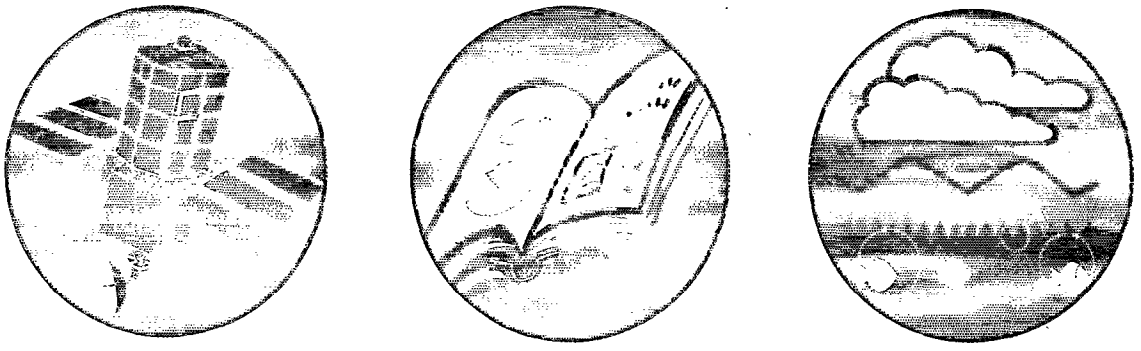
Synoptic State of the Environment Monitoring



Research and Development

Technical Report
E51

ENVIRONMENT AGENCY

All pulps used in production of this paper is sourced from sustainable managed forests and are elemental chlorine free and wood free

Synoptic State of the Environment Monitoring

Technical Report E51

M Gebhardt

Research Contractor:
Science Systems (Space) Ltd.

Further copies of this report are available from:
Environment Agency R&D Dissemination Centre, c/o
WRc, Frankland Road, Swindon, Wilts SN5 8YF

tel: 01793-865000 fax: 01793-514562 e-mail: publications@wrcplc.co.uk

Commissioning Organisation:
Environment Agency
Rio House
Waterside Drive
Aztec West
Almondsbury
Bristol BS32 4UD

Tel: 01454 624400 Fax: 01454 624409

HO-04/98-B-BAGQ

Dissemination status
Internal: Released to Regions
External: Released to the Public Domain

Statement of use
This report provides a concise demonstration of what the Compact Aerial Spectrographic Imager can achieve when monitoring the equipment. This report clearly shows how airborne remote sensing can aid environmental decision making and demonstrates how this technique could be useful in a cost effective monitoring program.

Research contractor
This document was produced under R&D Project E1-019 by:

Science Systems (Space) Ltd and
The National Centre for Environmental Data and Surveillance

Environment Agency's Project Manager
The Environment Agency's Project Manager for R&D Project E1-019 was:
Nick Holden, Environment Agency

CONTENTS

LIST OF FIGURES

EXECUTIVE SUMMARY

This report explains the use of the Compact Airborne Spectrographic Imager (CASI) for state of the environment monitoring. The document forms the third part of a package of work, the first two parts of which were the acquisition and operation of the CASI system and the production of a technical specification. A large number of current and potential applications are described, however, no attempt has been made to provide an exhaustive list of applications.

The CASI is an airborne multispectral remote sensing tool which can provide data for varied environmental applications. In many cases, the CASI is able to add value to traditional monitoring techniques by providing large-scale, homogeneous coverage via easily repeatable measurements. Another advantage of the CASI system is that it can be deployed at short notice in order to acquire data about transient or dynamic environmental events. Remote sensing tools such as the CASI are able to present an holistic view of the environment and provide information which is essential for the effective planning of environmental strategy.

Typical applications of the CASI have been described in terms of the Agency's public consultative paper, *Viewpoints on the Environment*. These viewpoints consist of:

- Land use and Environmental Resources
- Status of Biological Communities and Biodiversity
- Quality of the Environment: Compliance with Targets and Standards
- Health of Environmental Resources
- Environmental Change at Long-term Reference sites
- Aesthetic Quality of the Environment

Under these six viewpoints, CASI applications have been described relating to terrestrial areas, coastal zones and inland / coastal waters. Examples of CASI data have been provided in a number of different forms in order to highlight information relevant to the application at hand. Possible uses of CASI data fall into a number of applications areas which can be broadly categorised as:

- monitoring the condition of environmental resources
- coastal zone management
- flood defence
- water quality monitoring
- habitat monitoring and conservation
- discharge monitoring and pollution detection
- environmental change monitoring
- environmental impact assessment

The CASI instrument provides data that can supply a large scale spatial context for existing measurement techniques on an easily repeatable basis. These data add value to existing datasets and techniques and, in many situations, can provide information that has not previously been available. The flexibility of the tool allows it to be deployed at short notice or on a regular basis to provide data obtained at the most appropriate times for the application.

1 INTRODUCTION

1.1 Agency Business Needs

The Environment Agency plays a central role in consenting and improving the environment of England and Wales. The Agency's management activities are based on knowledge of the state of the environment and how it is reacting to the pressures placed upon it. In order to gain this knowledge, it is essential that the Agency maintains an effective, holistic environmental monitoring and assessment programme and that it tests environmental compliance with prescribed standards and targets. Techniques such as Remote Sensing form an integral part of the Agency's holistic monitoring programme by providing a synoptic overview of the environment. Data derived from instruments such as the Compact Airborne Spectrographic Imager (CASI) provide wide scale information about environmental processes and states.

The CASI is a flexible remote sensing tool which can provide data for varied environmental applications. In many cases, the CASI is able to add value to traditional monitoring techniques by providing large-scale, homogeneous coverage via easily repeatable measurements. The homogeneity of coverage allows traditional, point-based measurements to be interpolated and extrapolated over wide areas. This use of the CASI reflects a progression in measurement techniques from point-based to line-based to the integrated techniques which are presently in use. These techniques incorporate large area coverage and integration of various instruments to provide, for example, land cover mapping, elevation models and surface temperature data covering the same area.

The Environment Act 1995 places general duties on the Agency to help achieve sustainable industrial and economic development and form an opinion on the state of pollution of the environment. This act is supported by Department of the Environment, Transport and Regions (DETR) guidance on sustainable development which states that the Agency should take an holistic view of the environment. Remote sensing tools such as the CASI are able to contribute to this holistic view of the environment and provide information which is essential for the effective formulation of environmental strategy.

1.2 Scope of Report

This report presents the uses of the CASI instrument for monitoring the state of the environment. The CASI instrument is described in Chapter two and placed in context by describing how it relates to other remote sensing tools and systems. Data products produced by the CASI are described and an explanation is given of how the resource is managed.

Chapter three presents the applications of the CASI instrument. The various applications areas are divided into six sections, each representing a different approach to environmental monitoring. These six sections are based on those described in the Agency consultative paper, *Viewpoints on the Environment* and are listed below:

- Land Use and Environmental Resources;

- Status of Biological Communities and Biodiversity;
- Quality of the Environment: Compliance with Targets and Standards;
- Health of Environmental Resources;
- Environmental Change at Long-Term Reference Sites; and,
- Aesthetic Quality of the environment.

The use of the CASI is put into context for each of the six viewpoints. Example uses of CASI data are given for each viewpoint, with raw or derived CASI imagery illustrating the products that can be supplied.

Chapter four presents a summary of the uses of the CASI in order to provide an overview of its capabilities in the various areas described in *Viewpoints on the Environment*. A number of appendices are also provided, each of which contains a summary of one of the sections in Chapter three, together with example imagery.

1.3 Terms and Acronyms

CASI	Compact Airborne Spectrographic Imager
CCD	Charge Coupled Device
CMP	Coastal Management Plan
DEM	Digital Elevation Model
DETR	Department of the Environment, Transport and Regions
EA	The Environment Agency
ECN	Environmental Change Network
FLH	Fluorescence Line Height
GIS	Geographical Information System
GPS	Global Positioning System
HNDA	High Natural Dispersion Area
ITE	Institute of Terrestrial Ecology
ITE Land Cover Classification	Satellite-based, remotely-sensed classification of land-use in the UK
LEAP	Local Environment Agency Plan
LiDAR	Light Detection And Ranging
MLC	Supervised Maximum Likelihood Classification
NDVI	Normalised Difference Vegetation Index
NRA	National Rivers Authority (now amalgamated into the EA)
pixel	Picture element, each image contains rows and columns of pixels
R&D	Research and Development
raw imagery	Unprocessed, remotely sensed imagery
SAR	Synthetic Aperture Radar
SSSI	Site of Special Scientific Interest
USC	Unsupervised Classification
UWWTD	Urban Waste Water Treatment Directive
waveband	Selected portion of the electromagnetic spectrum (averaged)

2 OVERVIEW OF THE CASI

The Compact Airborne Spectrographic Imager (CASI) is used by the Agency in order to generate multi-spectral, remotely-sensed imagery of terrestrial, marine and riverine environments. The CASI is an imaging device, which, once installed on an aircraft, provides multi-spectral digital data for environmental monitoring and analysis. This chapter provides an overview of the instrument, including brief discussions on how it works, the data products that it can produce and how the resource is administered.

The CASI is mounted on a light aircraft and, once configured, is available for use at short notice. This high availability enables the CASI to be deployed anywhere within England and Wales in order to obtain time-critical imagery of events such as oil spills or algal blooms. Environmental events such as these are transient in nature and difficult or impossible to predict. The timeliness of the CASI makes it ideal for obtaining data about these transient and rapidly changing events. The flexibility of the system also makes it possible to redirect or stop flights at short notice if weather conditions make acquisition of good quality data impossible. This prevents the costly acquisition and processing of unsuitable data.

The CASI sensor, which produces imagery covering the visible and near infra-red wavelengths, can be used in conjunction with a thermal sensor in order to obtain data in the mid and far infra-red wavelengths. This complete imaging system allows both visual and thermal data to be acquired. Typical applications of the thermal imager include the detection of industrial discharges where there is a temperature differential between the discharge and the receiving medium.

This imaging system provides flexibility and resolution which is not available with current satellite-based imaging systems. By selecting preferred spectral bands, it is possible to obtain data which is tailored to suit the user's application. Also, by simply specifying the height of the aircraft, the data resolution and area of coverage can be adjusted as desired. Finally, in certain weather conditions, the CASI can avoid cloud-cover problems suffered by satellites by simply flying below the cloud base.

2.1 Imaging Process

The CASI is a passive sensor which generates imagery by detecting visible and near infra-red electromagnetic energy that is reflected from the earth's surface. The instrument operates in a pushbroom configuration, mapping out a swath that lies directly below the aircraft. By instantaneously imaging the full swath width at repetitive intervals, a full image is built up line by line. Figure 1 shows the imaging geometry of the CASI instrument.

Imagery produced by the CASI consists of up to 512 pixels across the swath and the spatial resolution (area represented by one pixel) can be varied from ten metres down to less than a metre by adjusting the altitude of the aircraft and the CASI imaging lens. The maximum operational altitude of the aircraft is 10000 feet, restricting the maximum swath width to approximately 5.2 km. If the area to be imaged is larger than the swath width available at the desired resolution, it is possible to obtain a number of adjacent flight lines and join these in order to generate a single, large image, or mosaic.

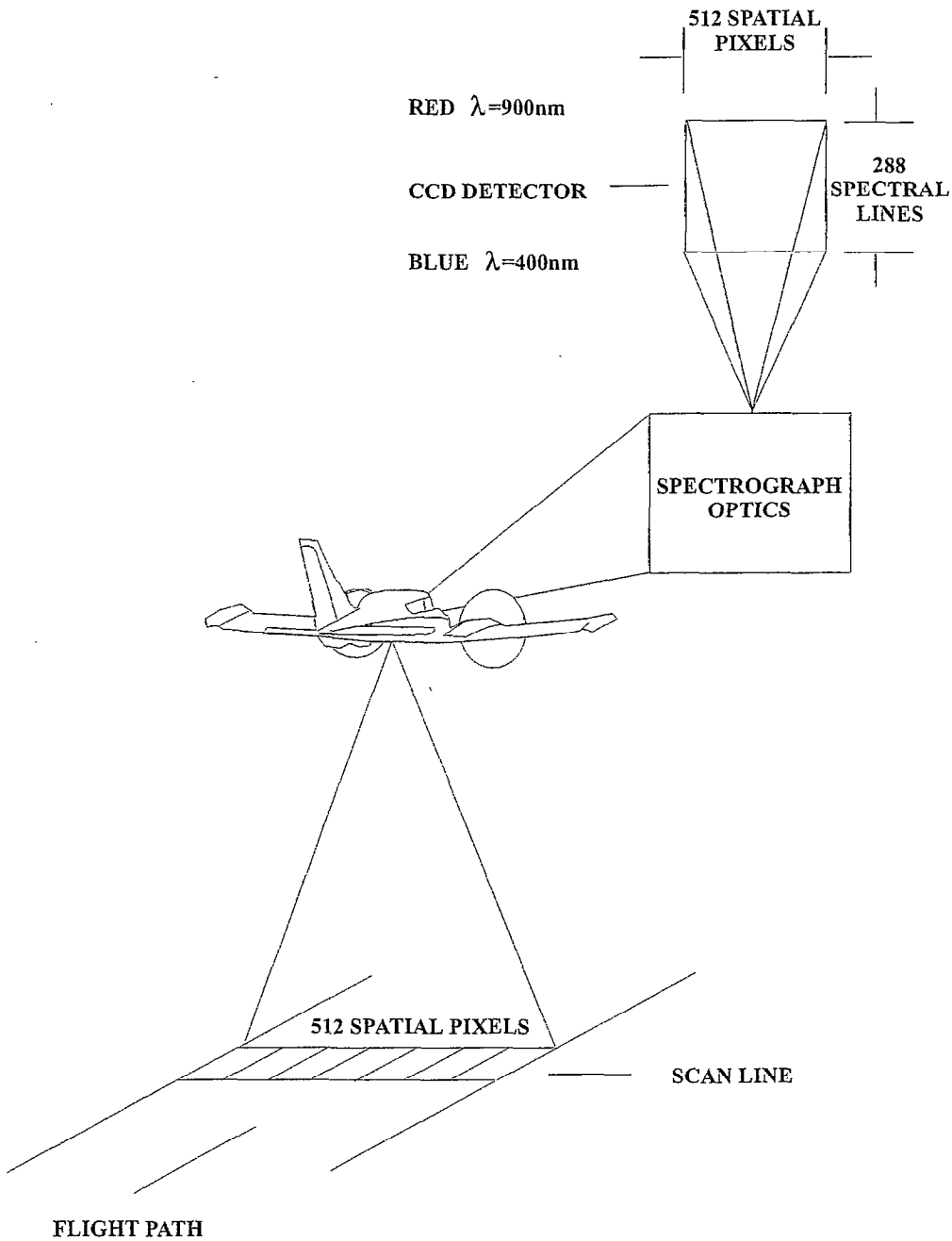


Figure 1: Principle of operation of the CASI.

The CASI uses a Charge Coupled Device (CCD) detector to produce hyperspectral imagery which can comprise up to 288 spectral bands (wavebands), covering the electromagnetic spectrum from 430 nm (visible blue light) to 900 nm (Near Infra-red).

The CASI has three operational modes which are suited to different applications and should be selected according to the spatial and spectral resolution required of the data. The operational modes are:

- **Spatial Mode:** All 512 swath pixels are recorded in up to 19 wavebands. The wavelengths covered by the bands and the width of the bands are configurable.
- **Spectral Mode:** Data from all 288 bands are recorded from 39 pixels across the swath.
- **Enhanced Spectral Mode:** This flexible mode allows a compromise between spatial and spectral modes to be achieved. The exact combination of pixels and bands that is achievable is determined by the amount of ambient light at the time of imaging.

The imagery can be geometrically corrected using data from a vertical gyroscope and a Global Positioning System (GPS) receiver which are mounted on the aircraft. These corrections compensate for variations in the aircraft attitude during image formation. Radiometric correction can be performed through the use of pre-flight calibration constants and by using an Incident Light Sensor to measure the downwelling radiance at the aircraft. This radiometric correction can be used to calibrate the imagery in terms of spectral reflectance values, rather than absolute radiance values and enhances the ability to make useful comparisons between data obtained at different times.

2.2 Products

The CASI instrument is capable of producing a number of digital outputs, each of which is suited to different applications areas. The mode of operation of the CASI should be chosen to suit the application, as it influences usefulness of the data outputs. The following are some of the possible data products:

- **True-colour composite imagery:** This is generated by displaying 3 bands that correspond to the visible red, green and blue wavelengths, resulting in imagery that resembles colour aerial photography. Operation of the CASI in spatial mode is most suited to the production of this imagery.

- **False-colour composite imagery:** In this approach, colours in the final image do not represent the true colour of the band to which they are assigned. This allows certain features or cover types to be highlighted, simply by choosing an appropriate mapping of wavebands to the three display colours. This imagery should be obtained with the CASI operated in spatial mode.

- **Spectral profiles:** These show the spectral signatures of individual cover types. Image intensity is plotted against wavelength and the characteristic shapes of various graphs can be used to identify different vegetation or cover types. These profiles can be generated

from all three operational modes of the CASI, but a more detailed analysis is possible when the instrument is operated in spectral mode or enhanced spectral mode.

- **Other value-added products:** Further products can be generated by performing image-processing techniques such as land-cover/land-use classifications, calculating vegetation indices, employing algorithms that produce quantitative measures and calculating area extents from class maps.

The data products listed above can be delivered in an number of formats, according to the user's need. These formats include:

- Digital data on compact disc or Exabyte/DAT tape
- Paper copies ranging from A4 to A1 in size
- Laminated paper copies for field work
- Tiff files for use in GIS applications

2.3 Availability

The CASI instrument is owned by the Agency and is installed and flown on a light aircraft on an annual contract basis. The system is available for data acquisition the entire year, but short notice flights can be performed from April to October when the aircraft is kept in a state of operational readiness. The CASI instrument forms part of an integrated imaging system and is supported by onboard computing equipment, a GPS receiver and a Hasselblad medium-format camera, producing digital or film outputs. Supporting imagery is also provided by a thermal imager and a colour video camera that are leased with the aircraft.

CASI Surveys are planned at the start of April of each year for the entire season. It is, however, possible to schedule surveys at a later date if the resource is available at the required time. For emergency response missions, a minimum advance warning of six hours is required in order to prepare the aircraft. The flying programme for the CASI includes a number of separate activities, all of which have to be accommodated in the flying season, these are:

- R&D;
- core surveys for environmental information gathering;
- business development; and,
- regional works aspects.

All planning requests should be made through the Survey Planner at the National Centre for Environmental Data and Surveillance. In order to plan a CASI survey, the following information is required:

- What the data is for (i.e. the questions that it needs to answer);
- What data products are required;
- The point or area where the data must be acquired;
- When the data must be acquired (i.e. is the data acquisition dependant upon tides or seasonal variations);

- Confirmation of funding approval; and,
- What ground truth data will be required.

Image resolution and swath-width requirements will be determined in discussions between the user and the Survey Planner.

3 CASI APPLICATIONS

This chapter describes typical applications of the CASI that are of direct importance and relevance to Environment Agency activities. The applications have been divided into a number of areas, according to the key environmental issues as identified in the Agency publication, *Viewpoints on the Environment.*

Each of the six sections below describes an environmental viewpoint, explains why it is of importance and describes how the CASI can contribute to monitoring and surveillance in this area. A number of examples are given in order to provide a flavour of the principle uses of the instrument.

3.1 Land Use and Environmental Resources

It is desirable to establish and maintain a comprehensive register of land use and environmental resources. Establishing the nature and extent of land cover and land use types will add to our knowledge of the environmental resources within England and Wales and allow these to be better managed.

By making use of Remote Sensing techniques and combining this data with relevant ground data, we can improve our knowledge of changes to, and the condition of these environmental resources. This knowledge can provide valuable input to environmental management strategies. Remote Sensing using the CASI system is able to provide medium-to-large scale, consistent views of land-use which may serve to fill some of the 'gaps' in present knowledge.

In order to fulfil the needs of the Agency, it is desirable to classify land use and land cover types into a number of specific classes. The table of classes given below has been derived from the ITE Land Use classification scheme and adapted to highlight those which are of most direct relevance to the work of the Agency.

Class	**Subdivisions**
Urban	- Industrial/Housing Estates - Parkland/Gardens
Deciduous Forest	
Coniferous Forest	
Inter-tidal Zone	- Saltmarsh - Inter-tidal muds - Inter-tidal vegetation
Beach/Shingle	
Inland waters	
Tidal waters	
Bare rock/soil	
Arable land	- Crop types - Bare fields

Class	Subdivisions
Pasture	
Heath/Bog	
Rough grass	
Disturbed Land	- Quarries/mines - landfill - Reclaimed land

The above table is not a definitive list of all land use and land cover types, but provides types that will cover a broad spectrum of applications. It is likely that certain applications will require slightly different class types or increased resolution in the form of more class subdivisions. Classifications performed using CASI data with appropriate supporting ground information can differentiate between the majority of the classes listed above, as shown by the examples given in this section.

3.1.1 Terrestrial Classification

Figure 2 shows a supervised land-use classification performed using 2m CASI data, together with true-colour composite CASI imagery for the same scene. The area is near Coventry and shows a number of typical terrestrial land use and land cover types. A maximum likelihood classification (MLC) was performed using 15 bands of CASI data and associated ground data for a number of selected training areas. The classification clearly distinguishes between areas of woodland, grasses, arable fields and man-made/urban features. Within these broad groupings, further classifications are made, indicating farming practices (ploughed and rolled fields / combine harvested fields), amount of vegetation cover (woodland / trees and shrubs) and grassland types (sparse grass and soil / grass / rough grassland). It is interesting to note that the network of dirt roads in the agricultural centre found in the south of the image has been classified as 'ploughed and rolled fields'. This is due to the fact that the road surface consists of the surrounding earth and has a similar roughness to the rolled fields. The shape of the features, however, makes it simple to distinguish between the road and field areas.

Classification of land cover types using CASI data can give a good indication of land use and land management practices. This land use data has applications in the control of farming practices, monitoring of areas of setaside and general monitoring of the state of the environment in natural or unspoilt areas. Large-scale classification schemes derived from satellite imagery can provide information on a national basis, but are often of limited use because of factors such as time of acquisition, degradation due to atmospheric effects and low spatial resolutions. Due to the flexibility of the CASI as an imaging tool, it is possible to obtain land use/land cover maps at the desired resolution for any area at the most suitable time of the year, thus adding to satellite-based classifications at the desired spatial and temporal resolutions.

Figure 2: Coventry area. Land use/Land cover classification (above) and true-colour composite (left).

3.1.2 River Corridor Classification

The CASI instrument has been used to classify land use and land cover types in river corridors. Classified areas have included the upper, middle and lower sections of river courses. Figure 3 shows a supervised maximum likelihood classification of the Lower Wyre. The classification is based on a CASI image with 3 metre pixels and clearly shows areas of deciduous wood, improved pasture, arable land and housing/built up areas. The meandering course of the river Wyre can easily be identified in the image.

Land cover maps at the resolutions shown in figure 3 have applications in habitat mapping and monitoring, conservation management and for assessing the impact of local land-use on water quality. Clearly defined, classified areas allow a quantitative measure of land cover to be established and can be used in monitoring expansion or retreat of land cover types.

3.1.3 Coastal and Intertidal Classifications

Intertidal zones can be classified in order to map the extent and position of valuable, diverse habitats such as saltmarshes. Figure 4 shows a classification of the intertidal zones in the Langstone Harbour. The classification was performed using imagery obtained on the 4th August 1996, at low water and clearly shows areas of saltmarsh, mudflat and dense/sparse algae. The Langstone and Chichester harbour areas have been declared as Sites of Special Scientific Interest (SSSI). Previous studies of the trophic state of the estuary have consisted of interpretation of false colour composite aerial photography, but more recently, a digital classification performed on CASI data was used. The automated digital classification is a more cost effective method which produces repeatable results.

In order to monitor the extent of habitats in the intertidal zone, CASI data can be used to establish the area covered and percentage cover of different cover types, as shown below for the Langstone and Chichester harbours estuary.

Land cover class	Area (hectares)	Percentage cover
Mud	1601	38
Sparse green algae	1351	32
Saltmarsh	449	11
Dense green algae	331	8
Sand	279	7
Wet Mud	154	4
Total	**4165**	**100**

Figure 3: Maximum likelihood classification of the Lower Wyre. Classifications: **mid-blue** = river; **light-blue** = pond/lake (shallow); **grey** = built up; **blue-green** = arable; **green** = pasture (improved); **yellow** = haycut; **dull green** = lowland rough grass; **red** = deciduous wood.

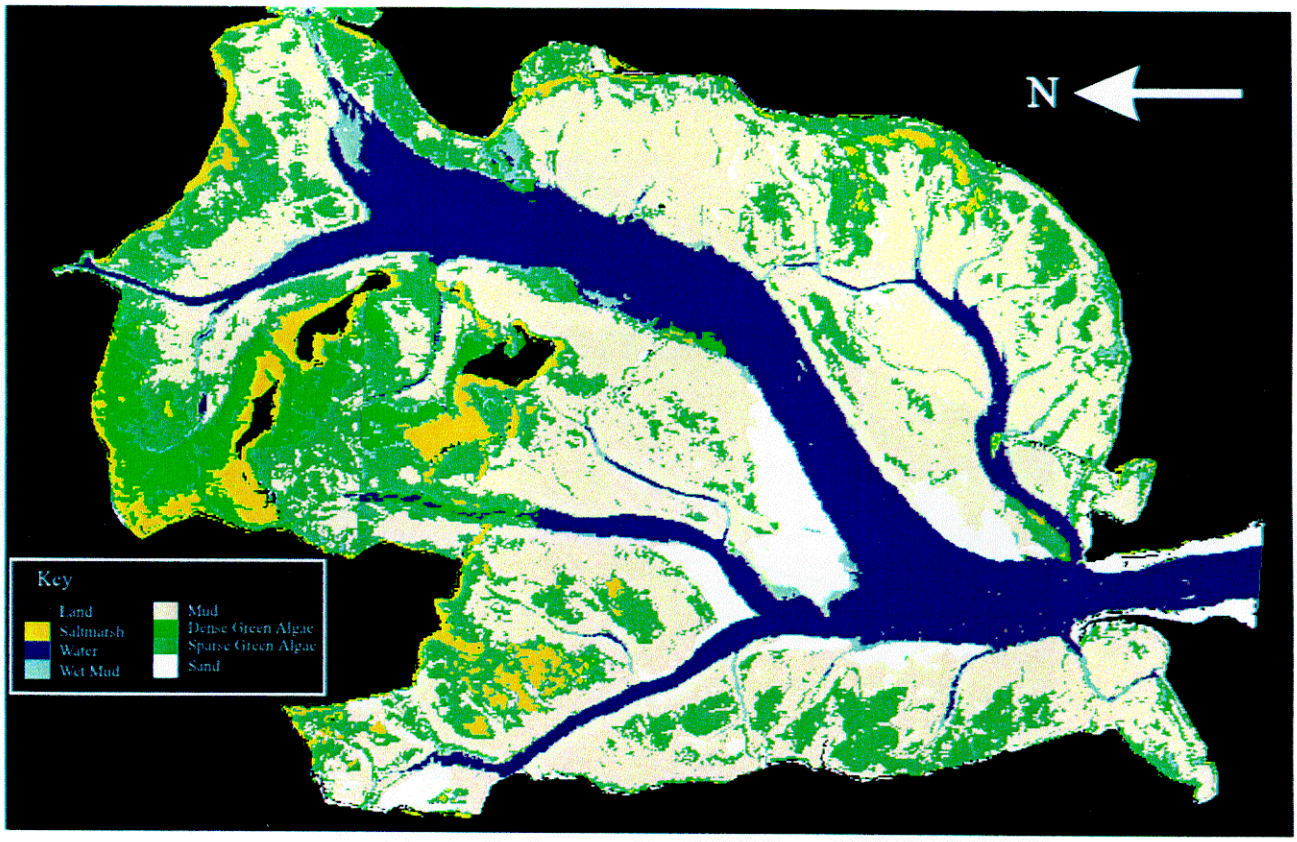


Figure 4: Langstone harbour. Land cover classification and true-colour composite.

CASI data yield valuable information about the features measured. As such, they also form a useful record for future change detection analysis. Data in the table above can be used to reveal changes in the extent of different habitat types over time. These changes will highlight any environmental problems and may indicate the presence of pollutants or illegal discharges. The table above shows a total algal cover of approximately 40% (Dense + Sparse green algae), this is in excess of the 25% considered to be indicative of sensitivity to eutrophication and indicates that further investigation of this sensitive area is required.

Classifications of the intertidal zone also have applications in flood defence and shoreline management. These applications need remote sensing data at high spatial resolutions, but broad level classifications at varying spatial resolutions are likely to be sufficient for strategic planning. The physical structure of the environment is the primary quantity to measure and examples of important functions include the detection of changes to saltmarshes and areas of erosion and accretion. The coastal zone classification shown in Figure 5 is of a 6 km length of coast at Wylfa, Anglesey in North Wales. This is an area of rocky coast, with cliffs, bays and some shingle. The industrial complex in the centre of the image is Wylfa nuclear power station and the small urban area to the east is the town of Cemaes Bay. The class map was produced using supervised Maximum Likelihood Classification (MLC), yielding 24 sub-classes which were amalgamated into 14 classes. Supporting ground truth data have confirmed the land-cover types as assigned by the classification. For the purposes of flood risk assessment, the urban and industrial areas represent high value areas where flood damage is likely to have a high economic cost. By the same principle, the areas covered with coastal heath are not crucial to flood risk assessment, as they are considered to have low economic value.

3.1.4 Flood risk assessment and water quality evaluation

It is possible to combine classified land-use data with Digital Elevation Maps (DEMs) that have been obtained using a tool such as LiDAR (Light Detection And Ranging) or SAR (Synthetic Aperture Radar). This combination of georeferenced land-use and elevation data has applications in flood risk assessment and water quality evaluation.

In the flood risk assessment scenario, it is possible to assign a value to land according to its usage type and elevation. This derived dataset can now be used to assess the damage that will be caused by flooding to a specified level. Modelling of this type allows flood defence mangers to quickly assess the economic cost of flood events and plan relevant flood defence strategies.

Arable land which coincides with high slope values has the potential to contribute high levels of Nitrates, pesticides and herbicides to run-off water. These areas contribute to Vulnerable Zones as specified by the Nitrates Directive (see section 3.3.5). Class maps and matching DEMs can be used to identify high risk areas and thus help in enforcing the associated directive.

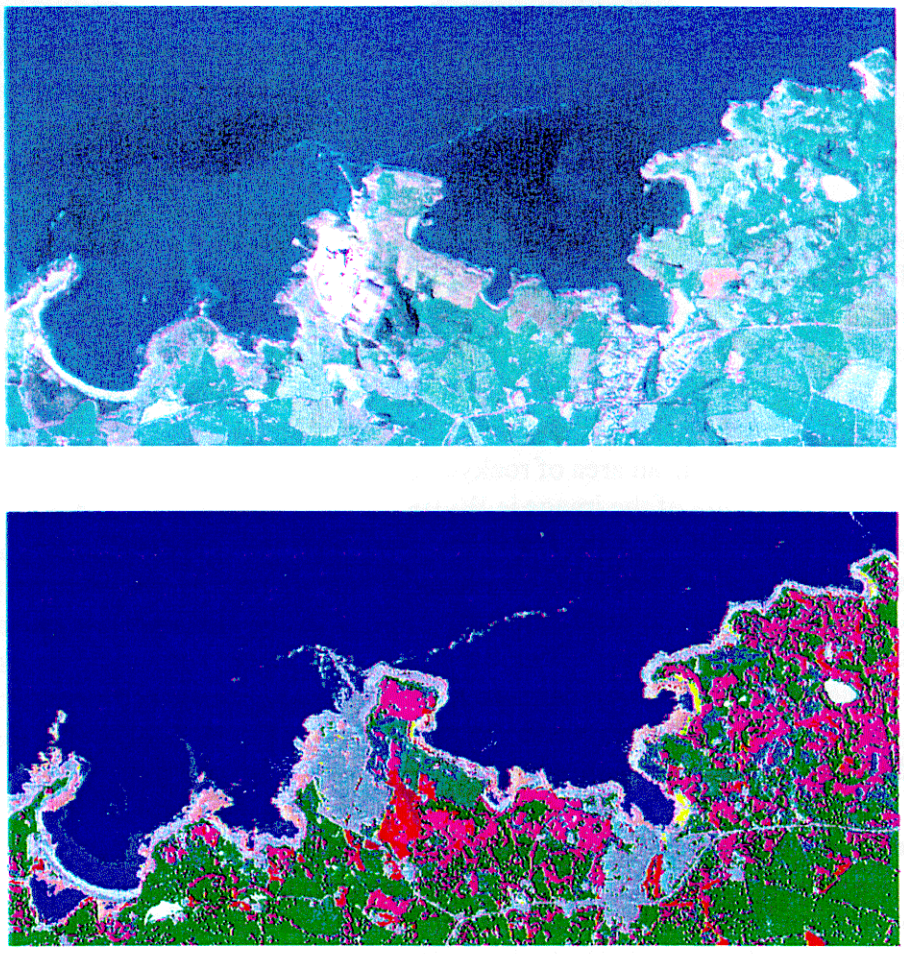


Figure 5a: CASI true colour composite and supervised classification of Wylfa, Anglesey, North Wales

Colour key for environment types

Figure 5b: Colour key for Figure 5a

3.2 Status of Biological Communities and Biodiversity

In order to monitor the status of biological communities and populations and gain an indication of biodiversity, it is necessary to identify the location and extent of various habitat types. It is desirable to differentiate between different habitats and also to monitor their health over time.

By monitoring habitats on a national basis, using an instrument such as the CASI, it is possible to build up an overall picture of natural capital and of the condition of ecological resources. The CASI is capable of providing complete, homogeneous coverage of habitats in order to contribute to knowledge at the national level. By obtaining large-scale coverage, the CASI can be used to identify habitats, such as saltmarshes and wildflower meadows, that are of interest to conservationists.

By providing a wider spatial context for ground surveys of biodiversity, CASI imagery is able to contribute to and increase confidence in the interpolation of ground-based survey results. Initiatives such as *Countryside 2000* can be made more effective by knowledge of the land use and cover types surrounding the selected sample areas.

Remote sensing of habitats and species within these habitats offers a number of distinct advantages over conventional methods. Fragile ecosystems such as saltmarshes are easily disturbed by conventional sampling techniques and the CASI offers a non-intrusive means of monitoring these areas without causing any damage to them.

3.2.1 Habitat identification

Figure 6 shows a CASI false-colour composite of the Somerset Levels, Tealham Moor, an area which has been classified as a Site of Special Scientific Interest (SSSI). Under normal circumstances, the fields in this area flood annually and are classed as wetland meadows. The image has a ground resolution of 2m, clearly showing fields and a system of drainage canals. In this false colour image, green vegetation is coloured red, with brighter shades indicating healthy vegetation. The blue and black areas in the lower half and top right hand corner of the image are fields which are covered with unhealthy vegetation or are bare. This area is prone to flooding and it is possible that the state of these fields is a result of previous floods. Clear variations can be distinguished between fields and also within individual fields.

The CASI imagery allows us to assess the relative health of the vegetation in this area and to examine the state of the habitats. The relative health of the vegetation can be monitored, as well as the number of drainage ditches and other man-made features, giving an overall picture of the health and type of habitats in this SSSI.

3.2.2 Saltmarsh health and biodiversity

Figure 7 shows a classified land cover map of the Eling and Bury Marsh area of the Southampton Water saltmarshes, taken on the second of August 1996 at low water. Clearly discernable are various saltmarsh types (Upper; Mid-Upper; Low-Mid and Pioneer) which have been classified according to their constituent plant/floral types (see figure). Observation of these areas over time

will reveal advance or retreat of the saltmarshes and will give an indication as to the health of the marshes, according to the extent of various floral species.

An interesting feature is the small area of dense green algae in the southern section of the image which is coincident with the outfalls of two sewage works that serve the Southampton urban area. Because of the sparseness of algal cover throughout the Southampton Water intertidal zone, the area is not considered to be vulnerable to eutrophication. However, the classification has revealed small areas with high algal densities that merit further investigation.

Figure 6: CASI false colour composite of the Somerset Levels, Tealham Moor area.

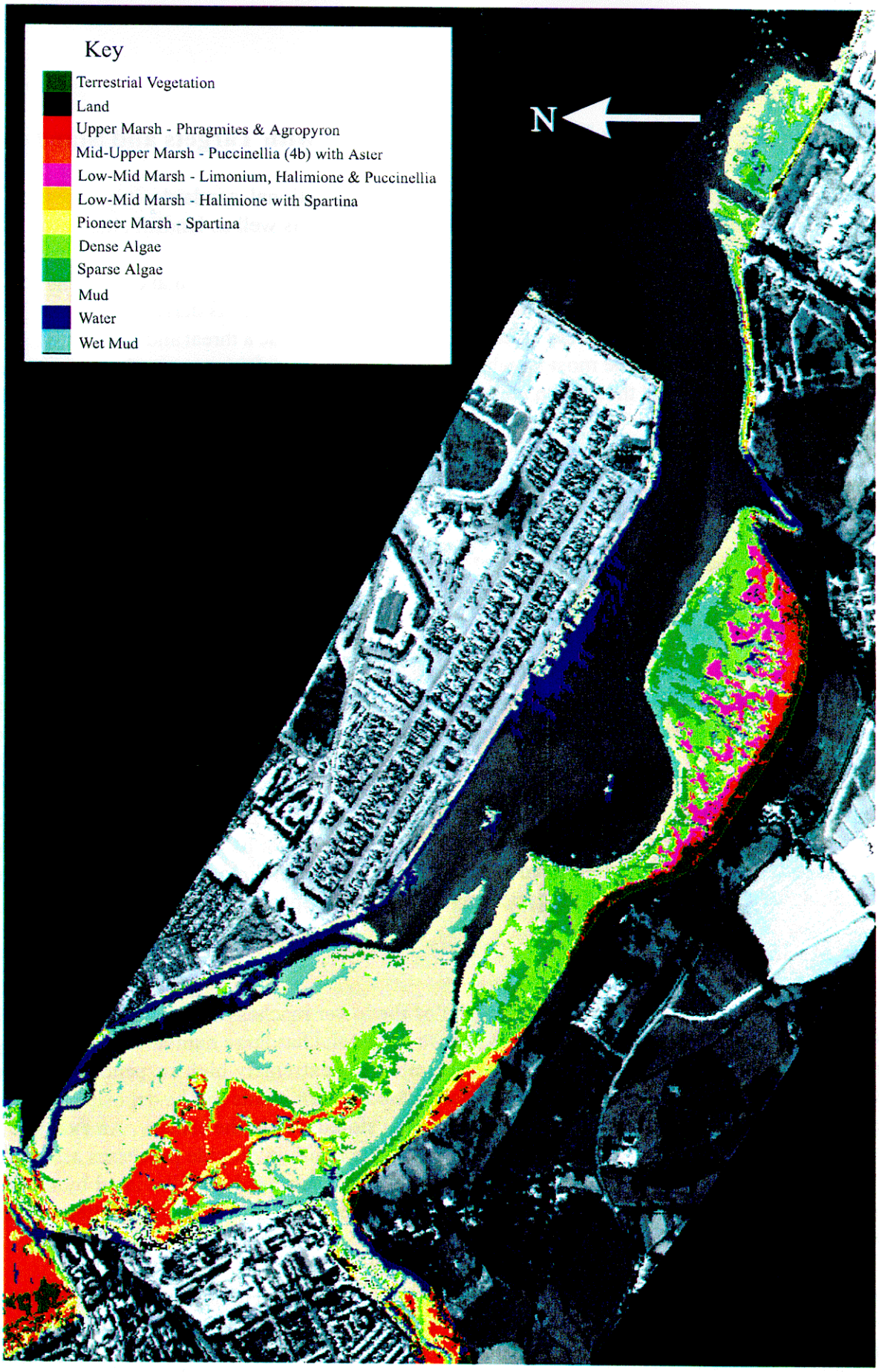


Figure 7: Unsupervised Classification of Southampton Water
Eling and Bury Marsh Area

3.3 Quality of the Environment: Compliance with Targets and Standards

In order to ensure compliance with both national and international standards, it is necessary to monitor discharges from industry, power stations and mines as well as landfill sites.

By monitoring the quality of the environment, the Agency is able to ensure that contaminants and dangerous substances do not become a threat to public health. Datasets derived from the CASI can be used to identify specific areas where contaminants may pose a threat and to direct baseline measurement activities to the most suitable locations. The aim of this monitoring is to protect both the environment and the human beings within it.

CASI data can be used in a number of ways to monitor the quality of the environment, these include:

- identifying times of discharge;
- locating areas of workings;
- monitoring settling pools;
- tracing runoff problems and
- mapping the extent of mixing zones.

The larger spatial context provided by CASI imagery can be used to direct sample taking to the most relevant areas, according to extra information gained from the imagery. Information about the nature of discharges such as whether they are continuous or pulsed can also be obtained from CASI data.

Remotely sensed data from the CASI have many uses in support of the directives which establish environmental targets and standards. Although CASI data can not be used to measure levels of contaminants, the CASI tool does have a valuable role to play in directing measuring activities and aiding the understanding of the processes involved in dispersion of contaminants.

3.3.1 Industrial discharges

Figure 8 shows a CASI true-colour composite of the lower reaches of the Humber estuary, at 10m spatial resolution. This area is heavily industrialised and has large numbers of both sewage and industrial outfalls. In addition, the river Humber has extremely high suspended sediment concentrations. There is a danger that industrially based contaminants will be deposited with the sediments, resulting in high levels of pollutants being stored within the estuary. An example of this type of pollution is iron staining, a by-product of the titanium dioxide processes associated with two of the outfalls in the estuary. This potential problem has been alleviated by moving these outfalls to deeper water where there is a stronger tidal flow and thus better effluent dispersion.

Figure 8 shows mixing zones from two of the outfalls in the lower Humber estuary, the imagery was acquired on a half-rising tide. The distinctive red and yellow colouring of the outfalls, makes the mixing zones easy to detect and provides a clear indication of the zones of influence of the two discharges.

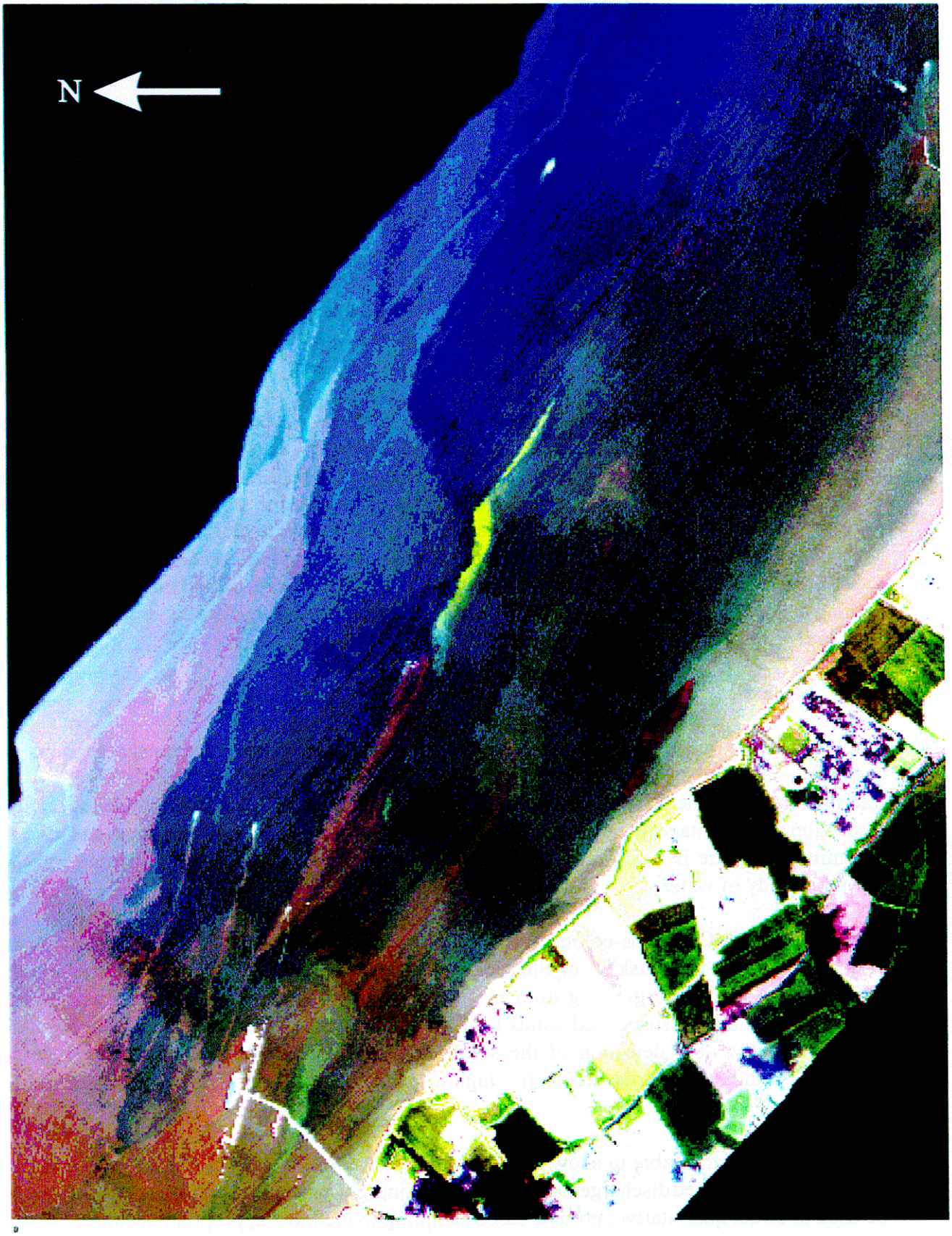


Figure 8: Enhanced CASI true-colour composite of the river Humber.

The outfall near the centre of the estuary results from a titanium dioxide plant, the elongate structure of this mixing zone indicating that there is little mixing of this acidic discharge perpendicular to the tidal flow.

Sets of CASI imagery, acquired at different tidal states can be used to direct sample taking within the estuary in order to enforce legislation such as the Titanium Directive. This will ensure that samples are taken within the correct discharge plumes and that no artificially low concentration readings will be produced.

3.3.2 Sewage works discharges

True colour composite imagery from the CASI can be used to monitor the nature of sewage discharges and the area of extent of associated mixing zones. Imagery is able to provide valuable data relating to mixing zones and detect the proximity of outflow to sensitive areas such as bathing beaches. Figure 9 is a true colour composite showing a sewage outfall approximately 1.5 km offshore, near Blackpool. The image has been enhanced to accentuate the offshore sewage discharge, leading to saturation of the beaches along the coastline on the right hand side of the image. It is interesting to note that the discharge is pulsed, with three individual pulses visible in this image. By obtaining imagery at different tidal states, a full picture can be established regarding the dynamics of the mixing zone associated with a particular outfall. The CASI can once again be used to direct sample taking to the most suitable locations and can also provide a good indication of which bathing areas are likely to have high levels of pollution and thus poor bathing water quality. This monitoring plays an important role in the enforcement of legislation such as the Bathing Water Quality Directive.

3.3.3 Mine discharges

Discharges from mines can pose environmental threats by introducing chemical contaminants and high levels of suspended solids into surrounding streams and rivers. Where discharges occur into small streams, the difference in suspended solids loading can be difficult to identify. High resolution CASI imagery can be used to locate discharges into small streams and rivers, assuming that there is a differential in the suspended solids loading of the discharge and the receiving body of water.

Figure 10 shows a CASI true-colour composite of the river Rother, adjacent to the Orgreave open cast coal mine on the outskirts of Sheffield. A discharge plume can be seen in the southern portion of the Rother, originating from an outlet on the east bank. This discharge is a sewage discharge with a high suspended solids loading. At the time of imaging, there were no mine discharges active, but detection of the sewage discharge indicates that detection of mine discharges with similar characteristics (i.e. high suspended solids loading) is possible using CASI imagery.

CASI imagery is thus able to show the areas of influence of licenced discharges and can also identify any unlicensed discharges associated with mining. The location of mixing zones can then be used to direct quantitative, ground-based sampling to the most appropriate location.

Figure 9: Sewage discharge off Blackpool

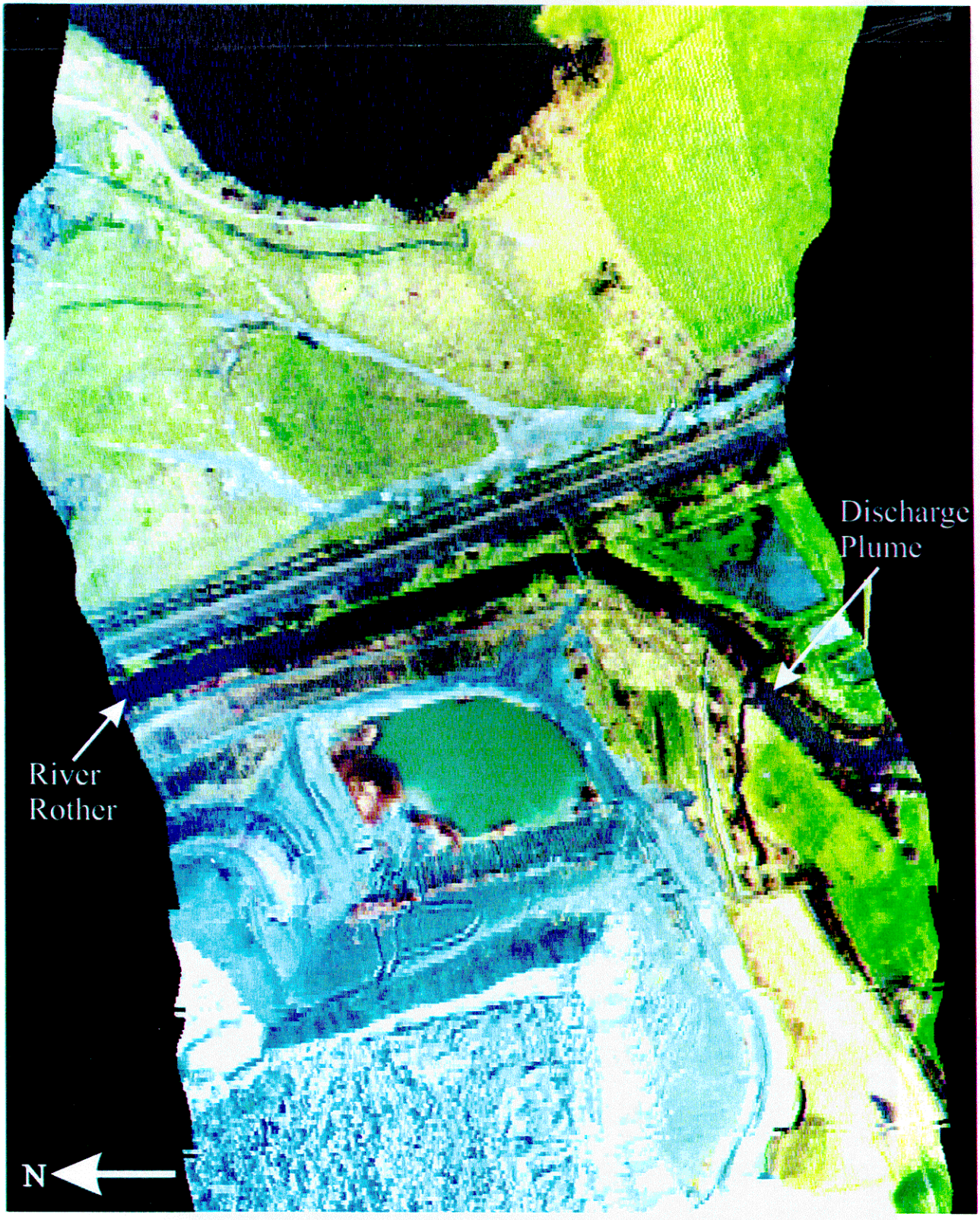


Figure 10: CASI true-colour composite of the Orgreave mine.

3.3.4 Estuary water quality

Remote sensing imagery can be used as a tool to predict the effects of proposed outfalls on the environment. Figure 11 consists of CASI data superimposed on an Ordnance Survey map of the Walney Channel and shows a cloud of Rhodamine Dye (large red area) which has been used to simulate a proposed outfall. Rhodamine dye has a high fluorescence and is easily detectable in minute quantities in water samples.

The dye was released at the proposed outfall site and imaged at regular intervals as the cloud moved under the influence of local tides and currents. The exercise served to show that discharge from the outfall would pose a threat to the sensitive coastal area and beaches which are adjacent to the dye plume in the figure.

A related application is the use of CASI data to detect the location of deep channels in rivers and estuaries. The CASI can differentiate between shallow and deep waters and hence is able to locate channels. This data provides information about the movement of water through the estuary or river and can reveal areas along these channels which are likely to be affected by any outfalls.

CASI data has also been used to measure and model the presence of suspended solids in estuaries. The estuarine environment changes rapidly according to tidal variations and the location of suspended solids from both natural and anthropomorphic sources is subject to a high degree of variability, influenced by the movement of both tidal and fresh waters. CASI data were acquired at regular intervals throughout a full tidal cycle over the Tamar estuary near Plymouth and these data were interpolated to generate a full simulation of suspended solids concentration in the estuary over the tidal period. Digital maps were produced, giving a quantitative measure of the suspended solids concentration throughout the estuary. This simulation was valuable in determining the dynamic nature of the estuary in order to assess the validity of existing statutory sampling sites.

3.3.5 Algal blooms

Figure 12 is of Coniston Water in Cumbria. The image shows the presence of a large algal bloom in the centre of the lake. The presence of this bloom indicates eutrophication of the water body and points to increased nutrient levels caused by nitrates from run-off from surrounding farmland or sewage discharges. Increased nutrient levels, together with favourable growing conditions for algae (warmer temperatures, increased sunlight) lead to increased phytoplankton and chlorophyll-*a* concentrations. High local concentrations manifest themselves as algal blooms. Blooms, in turn, can cause reduced oxygen concentrations which are damaging to other aquatic life and can also become toxic, poisoning aquatic species and posing a danger to humans. The presence of large quantities of algae in the water can also block fish gills. The Coniston bloom was unusual because, due to the wind in the valley, it formed at the centre of the lake. Conventional samples were gathered from the lake shore and would not have detected the presence of this bloom.

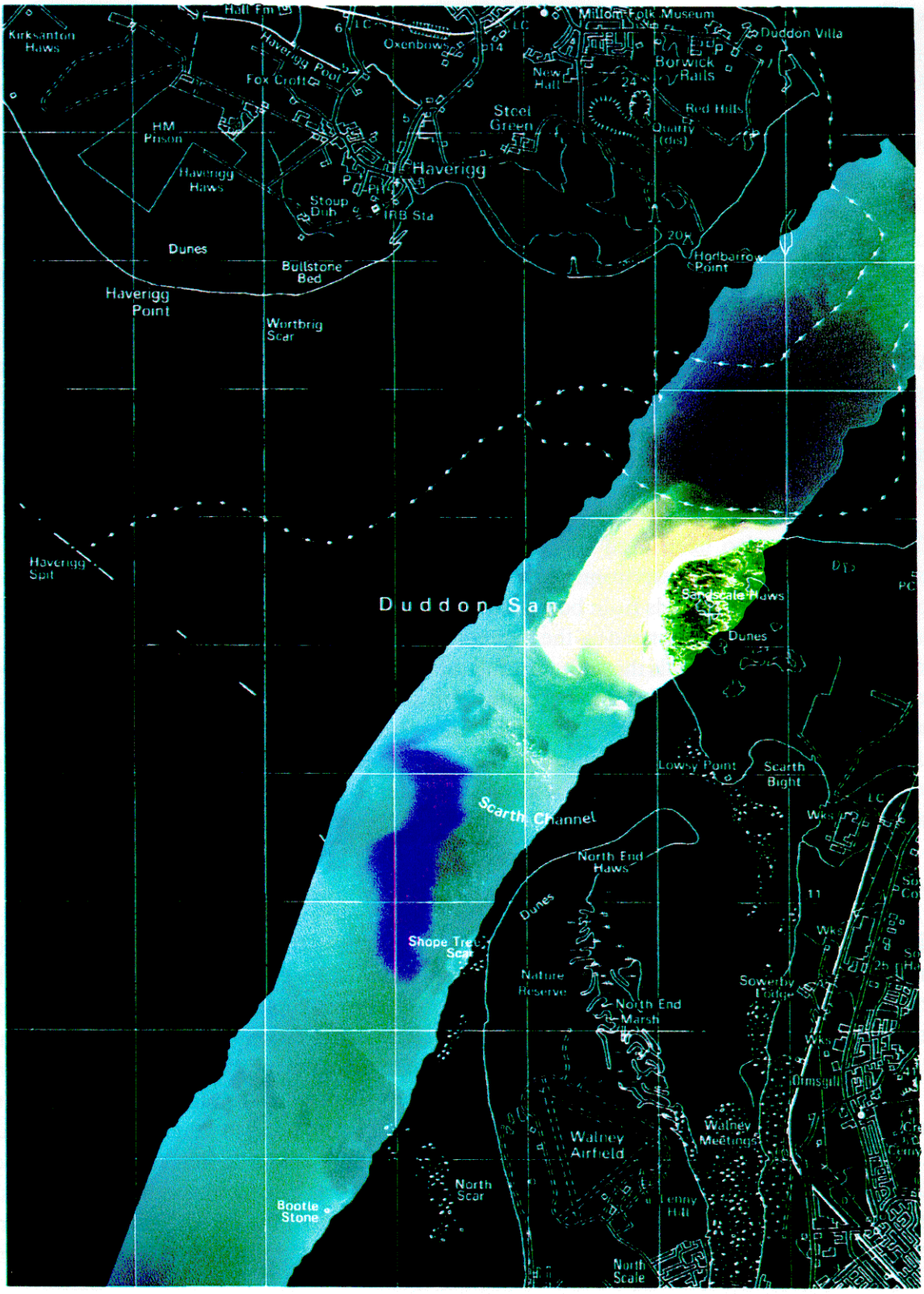
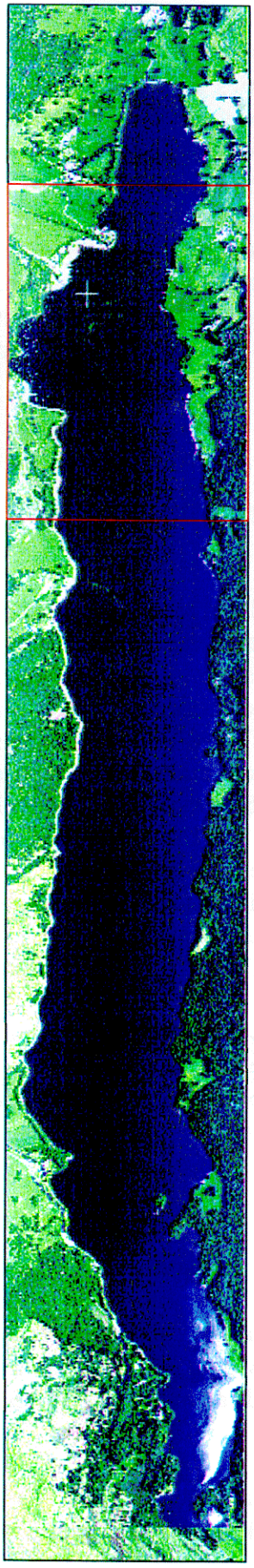


Figure 11: CASI true colour composite image of an area off the North coast of the Isle of Walney, Cumbria, with OS map data overlay. Image taken on 24 / 06 / 97 at 15:05 GMT



True colour composite image

Enhanced true colour composite image

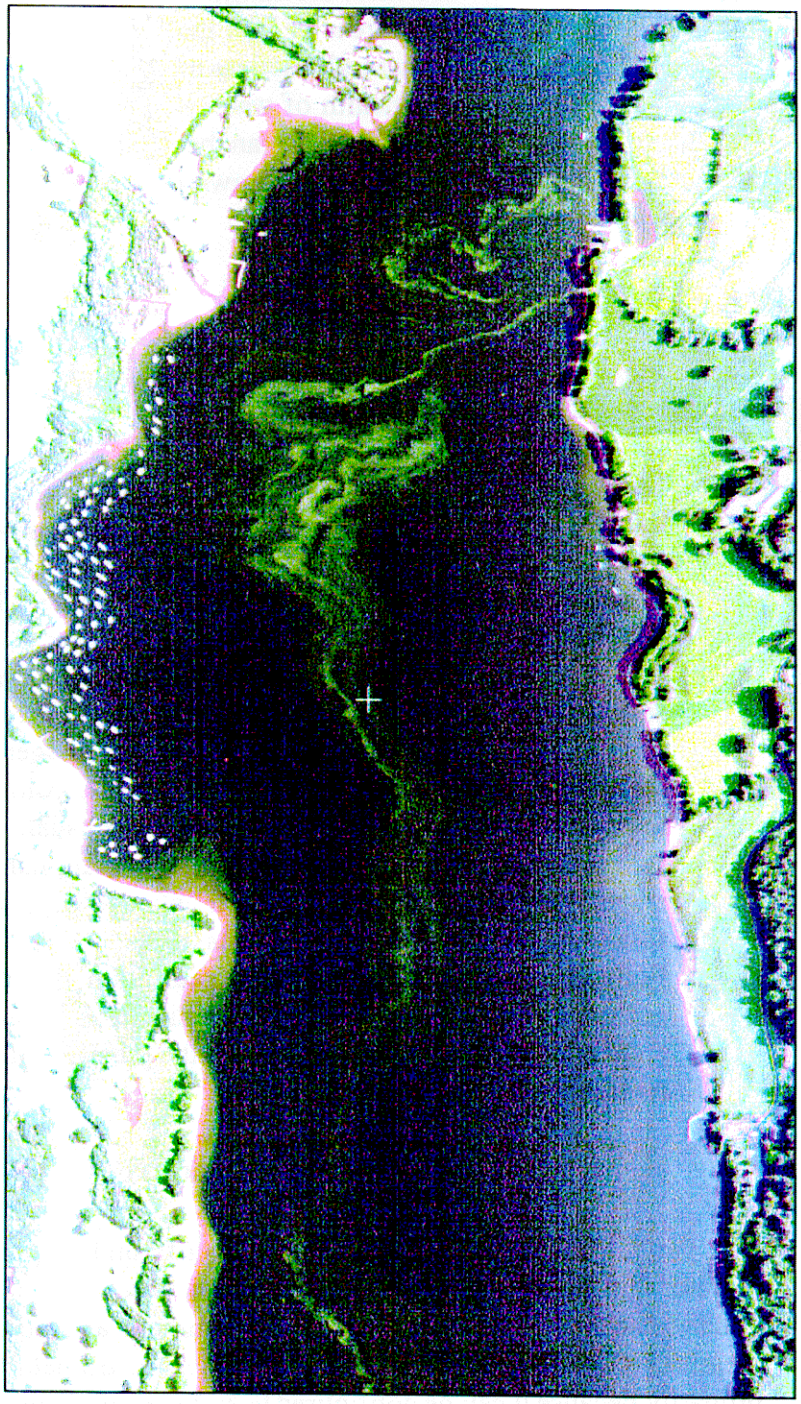


Figure 12: CASI imagery of Coniston Water.
Flown 22 June 1995 at 08:15:21 GMT.
An algal bloom can be seen in the middle of the lake.

Under the provisions of the Urban Waste Water Treatment Directive (UWWTD) (91/271/EEC) and the Nitrates Directive (91/676/EEC), inland waters and estuaries may be designated as Sensitive Areas or Polluted Waters respectively. The directives provisions state that, for those waters found to be Sensitive Areas, all qualifying discharges will have to be stripped of nutrients unless it can be proved that these discharges will not affect the level of eutrophication. For areas found to be Polluted Waters, areas of land that drain into the water body must be designated as Vulnerable Zones and agricultural practices in these zones must be restricted. The CASI provides a means of monitoring the health of water bodies in order to detect algal blooms and hence, increased nutrient levels. The data can be used to detect land-use and land cover within Vulnerable Zones. Inferences can be drawn regarding the high-risk land cover types and used to direct appropriate follow-up sampling.

3.3.6 Other Areas

CASI imagery has potential applications for monitoring the quality of the environment in a number of other areas, including:

- Dangerous substance and acid mine drainage: Mining of coal and metallic minerals has the potential to release environmentally damaging contaminants into the local drainage system. Acid mine drainage is produced when water comes into contact with pyritic material (iron sulphides) and oxygen in coalmines. The sulphuric acid associated with the iron sulphides lowers water pH and increases the solubility of metallic ions such as iron, aluminium, manganese and zinc. Water contaminated by acid mine drainage poses a severe threat to aquatic fauna and flora and is characterised by a reddish-yellow colour caused by ferric oxide precipitates. CASI imagery can be used to detect acid mine drainage through the presence of distinctively coloured waters.
- Monitoring of shellfish beds: These beds are usually situated in or near estuaries and are susceptible to poisoning by water-borne contaminants introduced into the estuary. High suspended sediment loading is often linked to water-borne pollutants and can indicate the source of any poisoning of the beds.
- Pollution from fish farms: High resolution CASI imagery can be used to monitor pollutants introduced into the environment as a consequence of fish farming activities. Again, differences in colour indicate the presence of suspended solids and any associated pollutants.

3.4 Health of Environmental Resources

It is part of the Agency's function to identify and map our environmental resources and to monitor the health and condition of these resources. Observing these resources aids our understanding of the health of the environment and how it is changing in response to the pressures placed upon it. The CASI is an ideal instrument for observing environmental health, primarily because it can be configured to suit various applications and can be used to obtain data when and where necessary.

The health of individual environmental resources is monitored on a regional basis. The high resolution capabilities of the CASI make it well suited to this task especially when used in

conjunction with ground based surveys. It is important that the CASI data acquisition is directed by local expertise in order to maximise the usefulness of the datasets and ensure that the correct bandsets and resolutions are chosen to complement ground survey work.

The European directive on the conservation of natural habitats and of fauna and flora imposes obligations on the European member states for the conservation of habitats and the protection of species. The central concept of the directive is the maintenance of favourable conservation status for both natural habitats and wild species of community interest. Favourable conservation status is defined by reference to factors such as species population dynamics, trends in the natural range of species and habitats and the area of habitat remaining. Implementation measures are designed to maintain or restore the favourable conservation status. Remote Sensing techniques have obvious applications in supporting this directive by mapping the area of natural habitats and changes to the range and position of these habitats.

3.4.1 Beaches and sea fisheries

Environmental resources such as bathing beaches and sea fisheries are easily affected by pollution incidents such as oil spills. The recent Sea-Empress oil spill at Milford Haven took place in an environmentally sensitive area, much of which is designated as nature reserve. Figure 13 shows an area of coastline at Tenby, with the oil slick clearly visible just off the coast. It is also interesting to note the orange colour of the beaches, caused by surface oil contamination. This imagery indicates which areas of coastline were affected by the oil contamination and shows habitats that have been damaged.

The wreck of the Braer, off the Shetland Isles in 1993 caused a large amount of oil to be discharged. Because of the remoteness of the area and bad weather, it was difficult to determine the extent of the contamination through conventional methods. The CASI was flown below the cloud base and was able to acquire good quality data which was used in determining the affected area. This serves to illustrate the versatility of operational remote sensing using the CASI instrument.

3.4.2 Water quality

Inland and coastal waters are important environmental resources and require monitoring in order to ensure that adequate water quality is maintained. Water quality can be degraded by industrial or mining outfalls, excessive nutrient levels and events such as oil spills. Excessive nutrient levels are caused by sewage discharges and nitrate-rich run-off from farming land and can often result in the formation of algal blooms. These blooms are large features, the presence and extent of which is easily detectable with the CASI. For an example of imagery that clearly shows the presence of an algal bloom in inland waters, see Figure 12 in section 3.3.5.

Pollution of water bodies is attributable to two major sources, these are point outfalls and diffuse pollution. Point outfalls can be identified from CASI imagery by the presence of mixing zones. These mixing zones are easily detectable when the suspended sediment loading of the outfall differs from that of the surrounding water body, see sections 3.3.1 to 3.3.3. Diffuse pollution is not as easy to detect, as it is a distributed phenomenon, mainly attributable to run-off from

agricultural land that may contain pesticides and fertilizers. Length and steepness of slope, as well as ploughing practices all contribute to the amount of polluted run-off from individual fields.

Because of increased rainfall, fields that are left bare in the winter months are likely to make a large contribution to polluted run-off. The CASI can be used to identify these fields in order to trace the origins of the diffuse pollution. Further information can be gained from CASI imagery obtained when the fields are under cultivation. This imagery can be used to identify the crop types and hence the chemicals which may have been used on each particular field. The matching of the CASI data from the two seasons can show which fields have been left bare in winter and what crops each of these fields had contained previously. This information can give some indication of the nature and extent of diffuse pollution as well as to direct farm management practices

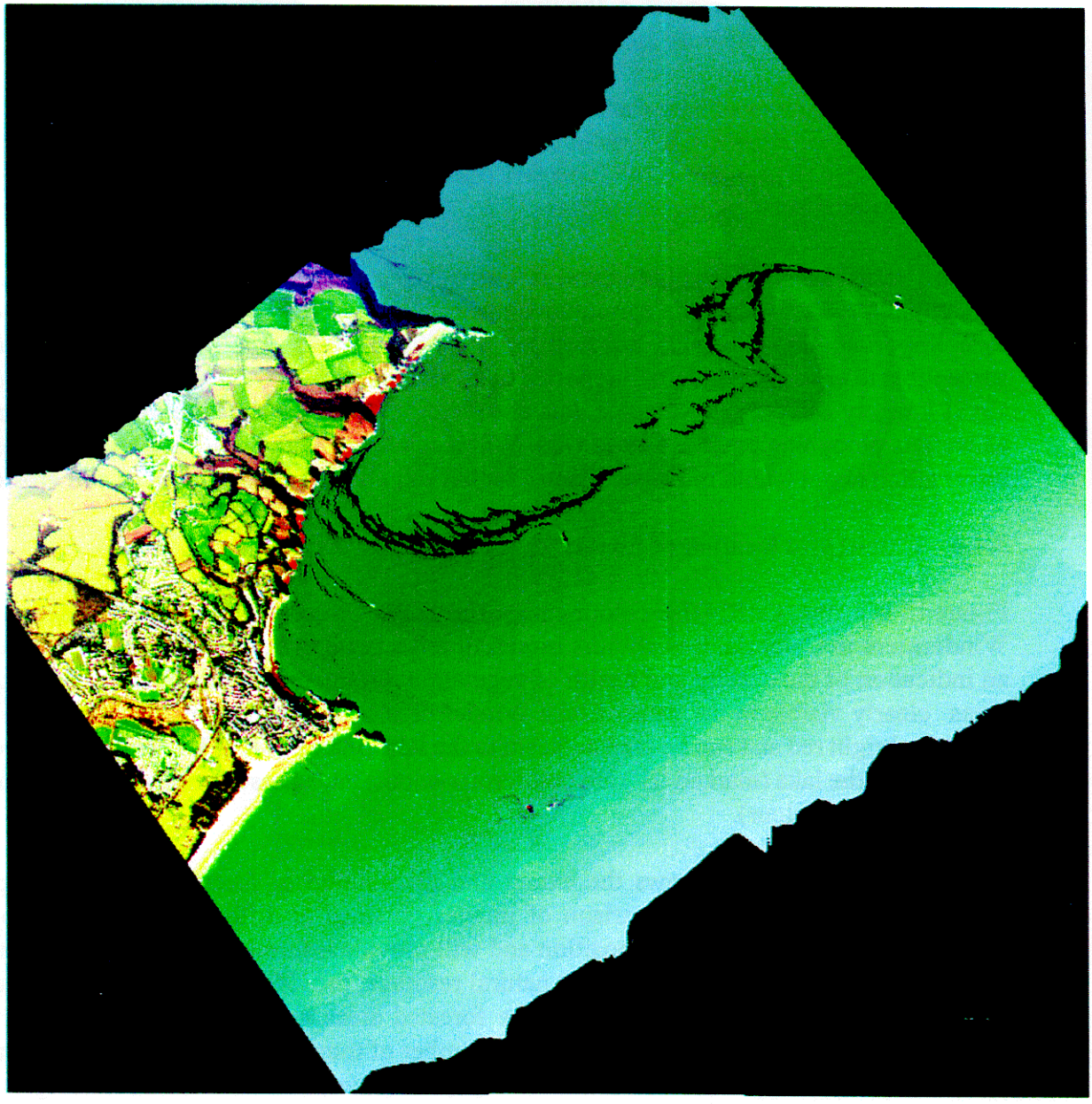


Figure 13: CASI image of the Tenby area in Camarthen Bay

3.4.3 Extent of erosion

Figure 14 is a 10m true-colour composite of part of the Windermere catchment in Cumbria. The image shows a mountainous area, consisting of valleys, lightly vegetated slopes and ridges, often characterised by areas of bare rock. Throughout the image there are patches of bare rock or soil. These patches either represent weathered rock (grey colour) or more recently exposed/broken rock (lighter shades). Also visible in the image is an extensive network of footpaths. The narrow footpaths are simply bare earth paths worn through use by the large number of tourists and walkers that this area receives each year.

The extent of the areas of bare rock and of the network of footpaths gives an indication of the health of the environment. Changes in these features from season to season will indicate areas of erosion and high resolution CASI imagery can be used to monitor this erosion and help in the formulation of natural management plans.

Soil is a valuable non-renewable natural resource which has to be conserved in order to sustain agricultural productivity. Good agricultural management practices can minimise soil erosion and it is important that these are adhered to. Satellite imagery can indicate areas which are susceptible to erosion and can be supported by CASI data which provide intra-field information. CASI imagery can provide valuable data about fields which are left bare in the winter months as well as ploughing practices employed. When combined with a DEM, the data can provide information about length of slope, a factor which can influence the amount of soil erosion.

3.4.4 Extent and location of forests

Figure 15 is a 10m, CASI false-colour composite of the Grizedale Forest area, adjacent to lake Windermere in Cumbria. Red colours represent reflectance in the near infrared band and give an indication of the density and health of vegetation. Of interest in this image are the forested areas clearly visible to the west of lake Windermere. Areas of healthy, deciduous wood are shown as bright red and can be seen adjacent to the lake (marked 'A'). The darker forested areas further from the lake (marked 'B') are coniferous woods, interspersed with areas of heather and bracken (purple colour).

This single CASI image shows the extent and distribution of forested areas, an important environmental resource. Comparison of images obtained at different times will show any changes in forest extent and composition and will provide information about tree health in the forested areas. Forests are an important natural resource, providing wood for the construction, furniture-making and paper industries. The forested areas also play a role as leisure areas, providing marked walking trails for the large number of tourists which visit this area annually. These data have applications in environmental maintenance and in the management of commercial forestry resources.

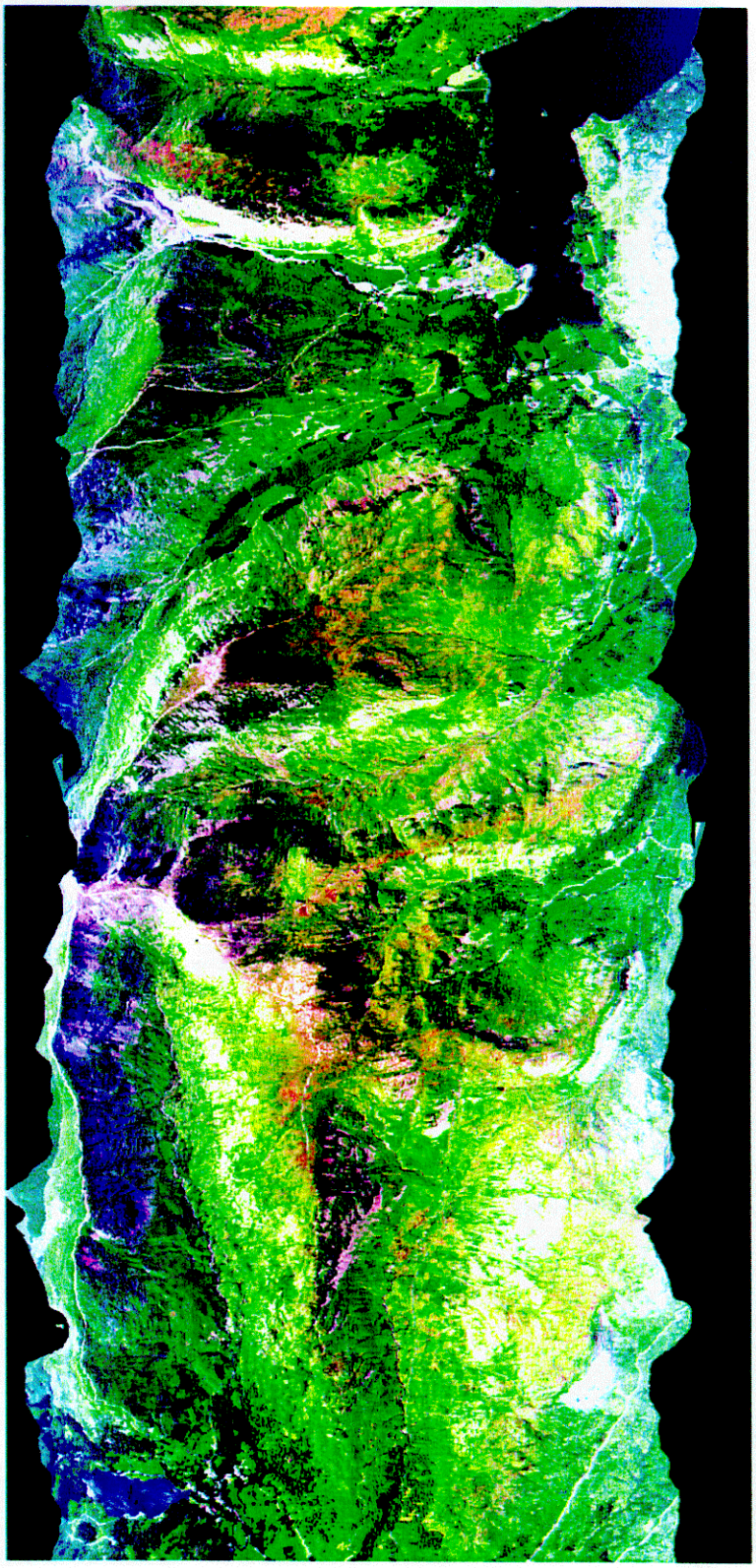


Figure 14: CASI true-colour composite of the area north of Lake Windermere

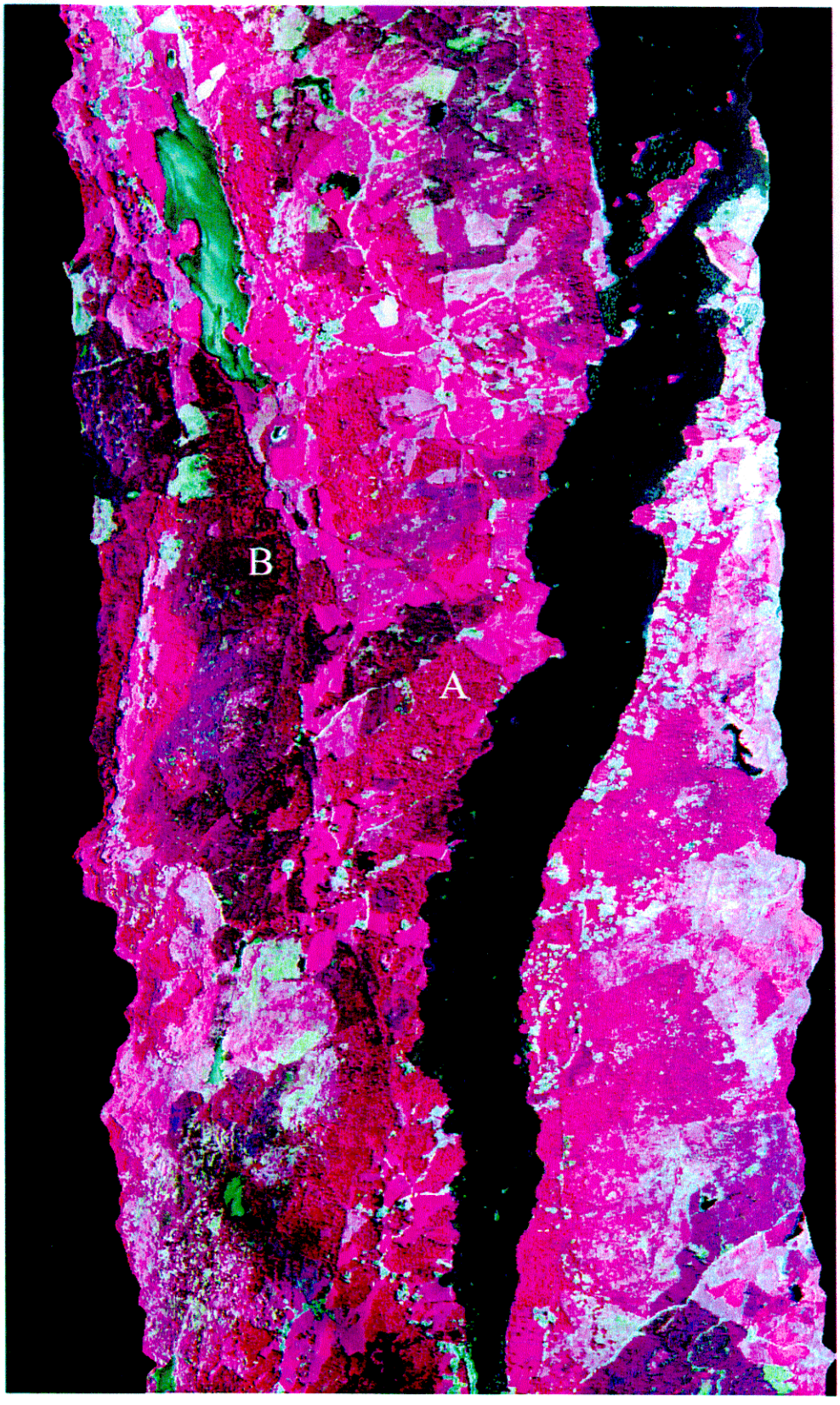


Figure 15: False colour composite of Windermere catchment

3.4.5 Coastal Waters

CASI imagery can be used to detect and map suspended solids in coastal waters. The presence of these solids (indicated by lighter areas of water in Figure 16) is indicative of naturally derived sediments and outfall mixing zones and can give an indication of the effect of local tidal behaviour on the dispersion of effluent. Figure 16 is a true colour composite CASI image of the coast off Flamborough Head, near Bridlington. The dominant feature of the image is a very clear headland eddy or gyre caused by the interaction of currents which meet at the headland. This imagery played a part in assessing the area as a High Natural Dispersion Area (HNDA).

Images such as Figure 16 also have a part to play in directing survey vessels to suitable sample sites. Information about the dynamic state of the coastal waters can be derived from the CASI imagery and can be used to identify the best sites for obtaining samples for measuring suspended sediment and effluent levels.

CASI imagery has also been used to develop algorithms for quantifying suspended solids concentrations in coastal waters. The large area measurements obtained in this way have a similar accuracy to those produced by continuous boat-based measurement. Calibrated CASI imagery can be used to produce maps of suspended solid concentration covering large areas. The algorithms developed tend to be specific to a given coastal area and are not portable to other geographic regions, however, portability to other times of the year has been proven. For further details, see the Agency R&D report, *Development and Testing of Suspended Solids Algorithms, Case Study 2.*

A related application is the measurement of chlorophyll-*a* concentrations in coastal waters. CASI-based measurements can provide accuracies similar to those from continuous track fluorometer data. A number of different algorithms are available for calculating chlorophyll-*a* concentrations, including Fluorescence Line Height (FLH) and Blue/Green channel ratios. These algorithms are not portable between surveillance events, even after the removal of atmospheric effects. There is thus a necessity to develop individual algorithms for each surveillance event, or water type.

3.4.6 Water Resources

By monitoring the health of vegetation, the CASI can detect illegal use of water resources during periods of drought and enforced restrictions. The near infra-red band can provide information about vegetation health. At high resolutions, this technique can be applied to urban areas that have hosepipe bans in place, in order to detect garden lawns which are regularly watered. These data, if combined in a GIS system with hosepipe licencing information, can produce output identifying possible transgressors. Figure 17 shows the infra-red band from a CASI dataset of March in Cambridgeshire with areas of healthy vegetation highlighted in red.

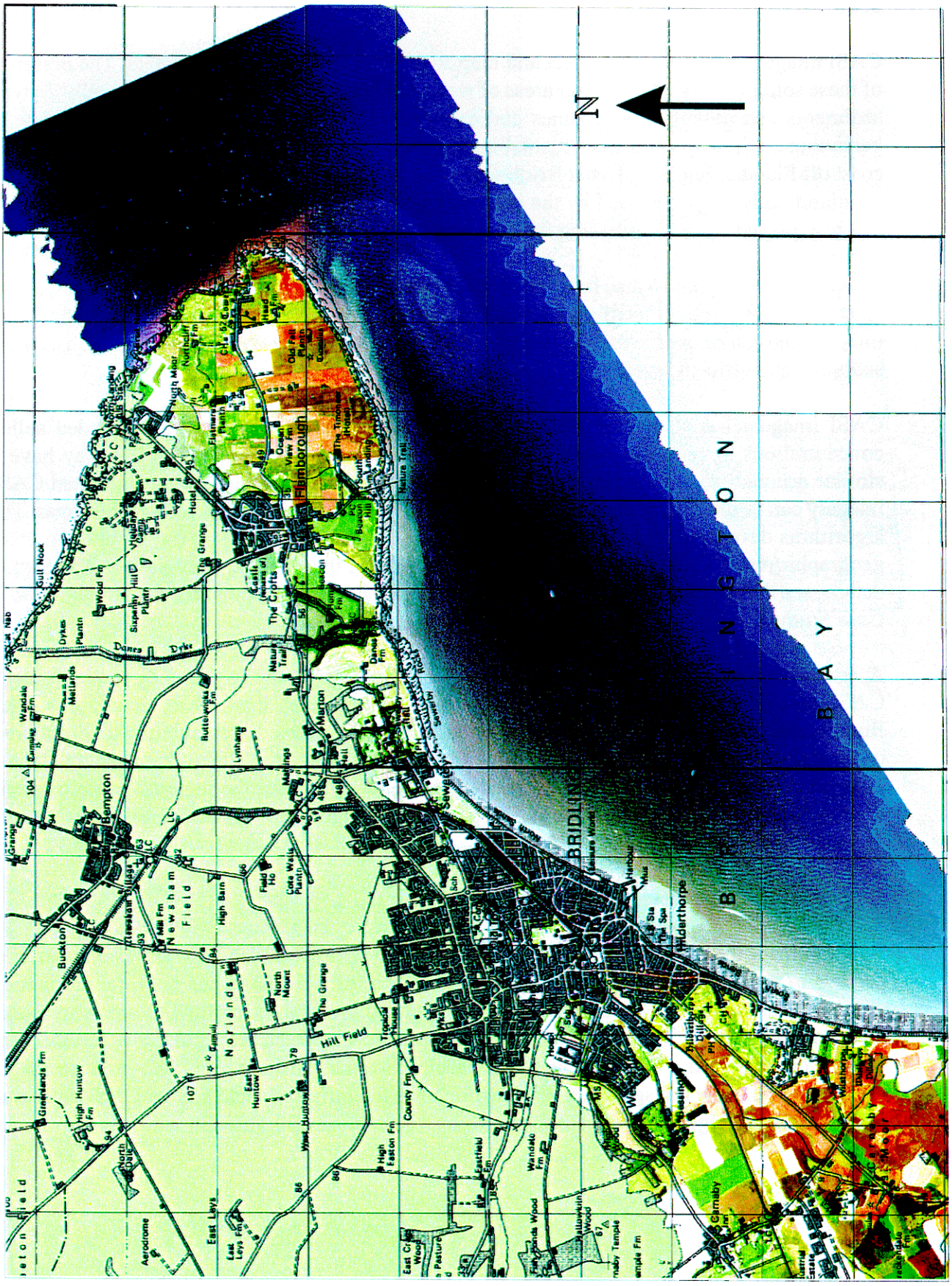


Figure 16: CASI true colour composite of the Flamborough Head area.

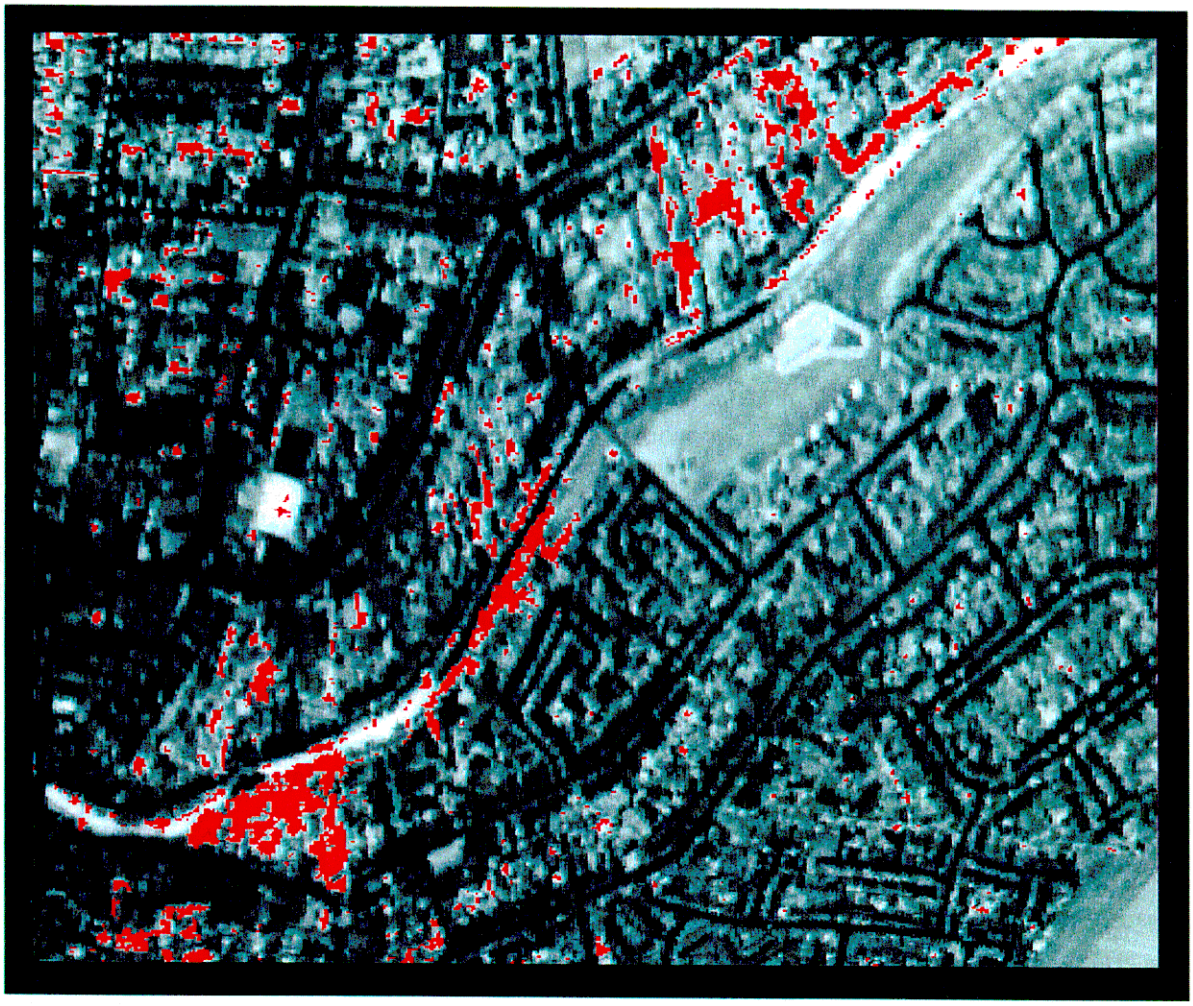


Figure 17: CASI image of March, Cambridgeshire. The image shows the near infra-red band, with areas of healthy vegetation highlighted in red.

A similar application is the detection of illegally abstracted water for use on potato crops. The CASI-derived Normalised Difference Vegetation Index (NDVI) produces an image which shows relative health of vegetation and serves to indicate which fields have received additional irrigation. Simple checks can reveal if these areas are licensed for the abstraction of water resources. The CASI thus serves as a monitoring tool to support the enforcement of water usage restrictions. For an example of NDVI imagery, see Figure 22 and the associated description in section 3.6.4.

3.5 Environmental Change at Long-Term Reference Sites

An important part of environmental monitoring is the tracking of long-term changes in the health and extent of natural resources. It is important to observe cyclical/periodic variations as well as the effects of unpredictable or episodic events.

By repeating data acquisition for the same area over a period of months or years, it is possible to build up a record of environmental changes that occur gradually over long periods of time and are otherwise difficult to monitor. The CASI is ideal for measuring the loss or gain of vegetated areas and long-term changes in environmental resources such as saltmarshes. These changes can be highlighted through the generation of change maps which are effectively the subtraction of two CASI images, revealing any areas of change. CASI data forms a valuable reference archive. Held in digital format, the data are particularly useful when overlaid with other spatial information, further aiding quantitative analysis. A further advantage is that once the data are acquired, the same datasets can be used for a variety of different applications.

An important part of Local Environment Agency Plans (LEAPs) is the surveillance of Sites of Special Scientific Interest (SSSI) within the local region. CASI data can be used for the monitoring of the general health of large areas and provides a larger scale view of the entire SSSI.

3.5.1 Coastal zone monitoring

The CASI can be used to monitor changes that occur within the coastal zone. By regularly flying the same areas, it is possible to monitor any erosion or deposition that is occurring and to obtain an indication of the rates of these processes. Closely related to this is the monitoring of the effects of change in sea-level and the influence on the coastal zone. CASI can, for example, monitor the size of saltmarshes, providing early, accurate indications of any reduction in these important tidal energy 'buffer zones'. CASI data can be used as an input to programmes of managed retreat or land reclamation and provide information which is not otherwise available to planners. The CASI-derived information can also play a part in local Agency Coastal Management Plans (CMPs) by contributing to flood prevention and environmental monitoring strategies.

The National Rivers Agency (NRA) conducted a Coastal Baseline survey of England and Wales on an annual basis. From 1992 to 1995, CASI data were collected as part of this survey. In all, 189 nautical flight lines were covered in each of nine different campaigns, covering the coastal waters out to three miles. From April 1996, the survey programme was taken over by the

Environment Agency. CASI data from these surveys (a total of about 2000 images), in combination with ship-based sampling, was able to provide valuable information on both the terrestrial and aquatic environments of the coastal zone. These data form a unique historic record for future comparative studies, and are available at the National Centre for Environmental Data and Surveillance in Bath.

3.5.2 Extent of natural features

Remotely sensed imagery can be used to determine the location and extent of natural features such as saltmarshes, dunes and forests. Simple calculations can reveal the area covered by these features and comparison of figures over time can reveal their advance or retreat.

Estuaries are sensitive zones which play an important role as a diverse habitat for many species of fauna and flora. Rising sea-level and advancing industrial and urban land use are squeezing these zones and, in certain areas, threatening to destroy them. CASI imagery can provide a clear picture of the extent of these areas and the pressures that are placed upon them.

3.5.3 Other monitoring applications

Remotely sensed data can contribute to the monitoring of Environmental Change Network (ECN) sites. On behalf of NERC, the Agency monitors 13 sites throughout England and Wales in order to obtain regular, long-term datasets for variables which have been identified as being of major environmental importance. Because of the small number of sites, this scheme does not provide complete, national environmental coverage. CASI data can be used, together with results from individual sites, to extrapolate environmental data on a larger scale. This, together with the spatial context which can be provided to the ECN sites by remotely sensed imagery, allows the CASI to make a valuable contribution to the ECN programme.

CASI imagery can be used to monitor the expansion of urban areas and the encroachment of the urban fringe on the countryside. Urban expansion threatens the health of the environment by destroying natural areas and restricting the movement of various species. It is possible that, because of the large scales involved, this application may be more suited to satellite based remote sensing. However, airborne remote sensing still has a role to play in certain cases, such as those where high-resolution imagery is needed or data acquisition is required at a specific time.

3.6 Aesthetic Quality of the Environment

Aesthetics play an important part in public perception of the state of the environment. Scientifically quantifiable measures are often considered to be less important than the more subjective perceptions held by the general public. Public perception of the state of the environment is often influenced by the extent and nature of parkland and the surrounding countryside and the contribution that these make to the general quality of life.

In order to minimise the visual impact of structural and engineering works on the environment, it is desirable to record and predict the effects of development on the natural landscape.

Modelling of proposed development can allow schemes to be devised in order to minimise the effects that this development has on the aesthetics of the environment.

CASI data can be used to aid visualisation of the impact of development on the environment. Modelling of proposed development, monitoring of ongoing works and determining the quality of the urban environment are all potential applications in this area.

3.6.1 Modelling visual impact

Figures 18a and 18b show three dimensional views of the area surrounding the River Arun. Each image consists of two datasets: a LiDAR generated DEM and a true colour composite CASI image. The images have been co-registered and the CASI data 'draped' over the LiDAR elevation model. The electronic data allow simulated views to be generated in all directions and from different altitudes, providing a useful tool for assessing the visual impact of construction or quarrying activities. Figure 18a shows a view along the Arun, from the south, towards Arundel.

Figure 18b is a similar view from a different position, to the south-west of Arundel. Both images represent the view from approximately 10 metres above ground level and all vertical heights have been multiplied by three in order to accentuate any terrain differences. These two images give a flavour for how a number of views may be generated, thus enabling the visualisation of an area from all angles. It is also possible to 'add' planned buildings and construction works to the visualisation, thereby showing their impact on the area.

This visualisation capability can be used to inform the public about the impact of any development and can demonstrate appropriate steps that have been taken to reduce any potential negative aesthetic effects.

3.6.2 Monitoring construction works

The CASI can be used to monitor work in progress in order to assess aesthetic impact during construction and help in the planning of the replacement of destroyed vegetation after development has been completed. Figure 19 is a CASI true-colour composite showing the Newbury bypass during construction. The area of construction is clearly seen as a white swath running the length of the image. The image shows where the bypass cuts through areas of meadow and woodland and its proximity to areas of housing. Imagery obtained at regular intervals during the clearing and construction of the bypass can be used in planning the re-vegetation of the cleared areas. Imagery can also be used prior to any construction work to determine the likely aesthetic impact and thereby provide possible alternatives to minimise any negative aspects of the development.

3.6.3 Quality of the urban/suburban environment

A possible indicator of the quality of the urban or suburban environment is the ratio of man-made to natural features. This takes into account the number and size of parkland areas and size of private gardens, giving a quantitative measure of the aesthetics of an area. Figure 20 shows

CASI true-colour composite imagery of the Wear estuary and surrounding areas. Large industrial and urban developments are found near the mouth of the estuary, with suburban and rural areas further up the course of the river. There is a clear increase in vegetation cover in and around the man-made features with increasing distance from the industrial areas at the mouth of the estuary. It is also noticeable that, whilst the urban areas near the coast are characterised by a small number of 'green' areas (parks and fields), the dwellings in the urban areas further away are evenly interspersed with trees and other vegetation, implying a higher quality urban environment. It is a relatively simple task to produce an index of vegetated vs non-vegetated areas in order to obtain a quantitative measure of urban density and the quality of the urban environment.

3.6.4 Impact of Landfill sites

Landfill sites can cover large areas and, until properly reclaimed with suitable vegetation cover, detract from the aesthetic value of the surrounding area and can produce leachates, together with unpleasant odours. CASI imagery can be used to identify landfill sites and monitor their reclamation to ensure that areas are returned to their natural state as quickly as possible. Figure 21 shows a CASI true-colour composite of Tatchells landfill site northwest of Wareham in Devon. The landfill site is associated with an active quarry, with the landfill (outlined in red) reclaiming the area to the north of the quarry. From the image, two distinct areas of landfill can be identified. The older of the two areas forms the eastern part of the landfill and has sparse vegetation cover, indicated by the light green shades in the image. The newer section of the landfill is to the west and, as yet, has no vegetation cover.

Figure 22 shows a Normalised Difference Vegetation Index (NDVI) image. The NDVI is a ratio calculated from reflectance measured in the visible red and near infrared channels. The NDVI provides a measure of vegetation biomass. The relative biomass can be used as an indicator of vegetation health, assuming that there is some knowledge about plant type within the imaged area. The NDVI has been colour coded to emphasise areas of high and low biomass. It can be seen that the partially reclaimed land on the eastern side of the landfill has a low biomass, indicating sparse vegetation, and the new area to the west has no biomass reading, indicating that this area is essentially bare ground. Products such as the NDVI can also be used to identify old landfills and monitor their re-vegetation.

Figure 18: 3D views along the river Arun, towards Arundel.
Top (18a) - from the south. Bottom (18b) - from the south-west.

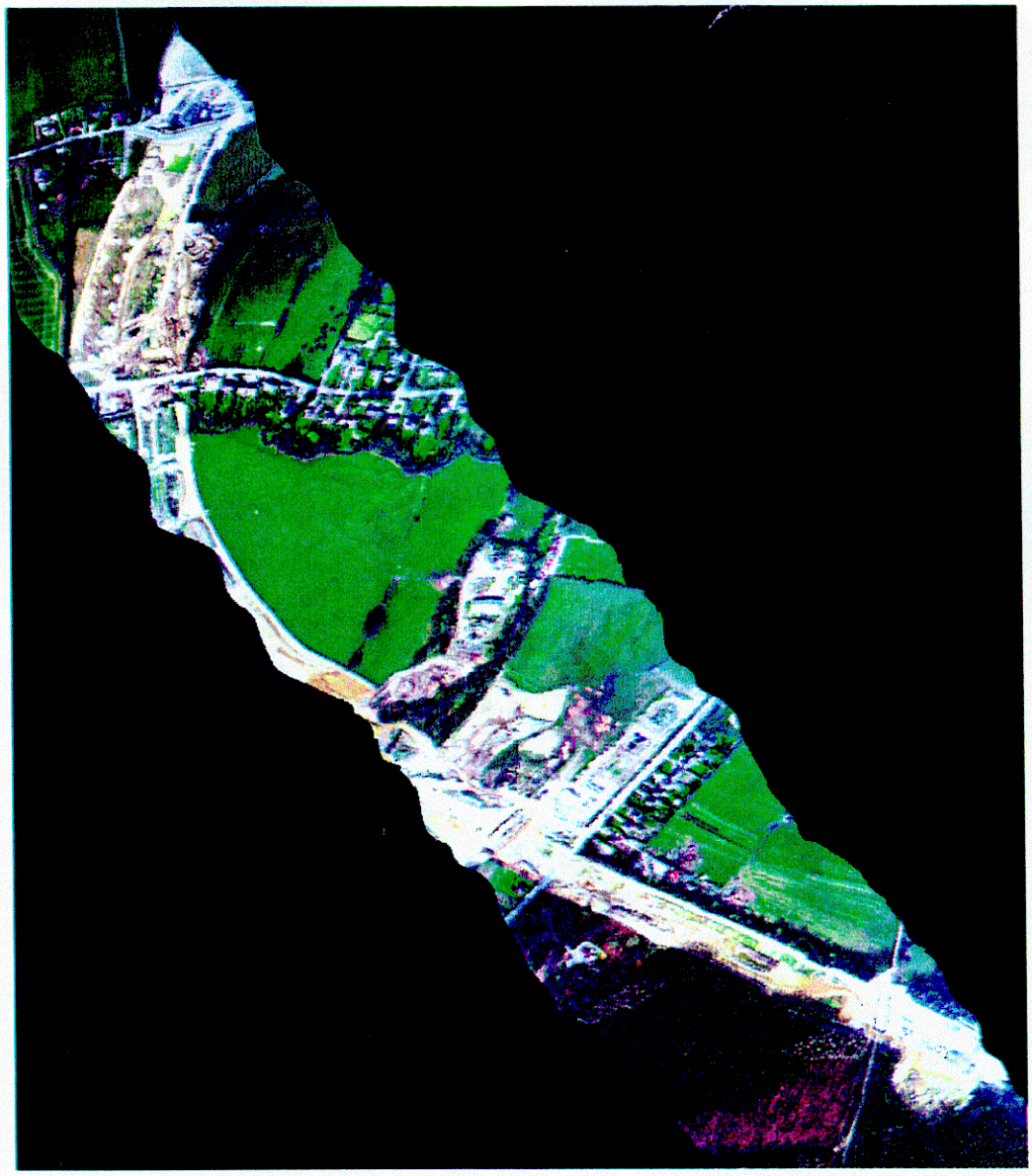


Figure 19: CASI true colour composite of the Newbury Bypass construction works

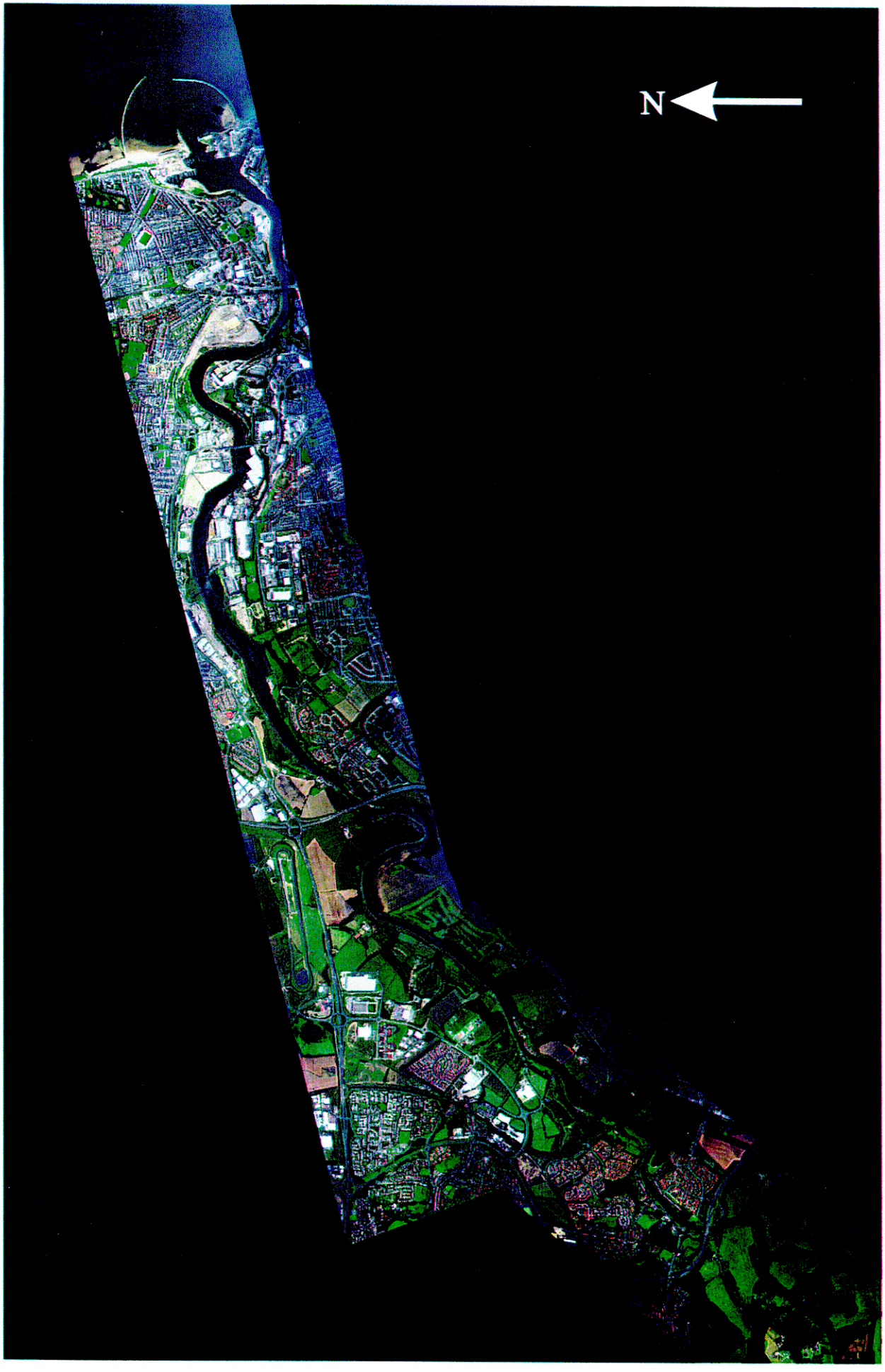


Figure 20: CASI true colour composite of areas surrounding the River Wear

Figure 21: CASI true colour composite of Tatchells landfill site
Image flown on the 2nd October 1996 at 11:15 GMT

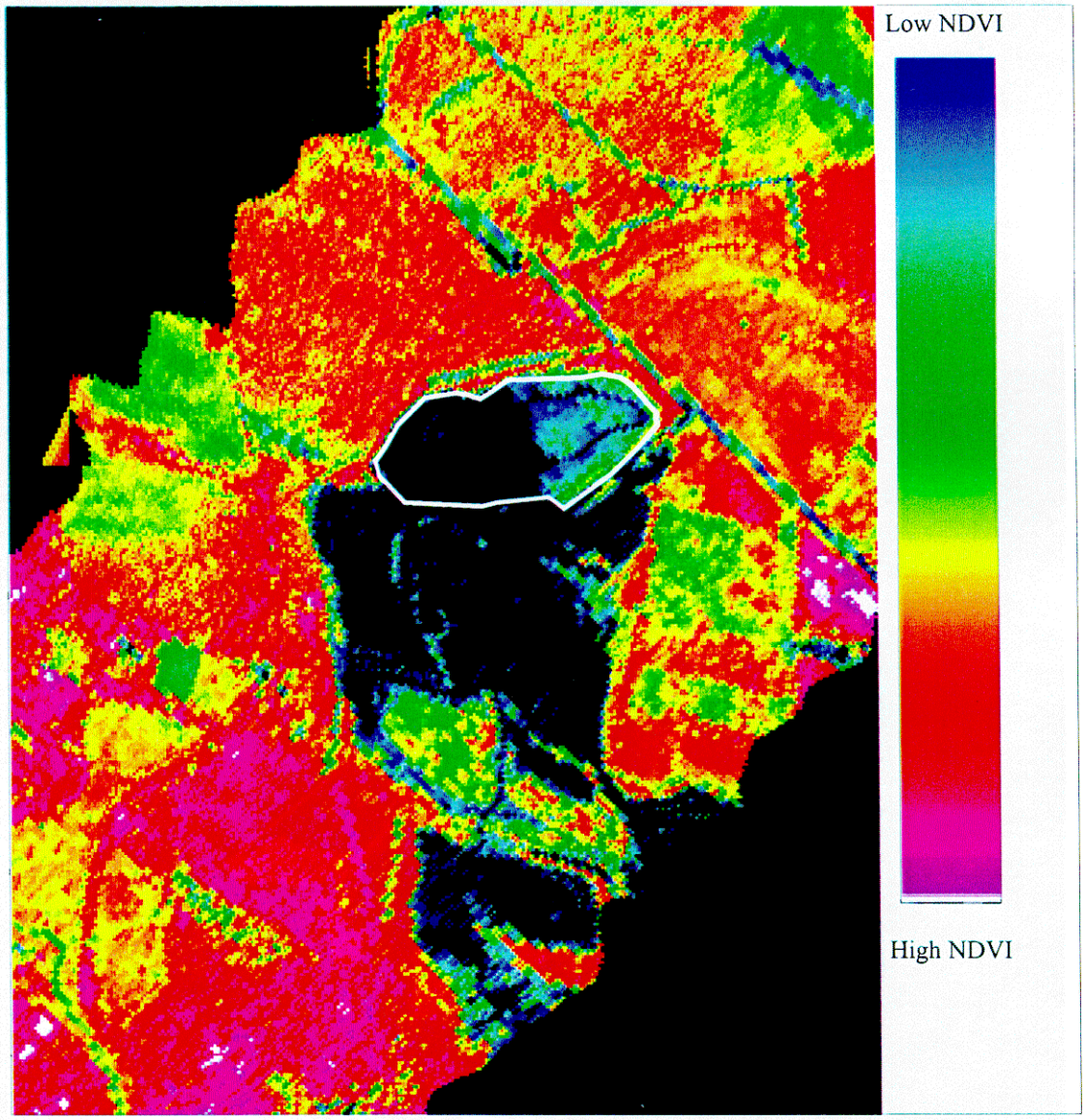


Figure 22 :NDVI image of Tatchells landfill site, colour coded to pick out high biomass areas in pink/red and low biomass areas in blue.

4 SUMMARY AND CONCLUSIONS

The CASI is a flexible remote sensing tool which can provide data for varied environmental applications. In many cases, the CASI is able to add value to traditional monitoring techniques by providing large-scale, homogeneous coverage via easily repeatable measurements. The homogeneity of coverage allows traditional, point-based measurements to be extrapolated over wide areas. This use of the CASI reflects a progression in measurement techniques from point-based to line-based to the integrated techniques which are presently in use involving large area coverage and integration of various instruments. The holistic view of the environment provided by the CASI contributes to the Agency's ability to fulfill its general duties to form an opinion on the state of the environment and also provides support for the monitoring and enforcement of european and national Directives.

The CASI is a multispectral imaging tool that is operated from a light aircraft. A number of modes of operation give the tool the flexibility to be configured for a wide range of different applications by simply varying the spatial and spectral resolution of the acquired data. A number of data products can be produced and made available as regular or laminated hard copies or on a number of digital media. The CASI system is owned by the Agency and operated by external contractors and, together with a suite of complementary instruments, can be made available throughout the year. Emergency or critical missions can be arranged on short notice between April and October.

Typical applications of the CASI have been described in terms of the Agency's six *Viewpoints on the Environment*. These are:

- Land use and Environmental Resources
- Status of Biological Communities and Biodiversity
- Quality of the Environment: Compliance with Targets and Standards
- Health of Environmental Resources
- Environmental Change at Long-term Reference sites
- Aesthetic Quality of the Environment

Under these six viewpoints, CASI applications have been described relating to terrestrial areas, coastal zones and inland / coastal waters. Examples of CASI data have been provided in a number of different forms in order to highlight information relevant to the application at hand. This non-exhaustive list of outputs and applications includes:

- **True-colour composite imagery:** 3 band optical wavelength imagery, resembling aerial photography. This has been used to detect and map discharge points and dispersion zones for industrial, sewerage and mining discharges in rivers, estuaries and the ocean. Other applications include the detection of algal blooms and the monitoring of environmental disasters such as oil spills. True colour imagery provides a useful overview of the state of the environment in areas of interest by showing features such as eroded land. Information about the aesthetics of the environment can also be obtained by observing, for example, road construction and the quality of the urban/suburban environment.

- **False-colour composite imagery:** 3 band imagery, including near-infrared bands combined with visible bands. The presence of the infrared band makes this imagery ideal for the monitoring of vegetation health. Demonstrated applications include the monitoring of forest location and extent, as well as the health of forestry resources. These images have also been shown to provide valuable information about the state of different habitats.
- **Land cover/Land use maps:** Classifications of land use and land cover type have been performed in terrestrial scenes, river corridors, coastal zones and intertidal zones. Features such as land use type, vegetation type and farming practices have been identified. Land cover classifications have been used to identify habitat types in the intertidal zone and high flood risk areas in riverine and coastal zones. Classifications of crop type also play an important role as an input to the detection of diffuse pollution affecting water quality.
- **Vegetation index maps:** Maps showing the relative health of vegetation in an area have applications in the monitoring of landfill reclamation and the detection of unlicensed use of water resources.
- **3 dimensional perspective views:** By combining CASI true-colour composites with digital elevation data, 3D views can be produced. These have applications in visualisation and the modelling of the aesthetic impact of construction and development on the environment.
- **Other value added products:** These include spectral profiles and quantitative maps of suspended sediment and chlorophyll concentrations.

The CASI instrument provides data that can supply a large scale spatial context for existing measurement techniques on an easily repeatable basis. These data add value to existing datasets and techniques and, in certain situations, can provide information that has not previously been available. The flexibility of the tool allows it to be deployed at short notice or on a regular basis to provide data obtained at the most appropriate times for the application.

REFERENCES

Manual of Environmental Policy: the EC and Britain. Nigel Haigh. Cartermill Publishing, October 1995, pp 9.9-1 to 9.9-11.

Calibration of CASI imagery for high concentrations of chlorophyll-a in turbid waters. Environment Agency R&D Report, 14 March 1997.

Development and Testing of Suspended Solids Algorithms, Case Study 2. Environment Agency R&D Report, 1997. April 1997.

The Investigation of Phytoplankton Dynamics in Coastal Waters Using Aerial Surveillance, Case Study 3. Environment Agency R&D Report, 14 April 1997.

Validation of Statutory Sampling Sites Using Aerial Surveillance, Case Study 4. Environment Agency R&D Report, May 1997.

Aerial Surveillance of Fourteen Estuaries in England and Wales. Environment Agency R&D Report, 14 March 1997.

T M Long, R C Allen. *Remote Surveillance of Mineral Extraction Discharges.* Environment Agency R&D project P2B(96). 1996.

R M Fuller *et al. Further Development of Airborne Remote Sensing Techniques: Cover Classification in Intertidal Zones and River Corridors (Parts I and II).* NRA R&D Note 472. Institute of Terrestrial Ecology, 1995.

RM Fuller *et al. Strategic Remote Sensing of Coastal and Estuarine Environment Types for Flood Defence and Conservation: Feasibility Study (Parts I and II).* Institute of Terrestrial Ecology, Project T05060g1, July 1996.

Viewpoints on the Environment: Developing a National Environmental Monitoring and Assessment Framework. The Environment Agency. 1997.

An Environmental Strategy for the Millennium and Beyond. The Environment Agency. 1997.

C S Rathore, R Wright. *Monitoring environmental impacts of surface coal mining.* Int. J. of Remote Sensing. Vol.14, no. 6. pp. 1021-1042. 1993.

A survey report: Remote sensing and baseline monitoring of the coastal waters of England and Wales, 1992-1993. National Rivers Agency R&D report. 1994.

NRA Applications of Remotely Sensed Data. NRSC report no. NR-RP-NRL-NA-0001 Issue 1.0, July 1995.

APPENDIX A. CASI Applications:

Land Use and Environmental Resources

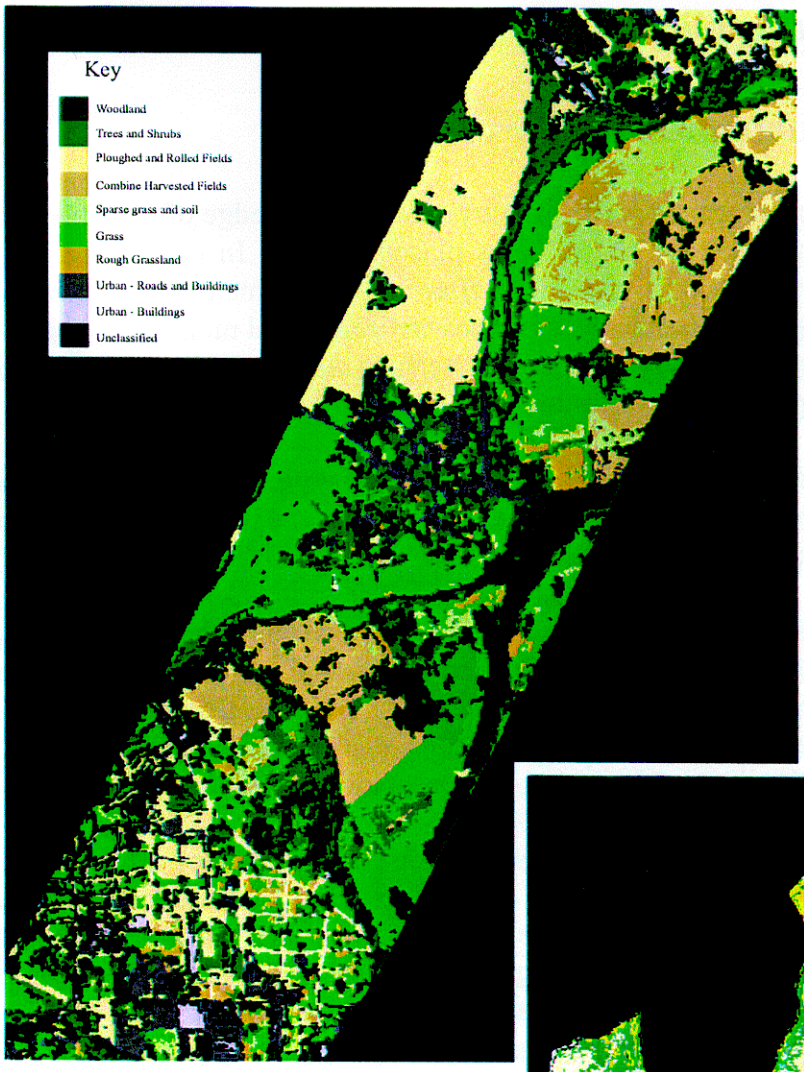
The Environment Agency's management activities are based on knowledge of the state of the environment and how it is reacting to the pressures placed upon it. In order to gain this knowledge, it is essential that the Agency maintains an effective environmental monitoring and assessment programme. This series of brochures describes environmental monitoring using the Compact Airborne Spectrographic Imager (CASI) remote sensing tool. A number of applications areas are described and examples of typical products are given.

The CASI is a flexible remote sensing tool which can provide data for varied environmental applications. In many cases, the CASI is able to add value to traditional monitoring techniques by providing large-scale, homogeneous coverage via easily repeatable measurements.

By making use of Remote Sensing techniques and combining this data with relevant ground data, we can improve our knowledge of changes to, and the condition of, environmental resources. This knowledge can provide valuable input to environmental management strategies. Remote Sensing using the CASI system is able to provide medium-to-large scale, consistent views of land-use which may serve to fill some of the 'gaps' in present knowledge.

The image opposite shows a supervised land-use classification performed using 2m CASI data. The area is near Coventry and shows a number of typical terrestrial land use and land cover types. The classification clearly distinguishes between areas of woodland, grasses, arable fields and man-made/urban features. Within these broad groupings, further classifications are made, indicating farming practices (ploughed and rolled fields / combine harvested fields), amount of vegetation cover (woodland / trees and shrubs) and grassland types (sparse grass and soil / grass / rough grassland).

Intertidal zones can be classified in order to map the extent and position of valuable, diverse habitats such as saltmarshes. The figure opposite shows a classification of the intertidal zones in the Langstone harbour estuary. The classification was performed using imagery obtained on the 4th August 1996, at low water and clearly shows areas of saltmarsh, mudflat and dense/sparse algae. The Langstone and Chichester harbour areas have been declared as Sites of Special Scientific Interest (SSSI) and, in addition, it is interesting to note that Langstone harbour is currently a eutrophic problem area under investigation. Previous studies of the trophic state of the estuary have consisted of interpretation of false colour composite aerial photography, but more recently, a digital classification performed on CASI data was used. The automated digital classification is a more cost effective method which produces repeatable results.



Supervised classification of the Coventry area.

Supervised classification of Langstone Harbour intertidal zone

APPENDIX B. CASI Applications:

Status of Biological Communities

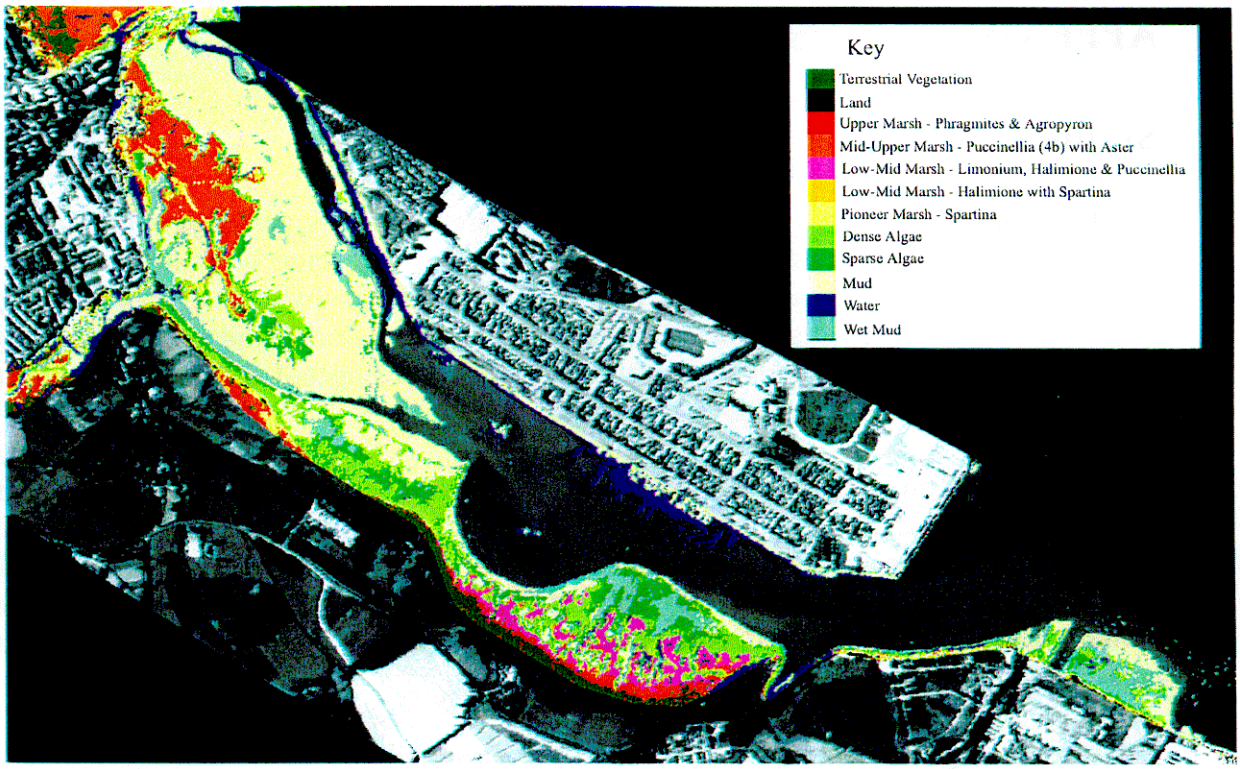
The Environment Agency's management activities are based on knowledge of the state of the environment and how it is reacting to the pressures placed upon it. In order to gain this knowledge, it is essential that the Agency maintains an effective environmental monitoring and assessment programme. This series of brochures describes environmental monitoring using the Compact Airborne Spectrographic Imager (CASI) remote sensing tool. A number of applications areas are described and examples of typical products are given.

By monitoring habitats on a national basis, using an instrument such as the CASI, it is possible to build up an overall picture of natural capital and of the condition of ecological resources. The CASI is capable of providing complete, homogeneous coverage of habitats in order to contribute to knowledge at the national level. By obtaining large-scale coverage, the CASI can be used to identify habitats, such as saltmarshes and wildflower meadows, that are of interest to conservationists.

Remote sensing of habitats and species within these habitats offers a number of distinct advantages over conventional methods. Fragile ecosystems such as saltmarshes are easily disturbed by conventional sampling techniques and the CASI offers a non-intrusive means of monitoring these areas without causing any damage to them. Another advantage lies in the repeatability of observations. The CASI instrument can provide a standard means of monitoring which will not change with time, giving confidence that any recorded change is due to environmental change and is not caused by changes in measuring techniques or operator perceptions.

The figure opposite shows a CASI false-colour composite of the Somerset Levels, Tealham Moor, an area which has been classified as a Site of Special Scientific Interest (SSSI). Under normal circumstances, the fields in this area flood annually and are classed as wetland meadows. The image has a ground resolution of 2m, clearly showing fields and a system of drainage canals. In this false colour image, vegetation is coloured red, with brighter shades indicating healthy vegetation. The black areas in the lower half and top right hand corner of the image are flooded fields. Clear variations can be distinguished between fields and also within individual fields. Fields which are coloured blue or white may represent bare land or vegetation cover that is less productive than that in the surrounding fields.

The second figure shows a classified land cover map of the Eling and Bury Marsh area of the Southampton Water saltmarshes, taken on the 2nd of August 1996 at low water. Clearly discernable are various saltmarsh types (Upper; Mid-Upper; Low-Mid and Pioneer) which have been classified according to their constituent algal types (see figure). Observation of these areas over time will reveal advance or retreat of the saltmarshes and will give an indication as to the health of the marshes, according to the extent of various floral species.



Unsupervised classification of Southampton Water intertidal zone - Eling and Bury Marsh area.

False colour composite of Somerset Levels - Tealham Moor

APPENDIX C. CASI Applications:

Quality of the Environment

The Environment Agency's management activities are based on knowledge of the state of the environment and how it is reacting to the pressures placed upon it. In order to gain this knowledge, it is essential that the Agency maintains an effective environmental monitoring and assessment programme. This series of brochures describes environmental monitoring using the Compact Airborne Spectrographic Imager (CASI) remote sensing tool. A number of applications areas are described *and examples of typical products are given.*

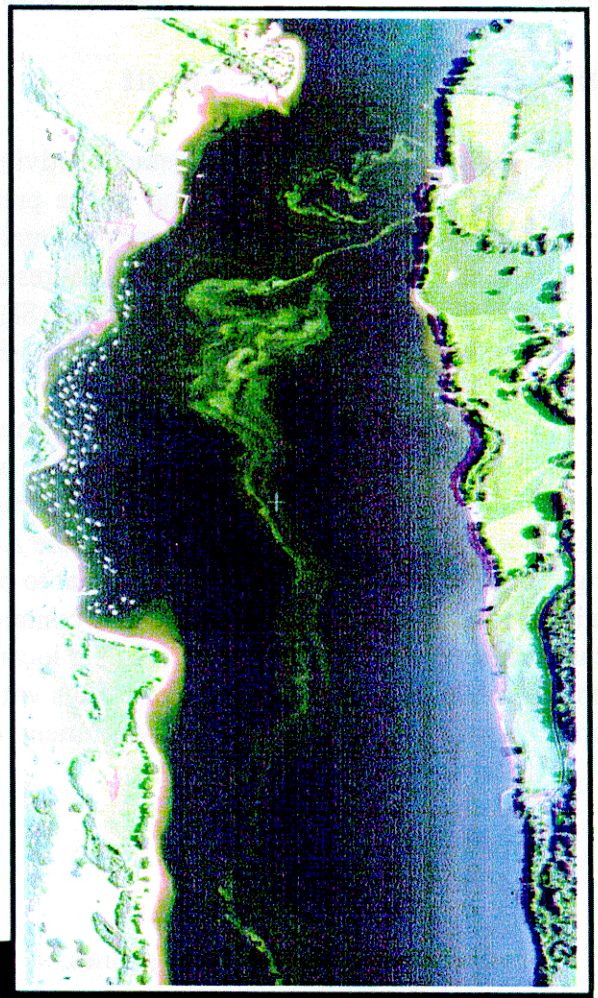
The CASI is a flexible remote sensing tool which can provide data for varied environmental applications. In many cases, the CASI is able to add value to traditional monitoring techniques by providing large-scale, homogeneous coverage via easily repeatable measurements. By monitoring the quality of the environment, the Agency is able to ensure that contaminants and dangerous substances do not become a threat to public health. Datasets derived from the CASI can be used to identify specific areas where contaminants may pose a threat and to direct baseline measurement activities to the most suitable locations. The aim of this monitoring is to protect both the environment and the human beings within it. CASI data can be used in a number of ways to monitor the quality of the environment, these include:

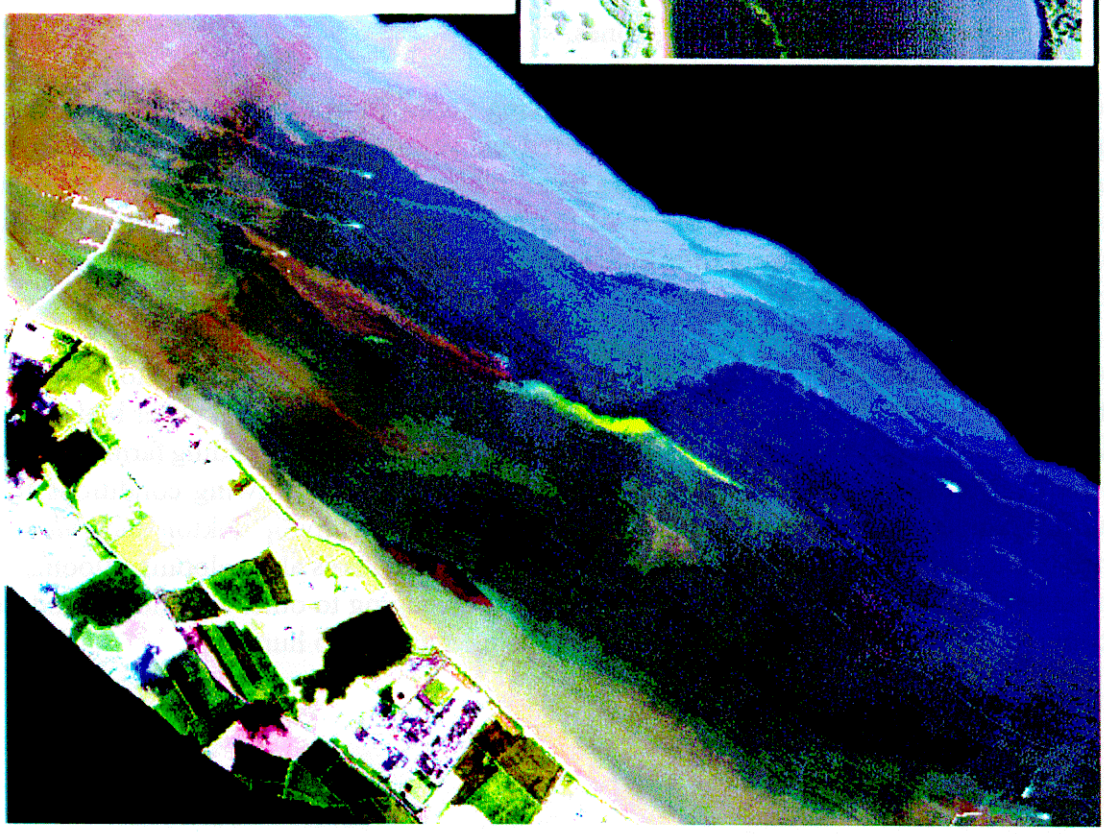
- identifying times of discharge;
- locating areas of workings;
- monitoring settling pools;
- tracing runoff problems; and,
- mapping the extent of mixing zones.

The image of the Humber estuary shows mixing zones from two outfalls, the imagery was acquired on a half-rising tide. The distinctive red and yellow colouring of the outfalls, makes the mixing zones easy to detect and provides a clear indication of the zones of influence of the two discharges. The outfall near the centre of the estuary results from an effluent discharge, the elongate structure of this mixing zone indicating that there is little mixing of this acidic discharge perpendicular to the tidal flow.

The image of Coniston Water in Cumbria shows the presence of a large algal bloom in the centre of the lake. The presence of this bloom indicates eutrophication of the water body and points to increased nutrient levels caused by nitrates from run-off from surrounding farmland or sewage discharges. Increased nutrient levels, together with favourable growing conditions for algae (warmer temperatures, increased sunlight) lead to increased phytoplankton and *chlorophyll-a* concentrations. High local concentrations manifest themselves as algal blooms. Blooms, in turn, can cause reduced oxygen concentrations which are damaging to other aquatic life and can also become toxic, poisoning aquatic species and posing a danger to humans.

Enhanced true-colour composite of Coniston Water





Enhanced true-colour composite of the Humber Estuary

APPENDIX D. CASI Applications:

Health of Environmental Resources

The Environment Agency's management activities are based on knowledge of the state of the environment and how it is reacting to the pressures placed upon it. In order to gain this knowledge, it is essential that the Agency maintains an effective environmental monitoring and assessment programme. This series of brochures describes environmental monitoring using the Compact Airborne Spectrographic Imager (CASI) remote sensing tool. A number of applications areas are described and examples of typical products are given.

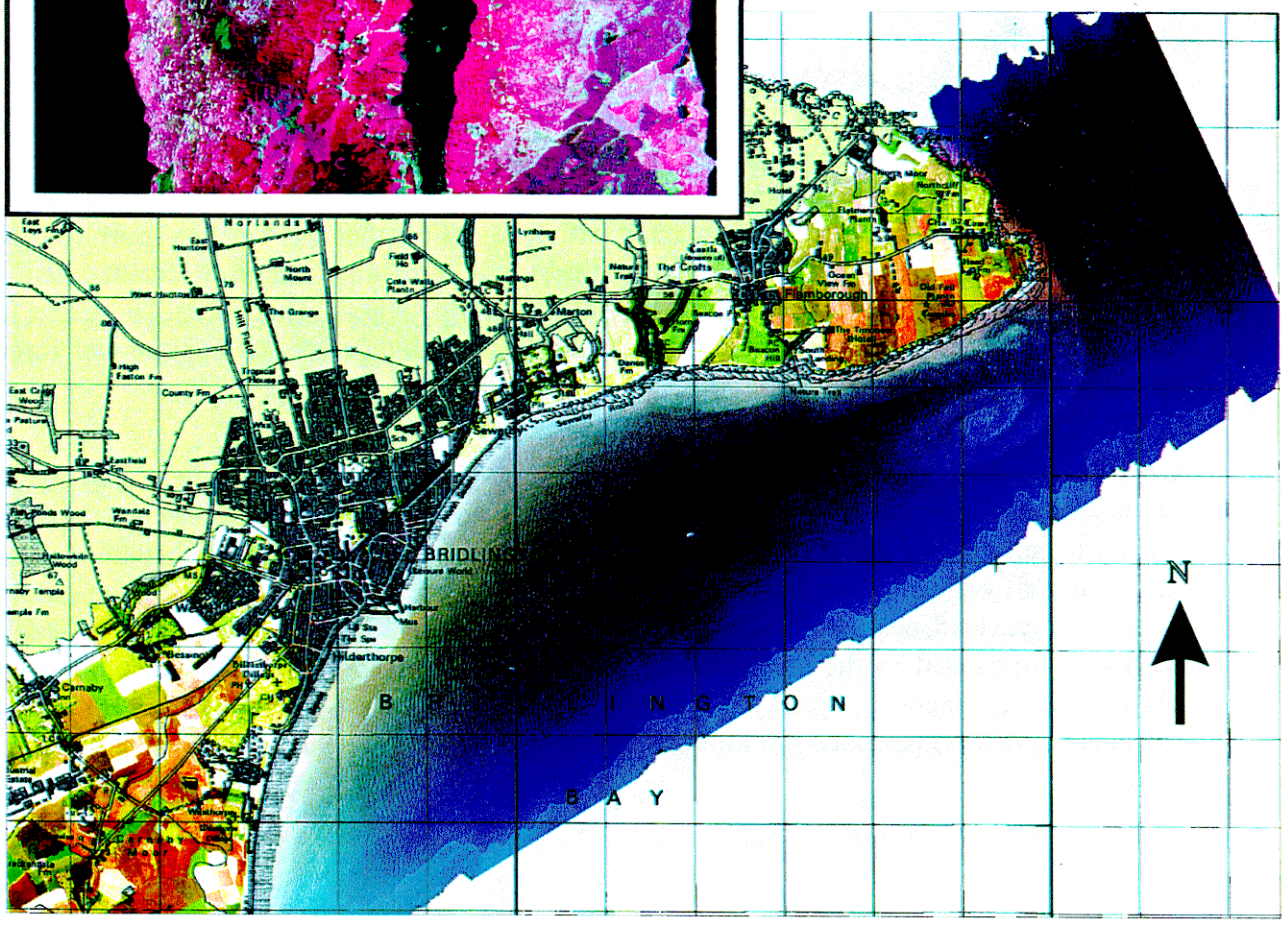
The CASI is a flexible remote sensing tool which can provide data for varied environmental applications. In many cases, the CASI is able to add value to traditional monitoring techniques by providing large-scale, homogeneous coverage via easily repeatable measurements.

It is part of the Agency's function to identify and map our environmental resources and to monitor the health and condition of these resources. Observing these resources aids our understanding of the health of the environment and how it is changing in response to the pressures placed upon it. The high resolution capabilities of the CASI make it well suited to this task especially when used in conjunction with ground based surveys. It is important that the CASI data acquisition is directed by local expertise in order to maximise the usefulness of the datasets and ensure that the correct bandsets and resolutions are chosen to complement ground survey work.

The image opposite is a CASI false-colour composite of the Grizedale Forest area, adjacent to lake Windermere in Cumbria. Red colours represent reflectance in the near infrared band and give an indication of the density and health of vegetation. Areas of healthy, deciduous wood are shown as bright red and can be seen adjacent to the lake. The darker forested areas further from the lake are coniferous woods, interspersed with areas of heather and bracken (purple colour). Comparison of images obtained at different times will show any changes in forest extent and composition and will provide information about tree health in the forested areas. These data have applications in environmental maintenance and in the management of commercial forestry resources.

CASI imagery can be used to detect and map suspended solids in coastal waters. The presence of these solids (indicated by lighter areas of water in the coastal image opposite) is indicative of outfall mixing zones and can give an indication of the effect of local tidal behaviour on the dispersion of effluent. The image is a true colour composite CASI image of the coast off Flamborough Head, near Bridlington. The dominant feature of the image is a very clear headland eddy or gyre caused by the interaction of currents which meet at the headland. This imagery played a part in determining that this area was not a High Natural Dispersion Area (HNDA), due to the fact that the suspended solids are clearly caught in the gyre and not dispersed into deeper waters.

False-colour composite of Lake Windermere catchment



True-colour composite of Flamborough Head, overlaid on digital map data

APPENDIX E. CASI Applications:

Environmental Change

The Environment Agency's management activities are based on knowledge of the state of the environment and how it is reacting to the pressures placed upon it. In order to gain this knowledge, it is essential that the Agency maintains an effective environmental monitoring and assessment programme. This series of brochures describes environmental monitoring using the Compact Airborne Spectrographic Imager (CASI) remote sensing tool. A number of applications areas are described and examples of typical products are given.

The CASI is a flexible remote sensing tool which can provide data for varied environmental applications. In many cases, the CASI is able to add value to traditional monitoring techniques by providing large-scale, homogeneous coverage via easily repeatable measurements.

By repeating data acquisition for the same area over a period of months or years, it is possible to build up a record of environmental changes that occur gradually over long periods of time and are otherwise difficult to monitor. The CASI is ideal for measuring the loss or gain of vegetated areas and long-term changes in environmental resources such as saltmarshes. These changes can be highlighted through the generation of change maps which are effectively the subtraction of two CASI images, revealing any areas of change. CASI data forms a valuable reference archive. Held in digital format, the data are particularly useful when overlaid with other spatial information, further aiding quantitative analysis. A further advantage is that once the data are acquired, the same datasets can be used for a variety of different applications.

The CASI can be used to monitor changes that occur within the coastal zone. By regularly flying the same areas, it is possible to monitor any erosion or deposition that is occurring and to obtain an indication of the rates of these processes. Closely related to this is the monitoring of the effects of change in sea-level and the influence on the coastal zone. CASI can, for example, monitor the size of saltmarshes, providing early, accurate indications of any reduction in these important tidal energy 'buffer zones'. CASI data can be used as an input to programs of managed retreat or land reclamation and provide information which is not otherwise available to planners. The CASI-derived information can also play a part in local Agency Coastal Management Plans (CMPs) by contributing to flood prevention and environmental monitoring strategies.

Estuaries are sensitive zones which play an important role as a diverse habitat for many species of fauna and flora. Rising sea-level and advancing industrial and urban land use are squeezing these zones and, in certain areas, threatening to destroy them. CASI imagery can provide a clear picture of the extent of these areas and the pressures that are placed upon them.

APPENDIX F. CASI Applications:

Environmental Aesthetics

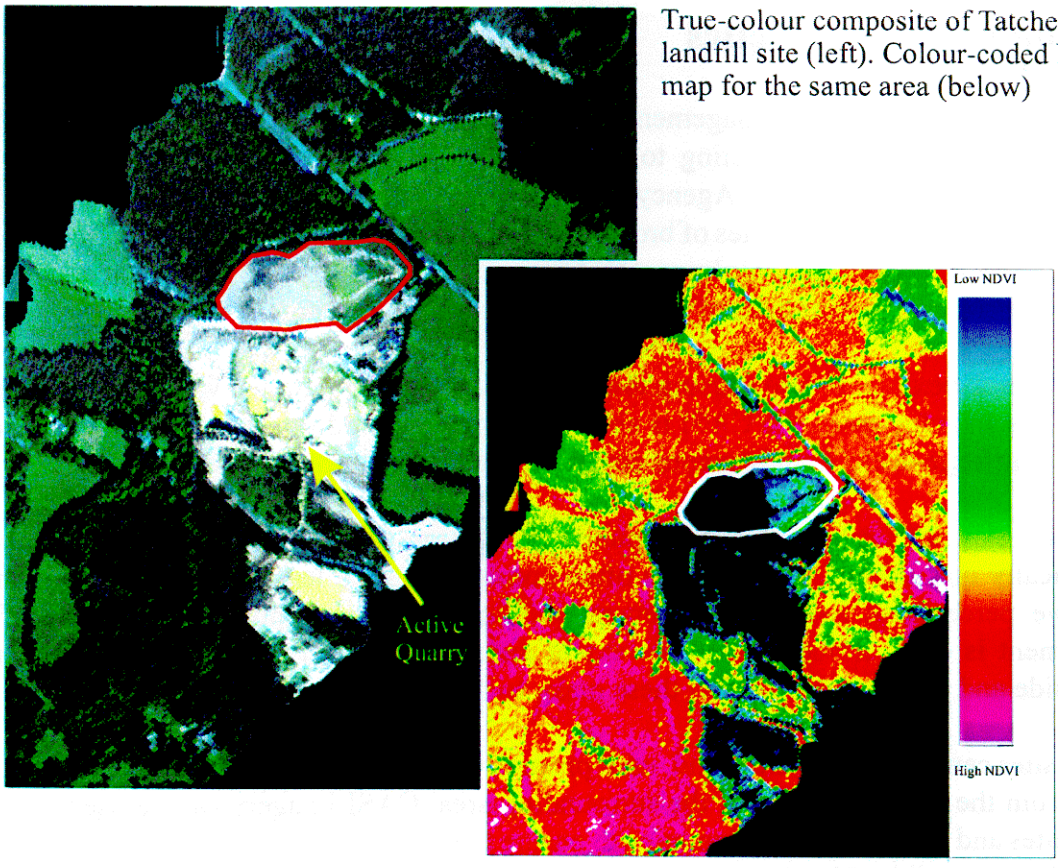
The Environment Agency's management activities are based on knowledge of the state of the environment and how it is reacting to the pressures placed upon it. In order to gain this knowledge, it is essential that the Agency maintains an effective environmental monitoring and assessment programme. This series of brochures describes environmental monitoring using the Compact Airborne Spectrographic Imager (CASI) remote sensing tool. A number of applications areas are described and examples of typical products are given.

The CASI is a flexible remote sensing tool which can provide data for varied environmental applications. In many cases, the CASI is able to add value to traditional monitoring techniques by providing large-scale, homogeneous coverage via easily repeatable measurements.

Aesthetics play an important part in public perception of the state of the environment. Scientifically quantifiable measures are often considered to be less important than the more subjective perceptions held by the general public. Public perception of the state of the environment is often influenced by the extent and nature of parkland and the surrounding countryside and the contribution that these make to the general quality of life.

Landfill sites can cover large areas and, until properly reclaimed with suitable vegetation cover, detract from the aesthetic value of the surrounding area. CASI imagery can be used to detect landfill sites and monitor their reclamation to ensure that areas are returned to their natural state as quickly as possible. The figures opposite show a CASI true-colour composite of Tatchells landfill site (red outline) northwest of Wareham in Devon and the associated Normalised Difference Vegetation Index (NDVI) image. The NDVI provides a measure of relative vegetation biomass. The relative biomass can be used as an indicator of vegetation health, assuming that there is some knowledge about plant type within the imaged area. From the image, two distinct areas of landfill can be identified. The older of the two areas forms the eastern part of the landfill and has sparse vegetation cover, indicated by the light green shades in the image (low biomass in the NDVI image). The newer section of the landfill is to the west and, as yet, has no vegetation cover.

The three dimensional view opposite is of the area surrounding the River Arun. Each image consists of two datasets: a Digital Elevation Model and a true colour composite CASI image. The images have been co-registered and the CASI data 'draped' over the elevation model. The electronic data allows simulated views to be generated in all directions and from different altitudes, providing a useful tool for assessing the visual impact of construction or quarrying activities. This visualisation capability can be used to inform the public about the impact of any development and can demonstrate appropriate steps that have been taken to reduce any potential negative aesthetic effects.



True-colour composite of Tatchells landfill site (left). Colour-coded NDVI map for the same area (below)

3D view of the area surrounding the river Arun