plume of warmer water, high in suspended solids loading from the creek opposite Seal Sands. Analysis of imagery from this region collected as part of the NCEDS project AAerial Surveillance of fourteen estuaries in England and Wales (NCEDS Estuaries Project- Environment Agency 1997*c*) also showed the presence of the plume which is made up of a discharge from the Eston sewage macerator and combined discharges from the ICI site. The behaviour of this plume is well understood by the Regional environmental quality staff and is not thought to raise any environmental problems. The imagery also showed the highly industrialised nature of the region and the apparent low quality of the land around the estuary, but did not specifically highlight any areas of concern.

3.2 Fuel production

3.2.1 Oil refineries

Imagery was collected of Fawley oil refinery on Southampton Water which clearly shows the presence of a warmer than ambient water outfall from Cadland Creek (Plate 2). This discharge was studied more extensively as part of the NCEDS Estuaries Project (Plate 3). On this occasion the plume was found to have a surface temperature at the centre of 11EC to 12EC above ambient. The plume was strongly deflected by the tidal stream, with a steep temperature gradient on the northern side, having a change in temperature of 7EC over approximately 10 m. The plume disperses to the south with the effects being experienced at least 3 km downstream, where the temperature of the plume is 5EC above ambient. The outfall is from the Esso Oil Refinery and consists of process cooling water.

The CASI imagery collected in 1998 shows no signal from this discharge, consistent with the absence of pollutants from this water. Data collected at low water in July 1997 showed a distinct dark colouration to the water, probably signifying the discharge of clear water into a sediment

rich environment. However, data collected on other occasions have shown the discharge to be pink in colour. This may be due to enhanced algal production due to the warmer water. Imagery from this region shows the presence of algae on the mudflats which had previously been supposed to be due to discharge of nutrients via the sewage treatment process. Again it is possible that the warm water from this industrial process is enhancing algal growth on the mudflats.

Imagery was also collected of Milford Haven. Again more extensive analysis of this area was made as part of an NCEDS project investigating the use of airborne remote sensing in the optimisation of statutory sampling sites. Three oil companies have constructed refineries within Milford Haven, these being Gulf, Elf and Texaco, with this complex having the largest refining capacity in Europe. These refineries discharge treated process water through consented discharges, which are monitored regularly. Aerial surveillance was carried out in Milford Haven on 23 September 1996. Discharges were recorded from both the Gulf and Texaco Oil Refineries evident as a thermal plume at varying tidal states, with a corresponding CASI signal at some tidal states. Thermal influences from these plumes are unlikely to have a detrimental effect on the surrounding environment, because of the size and direction of the mixing zones recorded (Environment Agency, 1997*c*).

The Estuaries Project did not investigate the release of pollutants to air. Imagery collected in 1998 did not show any clear environmental impact on the vegetation surrounding the two industrial complexes on Southampton Water and at Milford Haven.

3.2.2 Open cast mines

The use of aerial surveillance in the investigation of mineral extraction was investigated in R&D Project P2-022 (Environment Agency 1997*d*). Plate 4 shows an example image from this report illustrating the wealth of information which may be extracted from imagery of Orgreave open cast mine. This study showed that aerial surveillance would be most appropriate to overview large sites which are not routinely audited by ground level inspection.

3.2.3 Power stations

Data were gathered from three types of power station (see Appendix I). Didcot power station is mainly coal fired, though may be switched to oil fired if required. Plate 5a shows a false colour composite CASI flightline across the power station. This shows the presence of a coal pile as marked and illustrates both the extent of the site and the poor quality of land within it. The agricultural land to the North of the power station is shown in both this image and the true colour composite image of an adjacent flightline (Plate 5b) to be richer than that to the south. This vegetation in within the prevailing wind direction suggesting that the nitrates released from the process may be enhancing growth. Although further image processing techniques such as the determination of an NDVI, could be applied to the data to determine the quality of the vegetation, the narrow spatial scale of the imagery makes this processing inappropriate. It would not be able to determine if the differences are caused by the presence of the power station or by some other effect, for example a different soil type or fertiliser usage. Imagery was also collected of Drax coal fired power station (Plate 6) which showed similar features to those at Didcot. Again it was decided at an early stage that a much larger area needed to be flown to allow any conclusions to be drawn.

Data were also gathered from two nuclear power stations, Bradwell and Hinkley Point. In these cases the imagery was investigated for the presence of vegetation stress in the vicinity of the sites due to the release of pollutants to the air. No clear signs were seen in initial analysis and further processing was not carried out. In addition the nuclear power production process requires large amounts of cooling water, which in the case of the two stations is both extracted from and returned to the sea. The discharge points of this warmer than ambient temperature water are clearly shown in thermal imagery from the two sites (Plate 7). The presence of this warm water may potentially enhance primary productivity in the region, resulting either in algal blooms within the water column or enhanced algal growth on the mudflats. There is no evidence of algal blooms in the imagery. The imagery of Hinkley Point does show the presence of algae on the mudflats to the north of the power station (Plate 8) but further work would be required to establish whether this were attributable to the presence of the warmer water.

3.3 Landfill sites

The Factory Farm landfill site near Rochester was investigated as it is on the proposed route of

the Channel Tunnel rail link. Thermal imagery of the site shows the presence of two features: firstly a warmer area extending from the current landfill to reclaimed land to the north and secondly a plume of cooler water discharging into the river (Plate 9). There is no surface manifestation of the first feature in the vegetation in either the true colour or false colour composite CASI images of the site (Plate 10). Variations in the thermal imagery may be due to the presence of buried transformers within the landfill site. The true colour composite image shows a clear division between the old and new landfill sites. This will be mainly due to surface cover differences, but may also reflect the presence of a subsurface chalk barrier between the two parts of the site. Further investigation would be required of this site to provide a full understanding of this apparently complex region.

4 DISCUSSION AND CONCLUSIONS

From the imagery gathered over these various industrial sites the following potential environmental impacts were noted:

- signs of vegetation stress associated both with reclaimed land over old industrial sites and possible air pollution close to nuclear power stations
- signs of enhanced vegetation growth close to coal fired power stations
- enhanced algal growth on mudflats close to discharges of warm water from nuclear power stations and oil refinery processes
- warmer ground around reclaimed land fill sites

The analysis of the aerial data for this project has, however, been entirely subjective. Review of this analysis by representatives of the NCRAOA concluded that the data collected in this exercise showed potential for extraction of further information to be used in risk analyses. However, a more stringently planned schedule was required in order to provide a full scientific investigation of any of the sites studied. This report therefore provides a basis for any further work to be carried out in the future.

This report has shown that aerial surveillance provides the ability to overview an industrial area and indicate potential environmental impacts. Further work would be required in order to develop a full strategy for the implementation of such techniques in routine risk analysis studies.

Further investigation of the use of remote sensing for the identification and quality assessment of land contamination is being undertaken under R&D Project E1C(97)2 "Application of remote sensing for assessing the status and condition of land, water and ecological resources", due for completion in December 1999.

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APPENDIX I

The following locations were overflown with CASI and/or thermal imagery specifically as part of this project.

ICI Teesside

ICI Runcorn

Fawley oil refinery, Southampton Water

Gulf and Texaco oil refineries, Milford Haven

Bradwell nuclear power station

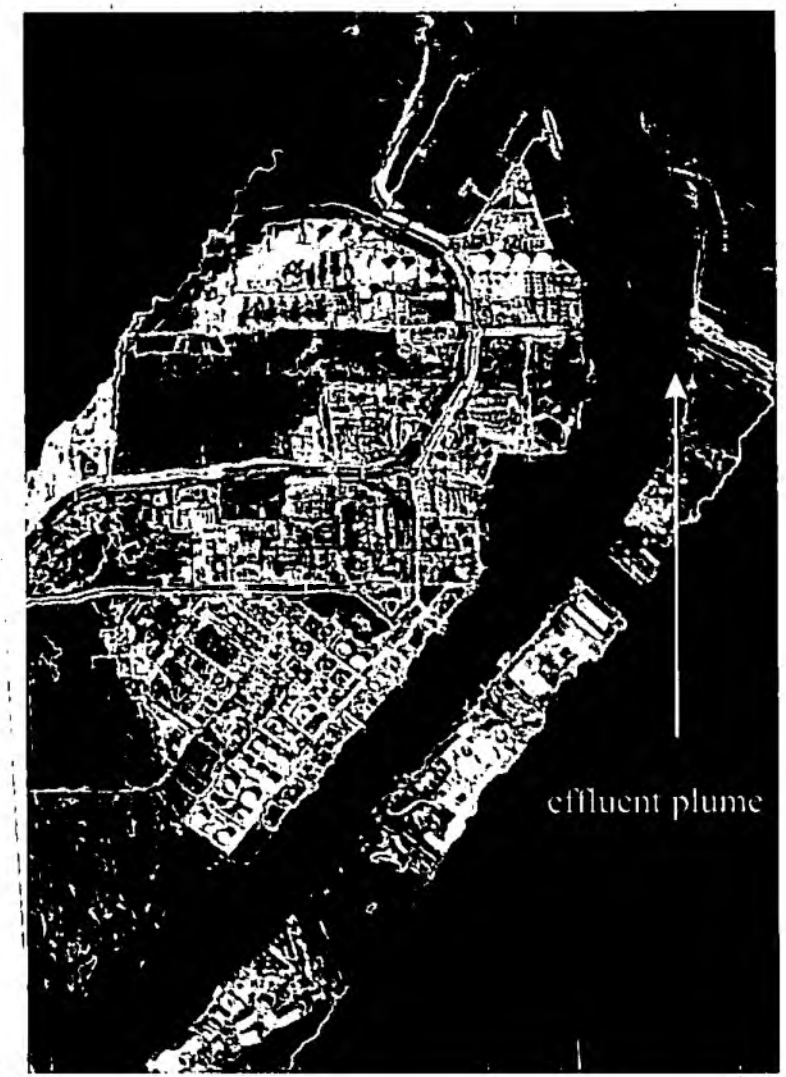
Drax gas and oil fired power station

Didcot coal and oil fired power station

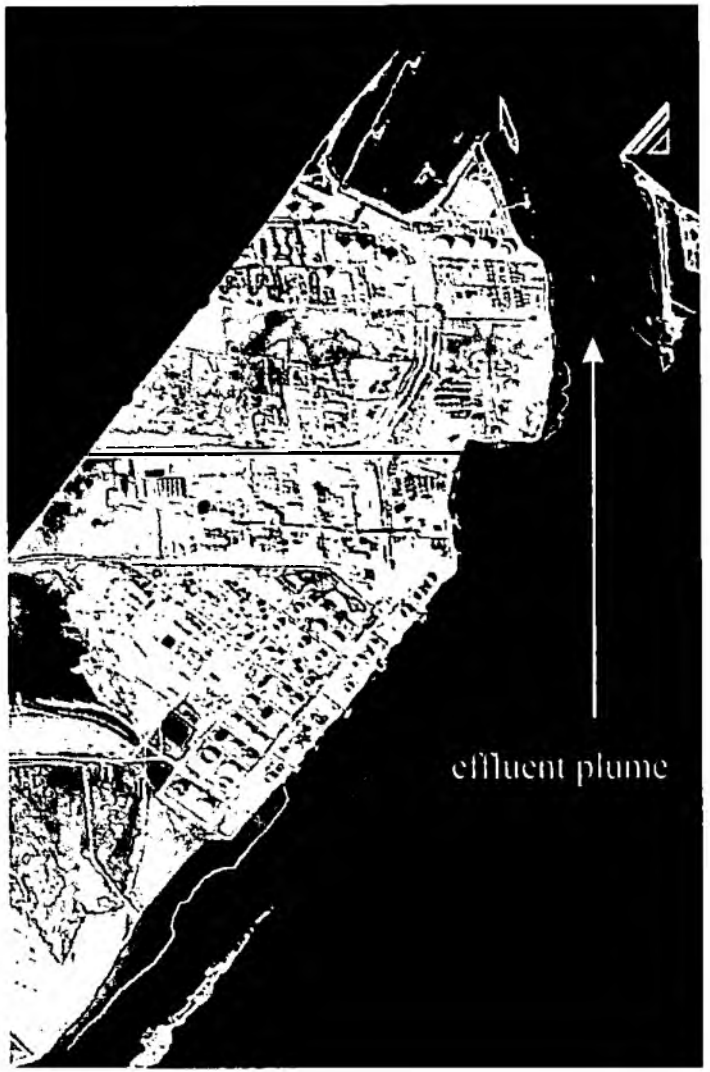
Hinkley Point nuclear power station

Factory Farm Land Fill site

a)



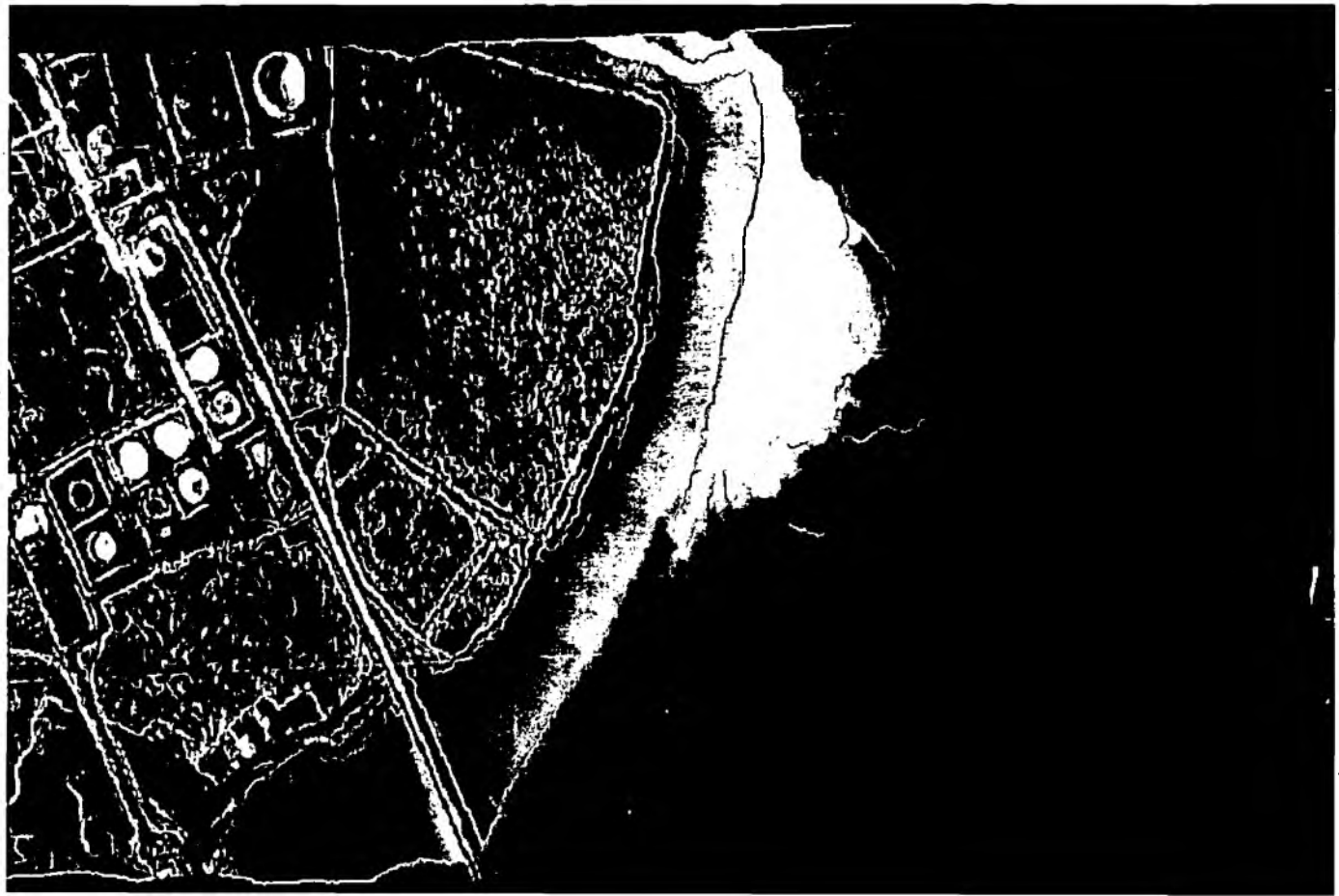
b)



Lower Tees Estuary

a) CASI true colour composite image
b) Thermal infrared image - cold areas are seen in black and warm in white

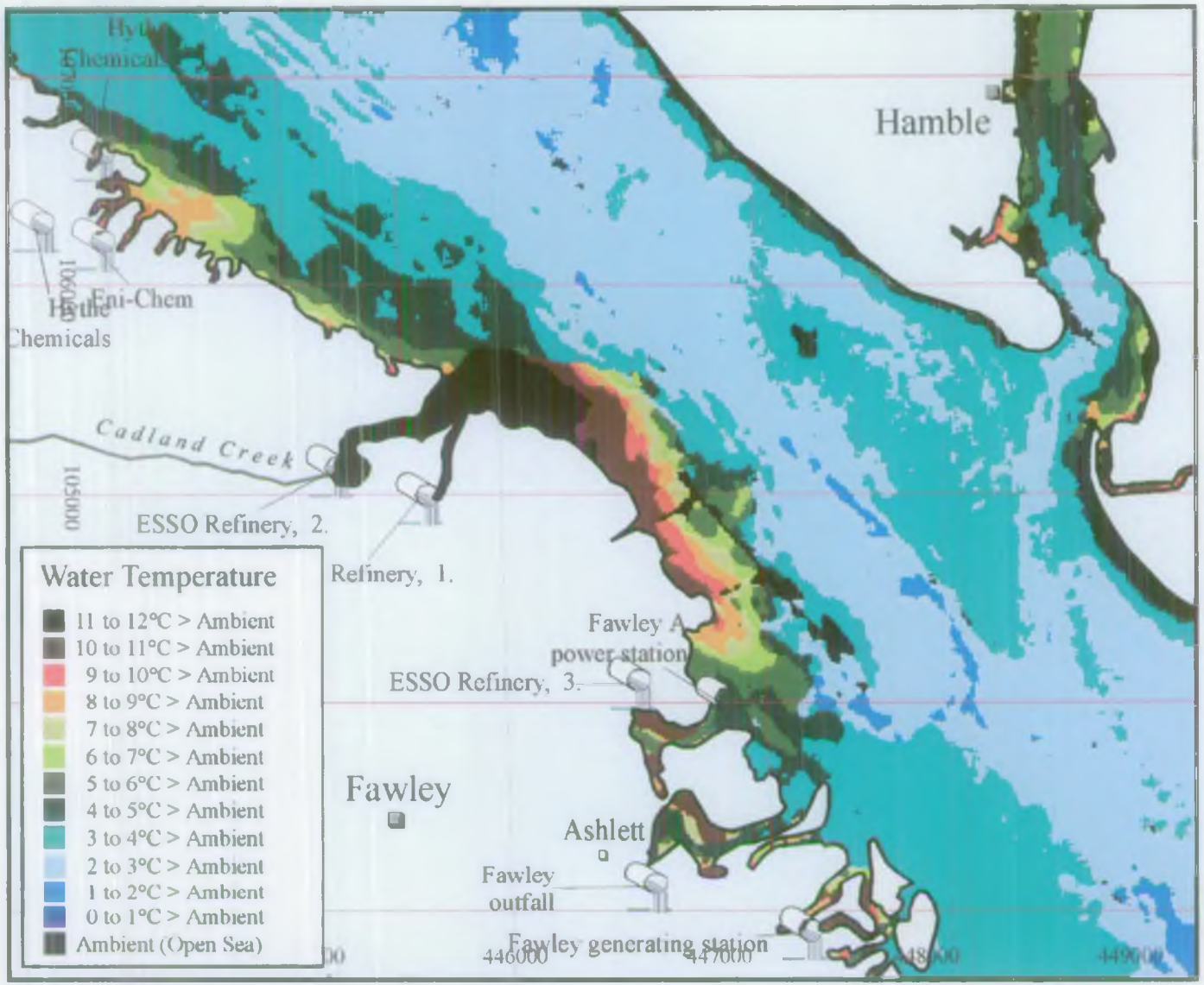
Plate 1



Fawley Oil Refinery

Thermal infrared image of refinery
discharge plume - cold areas
are shown in black and warm in white

Plate 2



Thermal map of Southampton Water

Map produced from calibrated thermal infrared imagery collected as part of the NCEDS Estuaries Project

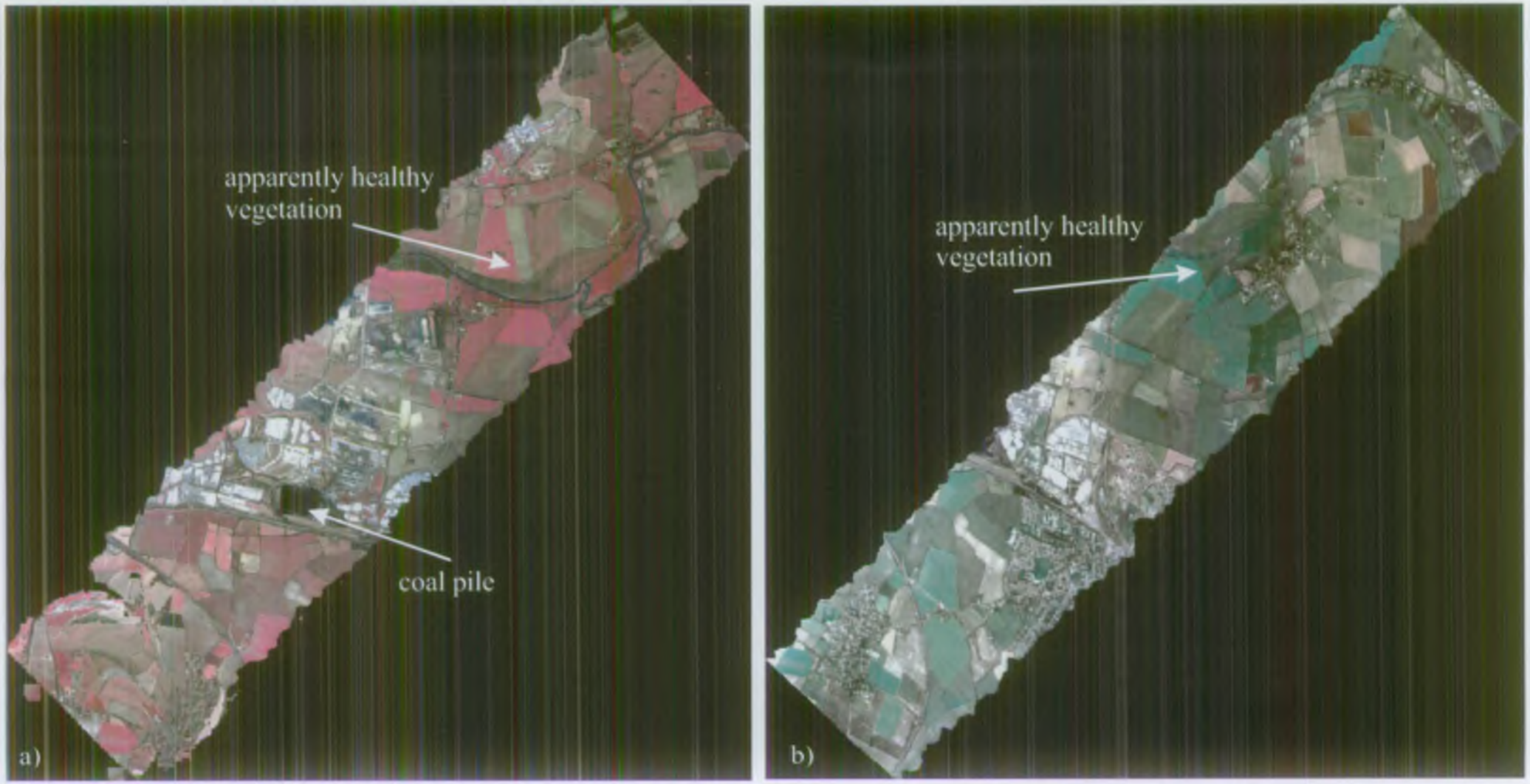
Plate 3

Orgreave Coal Mine

CASI true colour composite with sites of interest highlighted

Plate 4

(Plate 1 from R&D report P111)

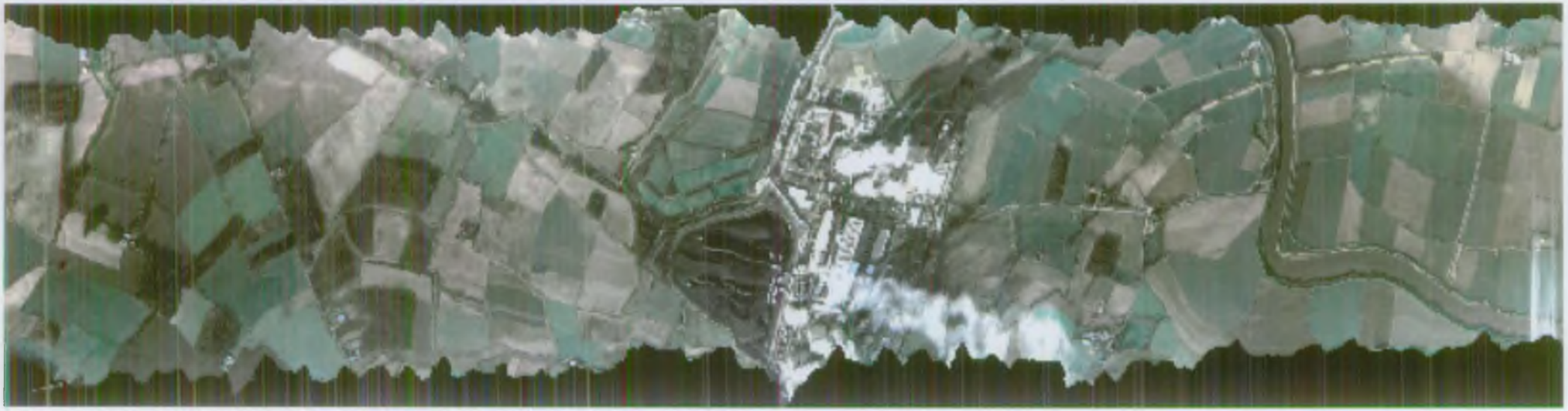


Didcot Power Station

a) False colour composite CASI image showing vegetation in shades of red

b) True colour composite CASI image of adjacent flightline showing vegetation in shades of green

Plate 5



a)

b)

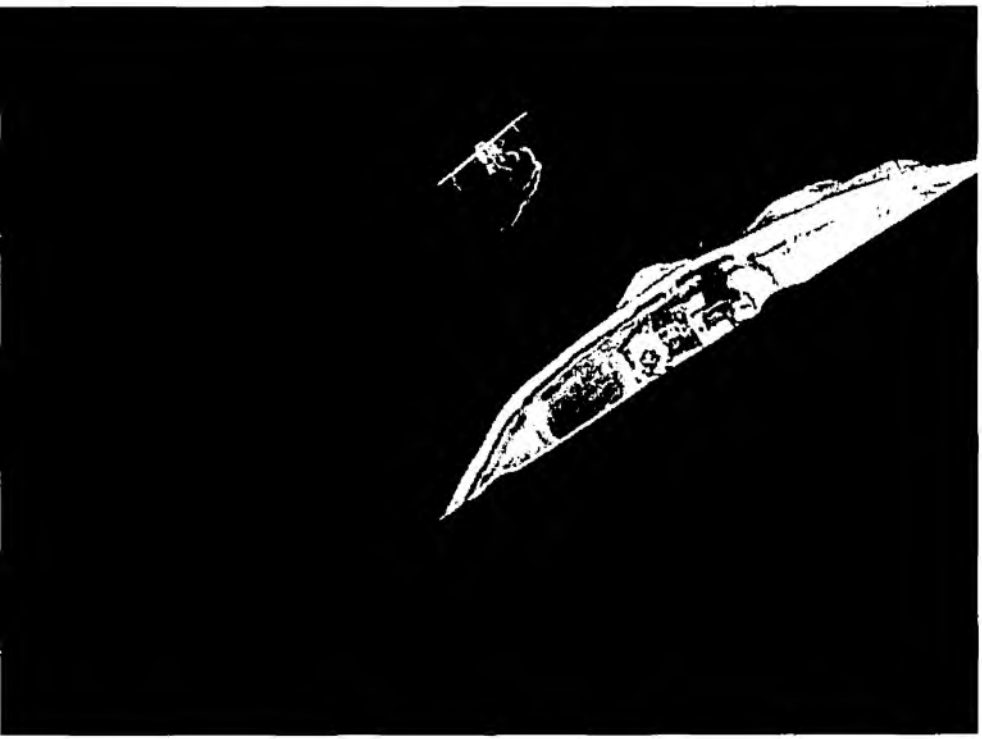
Drax Power Station

a) CASI tue colour composite image
b) Thermal infrared image - cold areas are shown in black and warm in white

Plate 6

a)

Plate 7



b)

Thermal imagery of power station discharges

a) Hinkley Point nuclear power station outfall
b) Bradwell nuclear power station outfall

Cold areas are seen in black and warm in white

a)

b)

Hinkley Point Nuclear Power Station

a) CASI true colour composite image showing algae on mudflats in green
b) CASI false colour composite image shwing algae on mudflats in red

Plate 8

cold water plume

warm area beneath reclaimed landfill site

Rochester Landfill Site

Thermal infrared image
Cold areas are shown in black
and warm in white

Plate 9

a)

Rochester landfill site

a) CASI true colour composite image
b) CASI false colour composite image

Plate 10

b)