The National Centre for Environmental Data and Surveillance

AERIAL SURVEILLANCE OF FOURTEEN ESTUARIES IN ENGLAND AND WALES

ENVIRONMENT AGENCY

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EXECUTIVE SUMMARY

INTRODUCTION

This project studied remote surveillance applications using thermal infrared and CASI data to the assessment of quality in fourteen key estuaries in England and Wales, namely the Deben, Fal, Humber, Leven, Lune, Mersey, Severn, Tees, Tyne and Wear estuaries, Poole, Langstone and Chichester Harbours, Southampton Water and Milford Haven.

The extent to which effluent mixing zones could be visualised and digitally mapped was determined and their value for consent setting and monitoring assessed. The extent of saltmarsh and inter-tidal vegetation zones were characterised and mapped. The value of inter-tidal vegetation mapping for the designation of Sensitive Areas and Nitrate Vulnerable Zones under the provisions of the Urban Waste Water Treatment Directive (91/271/EEC) and the Nitrate Directive (91/676/EEC) respectively was assessed.

Although outside the scope of the original project objectives, remote surveillance application to monitoring the state of the estuarine environment was attempted. This was considered particularly important since the UK's estuaries concentrate much of its economic and natural wealth into their relatively small areas, and there is particular sustainable development conflict of interest between the desire to raise living standards by economic development and to preserve the environment.

Finally, a preliminary review was made of the risks facing these high economic and natural asset concentrations from long term sea level and temperature changes arising from global warming.

CONCLUSIONS

Control of Discharges

- Consent setting for estuarine discharge is too complex to be represented by combined distribution approaches, and computer modelling is commonly used. Discharge plume visualisation from remote surveillance techniques is potentially a useful tool to validate predictive models.

- This study showed that many, but not all, discharges could be imaged by CASI and thermal sensing. A major omission was secondary treated sewage effluent which does not contain enough suspended solids to be readily detected against receiving waters.

- Further development is needed to provide an optimal arrangement for discharge plume detection. Examples include the use of dye tracing or focussing of surveillance at seasons when temperature differentials are greatest.

Saltmarsh and Inter-tidal Vegetation

- The application of mapping the saltmarsh environment was highly successful providing accurate digital maps of saltmarsh extent in each of the estuarine environments. Saltmarsh was found to be the dominant land cover class in the inter-tidal zone of the Deben and Lune estuaries covering more than 40% of inter-tidal zone. Saltmarsh is absent from some estuaries in the North East, such as the Tyne and Wear.

- Some information on the nature of marsh protection was obtained for this study, with SSSI marshland being identified. However, the protected area information base should be enhanced.

- Indications are that much of the protected marshland is under threat from sea level rise due to climate change. Imagery identified sites where managed retreat was feasible, and those where this conservation option would be constrained by the presence of hard flood defences of assets.

- The application to mapping of inter-tidal vegetation was highly successful allowing digital mapping of inter-tidal vegetation in each of the estuaries surveyed. This showed that cover by dense green macro-algae varied from 4% to 31% of the inter-tidal zone.

- Imagery of the extent of inter-tidal vegetation is valuable in the characterisation of areas subject to eutrophication and for supporting applications for Sensitive Areas and Vulnerable Zones under the Urban Waste Water Treatment and Nitrates Directives respectively.

Viewpoints on the Environment

- CASI imagery is highly applicable to monitoring aspects of the six proposed viewpoints on the environment.

- This project was not designed to study this environmental aspect, but it is likely that estuarine environmental indicators for these viewpoints can be developed from imaging techniques. Some indicators have been proposed in Section 6.

- Remote surveillance techniques have a uniquely valuable contribution to make to the issue of predicted sea level rise, both in monitoring the extent of sea level rise and in providing information for modelling options to protect economic assets without placing environmental resources at risk.

RECOMMENDATIONS

- The value of visualising the discharge plume for the validation of predictive models to establish consent conditions should be confirmed by users. Given such confirmation further studies should be carried out to develop a set of techniques for visualisation of all discharges.

- A national database of discharge locations should be compiled from the regional consents register. Additional information should be sourced from other databases on the actual location of the discharge point.

- A protected areas database should be developed within a Geographical Information System, including information for example on Sites of Special Scientific Interest and Areas of Outstanding Natural Beauty. The imagery from this study should be re-interpreted to further investigate the potential threat to protected marshland.

- Imagery of inter-tidal vegetation should be adopted as a routine component of the techniques to designate Sensitive Areas and Vulnerable Zones for the Urban Waste Water Treatment and Nitrates Directive implementation.

- Imagery from this study should be re-interpreted to develop a preliminary set of indicators for assessing Viewpoints of the State of the estuarine environment. A tentative set is given in Section 6.

- Imagery from this study should be supplemented with LIDAR height imagery to study the possible effects of climate change on estuarine environmental assets.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

1 INTRODUCTION

1.1 This document reports on the surveillance study undertaken by the Environment Agency's National Centre for Environmental Data and Surveillance during 1996 on fourteen key estuaries in England and Wales.

1.2 The objectives of this project were:

- To identify the presence of discharge mixing zones within each estuary and map their position and extent at each tidal state measured.
- To produce a digital map and report on the presence of vegetation in the inter-tidal zone.
- To produce a digital map and report on the presence of saltmarsh and beaches within each estuary.
- To use the above data and information from other sources to comment on the environmental quality of the estuaries studied.

1.3 Part way through this project the Agency published its draft strategy on monitoring the state of the environment. Although it was too late to restructure the surveillance programme, interpretation was expanded to include applications to monitoring the state of the estuarine environment, in addition to the agreed topics, even though the surveillance imagery was not completely adequate for these extra purposes.

1.4 The estuaries surveyed were selected by consultation with Environment Agency regions. Reasons for selection ranged from the presence of heavy industry, important inter-tidal vegetation communities, or the use of the estuary for recreation. Table 1 lists the estuaries chosen and the main reasons for selection.

1.5 Figure 1 shows the geographical positions of the estuaries surveyed during this study.

1.6 The report outlines the rationale and background of the project (Chapter 2: Background). It is then divided into subsections for each estuary, with information on the presence of discharge mixing zones, the amount and location of ecologically important saltmarsh and mudflat environments, and the presence and density of macro-algae in the inter-tidal zone (Chapter 3: Estuary Descriptions). Chapter 4: Overall Discussion, summarises the key findings from all of the estuaries and discusses how these may be used in assessing the state of the estuarine environment. Conclusions and recommendations are made in Chapter 5.

Estuary Name	Mixing Zones	Intertidal Vegetation	Flood defence	Recreation
Deben		✓		
Fal	✓sewage	✓		
Humber	✓industrial	✓	✓sedimentation	
Langstone and Chichester		✓	✓marshes	✓
Leven			✓shifting sandbanks	
Lune		✓	✓shifting sandbanks	
Mersey	✓industry	✓	✓shifting sandbanks	
Milford Haven	✓petrochemicals			✓
Poole Harbour	✓sewage	✓		
Severn and Avonmouth	✓industry	✓	✓marshes/ shingle banks	
Southampton Water	✓petrochemicals	✓		✓
Tees	✓industrial	✓	✓marshes	✓
Tyne	✓industrial			✓
Wear		✓		

Table 1: Estuaries selected and reason for selection

Figure 1.
Estuaries Studied

2 BACKGROUND

2.1 THE IMPORTANCE OF ESTUARIES

2.1.1 Since the nineteenth century much of the United Kingdom's heavy industry and associated great cities have been located at major estuaries to take account of ready access to raw materials and easy waste disposal. The volume of trade now passing through British ports is second only to that of Holland among European Community (EC) countries. Moreover, the UK's coastal zone in general, and its estuaries in particular, now contain a large proportion of the nation's economic assets and environmental resources. As an illustration, some 40% of its manufacturing industry and 26% of its population are sited close to estuaries and the coastal zone, and 10% of its protected reserves and 57% of its grade 1 agricultural land lie within the coastal zone as a whole (DoE, 1996).

2.1.2 In the past estuaries and coastal waters were not subject to the same extent of legislation and surveillance as rivers, and some have become polluted since the start of industrialisation. Current legislation is strongly influenced by EC Directives, namely the Directive on Bathing Water Quality (76/160/EEC), the Directive on Quality of Shellfish Waters (79/923/EEC), the Dangerous Substances Directive framework (76/464/EEC), the Titanium Dioxide Directive (78/176/EEC) and the Urban Waste Water Treatment Directive (91/271/EEC). These and other criteria are used to set Environmental Quality Standards (EQS) for estuarine waters, with discharges consented and monitored to meet EQS requirements. In addition, the Environmental Protection Act, 1990 directs the control of processes as well as discharge quality through the principles of Integrated Pollution Control.

2.1.3 The Environment Act 1995 gave the Environment Agency the pollution control functions of its predecessor bodies (National Rivers Authority, Her Majesty's Inspectorate of Pollution, Waste Regulation Authorities and parts of the Department of the Environment) together with a new duty: to form an opinion on the general state of the environment. The Agency's principal aim is to protect or enhance the environment taken as a whole in order to play its part in attaining the objective of sustainable development. The UK Strategy for Sustainable Development, published in 1994, sets out the government's commitment made at the Earth Summit of June 1992 in Rio. One commitment is the development of a set of indicators of sustainability. Estuarial water quality, inputs of contaminants, contaminant concentrations in water and in fish, bathing water quality and oil discharges and spills are all identified as relevant estuarine environmental indicators in the UK Strategy.

2.2 THE REQUIREMENT FOR AERIAL SURVEILLANCE

2.2.1 Conventional sampling and analysis gives highly accurate information on the chemical quality of discrete points within an estuary. However, estuaries and their inter-tidal zones represent a highly dynamic environment, with short term changes due to tidal variability and longer term climate changes. Discrete sampling alone therefore has a limited ability to describe the estuarine environment.

2.2.2 The assessment of ground cover from boat or hovercraft provides an accurate indication of the area monitored. However, interpolation of this to a wider scale is difficult from ground level. A synoptic view from a remote sensing platform gives a true measure of the balance of different surfaces.

2.2.3 Remote surveillance provides the ability to reinforce conventional analysis with a spatial overview. Although satellites offer an overview of an entire estuarine environment in a single view, they do not offer the required spatial resolution to investigate small scale processes such as changes in vegetation cover on mudflats. Moreover the temporal resolution of currently available satellite systems is too coarse to truly represent variability in a tidal environment.

2.2.4 Aerial surveillance techniques offer the ability to vary the spatial resolution by altering the altitude at which the system is flown. Overpasses may also be timed to coincide with different tidal states and simultaneous vessel surveys.

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

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

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

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

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

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

2.2.9 By using the full 15 spectral channels a digital classification procedure may be applied. This differentiates between surface cover types based on the spectral properties of the cover. The classification procedure used in this study is an unsupervised technique. This means that the image is divided into classes based purely on the spectral properties. These classes are then aggregated by investigation of available ground truth data and comparison with other available information to form descriptive classes.

2.2.10 The thermal sensor operates in the 10-12 μm range measuring the radiation emitted from the very top of the land or sea surface. This information is displayed as a grey scale image. The digital number of the image may be used to determine variation in the temperature across an image, showing relative change to an accuracy of 0.1°C. In order to calculate absolute temperature a calibration must be made against *in-situ* temperature measurements.

2.3 ESTUARINE QUALITY ASSESSMENTS

2.3.1 The UK Sustainable Development Strategy uses an estuarial water quality indicator based on the previous NRA classification comprising of biological, aesthetic and chemical quality and dissolved oxygen content.

2.3.2 A new estuarine General Quality Assessment (GQA) scheme is presently being developed, and will comprise of dissolved oxygen, ammonia, sediment quality, nutrients and aesthetic indices. Information on the spatial characteristics and dynamics of estuarine waters is presently only available from relatively costly boat surveys that can only yield point information. Similarly, surveys of inter-tidal vegetation have traditionally been carried out by intensive ground based surveys. The opportunity exists, however, to concentrate previously gained experience on aerial surveillance techniques to this task. The use of aerial and satellite surveillance can give a synoptic overview of the whole area.

2.3.3 Remote sensing techniques provide information on spatial patterns in surface water colour and temperature. This allows the detection of boundaries between different water bodies, for example marking the position of the intrusion of tidal water into an estuary. It also reveals any discrete inputs to the water, for example from effluent disposal, assuming they affect the colour or temperature of the estuary.

2.3.4 Aerial surveillance also provides information on the inter-tidal zone, with the ability to detect changes in inter-tidal vegetation and distinguish between different surface cover types with different spectral signatures.

2.3.5 The key advantage of remote sensing techniques is the ability to look over large areas in a short time interval. This is of great importance in estuarine environments which are tidally variable. A remote sensing system may be deployed at varying states of the tide, allowing a picture of tidally controlled variability to be built up. Moreover, remote surveillance may have a particular application to overviewing the aesthetic quality parameters to be defined as part of the estuarine GQA.

2.4 DISCHARGE MIXING ZONES

2.4.1 In setting discharge consents and authorisations, Environment Agency staff require information on potential mixing zones of any discharge to tidal waters including estuaries. Aerial surveillance techniques provide evidence of the position and extent of existing discharge mixing zones, which will provide information on the likely influence of future discharges on the environment.

2.4.2 In practical terms, the mechanism of dissipation of effluents in estuaries can be complex and difficult to predict. The effluent discharge is subject to a number of influences such as river flow, tidal rise and fall and fluid mechanics of the tidal basin. The consequence is that rather than rapidly mixing and diluting, the discharge can form concentrated plumes of effluent which impact on specific areas of the estuarine environment. It is essential that as complete an understanding as possible is gained of the physical characteristics of the receiving waters to allow accurate consenting and compliance monitoring. The behaviour of current discharge mixing zones within an estuarine environment provides key data on the dispersion abilities of the receiving waters and the likely impingement of effluent on surrounding coastline.

2.4.3 The position and extent of discharge mixing zones has been shown in the past to be evident from aerial surveillance techniques (NC/MAR/016 part 7). Such techniques provide a spatial picture at any particular instant, of particular relevance in tidally influenced areas. Data may be gathered regularly across different tidal states to produce a full picture of the mixing zone.

2.4.4 If the temperature of the discharging water differs from that of the receiving waters at the surface then the mixing zone will be detected at the surface by a system measuring emitted radiation from that surface. Dependent on the characteristics of the effluent, the discharge may also be evident via a change in the colour with respect to the background waters. There are a number of causes of variation in the colour recorded by the sensor, which are dependent on the absorption and scattering of incoming light by the water mass and by particles within it. Thus an input of highly turbid waters will have a different signal to the clearer receiving waters. For the investigation of industrial discharges, there may be specific colour changes linked to the source of the discharge, for example from chemical plants. These combined characteristics can be used to determine the mixing zones of the discharges.

2.4.5 In order to investigate the use of aerial surveillance in determining the fate of discharges in estuarine mixing zones, reference information on discharge points is required. Details of all licensed discharges are held by the Environment Agency on a series of regional databases, which contain information on both sewage and trade effluent discharges. These databases hold information such as the name of the consented discharger, the position of the discharge and the consented volume. One problem in linking airborne surveillance data to discharges is that the regional archives record the effluent monitoring site position, and the end of the discharge pipe may not always correspond with this site.

2.4.6 There are further databases for specific types of discharge, for example the database of toxic and persistent substances. Discharges from power stations and major industrial processes which are of warmed water only may not be included on these databases although these can result in elevated temperatures over a large area, with potentially significant effects upon surrounding coastlines, for example an alteration in the biological communities within the water column.

2.4.7 The database held by the Ministry of Agriculture Fisheries and Food has been compiled from these combined databases, and additionally records the point at which the discharge reaches the estuarine water. This was considered to be most suitable for comparing against the aerial surveillance data. However, the database is in places out of date, particularly with the many recent changes to sewage treatment as a result of the Urban Waste Water Treatment Directive (91/271/EEC). A combination of all available databases was used to attempt to relate identified mixing zones to effluent discharges.

2.5 SALTMARSH AND BEACHES

2.5.1 Saltmarshes represent an important resource in the coastal zone for two key reasons. Firstly, they act as a barrier to the effects of flooding, dissipating the storm wave action by absorbing the tide and wave energy (Donoghue *et al.*,1995). Secondly, they are biologically diverse, holding a large variety of species of flora and supporting important bird populations.

2.5.2 The Environment Agency has a responsibility under the Land Drainage Act 1991 and the Water Resources Act 1991 to prevent the occurrence of flooding. The Flood Defence Strategy inherited from the National Rivers Authority recognises the role of beaches and saltmarshes as natural flood defences and areas of set back. Data collected by aerial surveillance on the distribution and coverage of such surface types will provide useful information for Flood Defence staff.

2.5.3 The total area covered by active saltmarshes in the United Kingdom is approximately 44,000 ha, of which 80% have SSSI status (Brampton, 1992). Predicted rises in sea level, however, threaten the existence of these saltmarshes. Climate change predictions estimate a global sea level rise of 37 cm by 2050 (DoE, 1996). When combined with decrease in land elevation, East Anglia expects a net effect of +50 cm by 2050 (DoE, 1996).

2.5.4 The landward retreat of marshes is often threatened by the presence of man made features such as sea walls and transport infrastructure (Donoghue *et al.*, 1995). Saltmarshes are therefore suffering from the process of coastal squeeze (NRA, 1992).

2.5.5 In order to assess changes in saltmarshes it is necessary to map the positions of key boundaries. Data collected by aerial surveillance techniques offers the opportunity to map surface cover types over large spatial scales, with relatively low cost as compared with intensive land mapping surveys. Different surface types will return differing spectral signatures to the remote sensing device, allowing digital classification procedures to be applied, and to allow targeting and mapping of specific areas (ITE, 1995).

2.5.6 Maps produced by the classification procedure may be integrated into a Geographical Information System to allow a quantitative evaluation of change to be made, both compared with previously mapped saltmarshes and beaches and with future data. There is the potential for these to be used as a contextual layer when making informed management decisions.

2.6 INTER-TIDAL VEGETATION

2.6.1 Under the provisions of the Environment Act 1995, the Agency has a responsibility to promote the conservation of flora and fauna which are dependent on the aquatic environment. The intertidal zone is a highly diverse environment, with a wide range of vegetation species, which are sensitive to changes in both the aquatic and terrestrial environments.

2.6.2 Changes in inter-tidal vegetation communities may be linked to the presence of increased nutrients from anthropogenic sources, for example sewage treatment works. The growth of macrophytes on mudflats, for example *Enteromorpha spp*, is one indicator of eutrophication. Under the provisions of the Urban Waste Water Treatment Directive (91/271/EEC) and the Nitrates Directive (91/676/EEC) estuaries may be designated as Sensitive Areas or Polluted Waters respectively. The directives provisions state that for those waters found to be Sensitive Areas and receiving qualifying discharges nutrient stripping will be required to be applied to the discharges, unless it can be proven that this will not affect the level of eutrophication. For those areas found to be Polluted Waters, areas of land draining into the estuary must be designated as Vulnerable Zones and agricultural practices in these zones be restricted.

2.6.3 The use of aerial surveillance for the assessment of intertidal vegetation in estuarine environments has been recognised as an important tool by Environment Agency Conservation staff.

2.6.4 Traditional methods for the determination of ground cover consist of detailed biological surveys either by foot or using hovercraft. These point samples must subsequently be interpolated to produce spatial maps for the area of interest. Whilst this is a highly accurate method for small scale surveys, it is difficult to transfer the technique to larger areas, such as entire estuaries.

2.6.5 More recently false colour near infrared photography has been used to provide spatial estimates of algal cover. This technique relies on the variation in near infrared response between vegetated and non-vegetated surfaces. Although this provides accurate results it relies intensively on experienced operators' subjective knowledge, and can involve relatively expensive contracts.

2.6.6 Aerial surveillance using a digital system offers the potential to develop an automated classification procedure. The digital data records information from a number of wavelength ranges within the electromagnetic spectrum, which will allow greater differentiation between cover types. Moreover, the data may be analysed using automated classification procedures, to produce clear maps of inter-tidal vegetation cover.

2.6.7 However, individual vegetation species cannot always be differentiated on the basis of spectral characteristics alone. To provide information on species composition, aerial surveys should be complemented by traditional biological surveys of flora and fauna. Integration of these two data sets would allow the production of species maps thereby allowing the assessment of gross changes. This level of detail is not, however, required for the assessments of Sensitive Areas of Polluted Waters under the provisions of the Urban Waste Water Treatment and Nitrates Directives (91/271/EEC and 91/676/EEC).

2.7 VIEWPOINTS ON THE STATE OF THE ENVIRONMENT

2.7.1 The Environment Agency's draft Strategy for reporting the state of the environment proposes a framework of six basic components that provide complementary viewpoints on the state of the environment, as follows:

- (i) land use and environmental resources;
- (ii) the status of key biological populations, communities and biodiversity;
- (iii) the quality of the environment with respect to compliance with existing standards and targets;
- (iv) the "health" of the environment;
- (v) environmental change at long term reference sites; and
- (vi) the aesthetic quality of the environment.

2.7.2 The draft Strategy for measuring the state of the environment was not finalised in time to influence planning of the airborne surveillance for this project. The imagery obtained in this study was nevertheless evaluated as a preliminary scoping study to assess the contribution that remote surveillance could make to measuring the state of estuarine environments.

2.7.3 A review of available information suggests that aerial surveillance will have application to developing environmental indicators for the six components. Estuarine land types can be classified by surveillance (see Section 2.5 and 2.6). Visualisation of discharge mixing zones can provide information on the extent of chemical quality zones (see Section 2.4). The health of vegetation can be inferred from specific wavelengths in the visible spectrum. Aerial surveillance imagery can be used as reference data to chart environmental changes due to long-term sea level and temperature movements. The application of remote surveillance to the status of key biological communities has yet to be explored, but section 2.6.7 above indicates how ground surveys can be built on and enhanced by aerial surveillance imagery.

2.7.4 Aerial surveillance may have particular application to one aspect on the state of the estuarine environment, this being measurement of the effects of climate change. Potential applications range from accurate metrology of sea level rises with respect to land levels, prediction of the protection required for urban or industrial assets, prediction of risks to wetland Sites of Special Scientific Interest (SSSI), and characterising habitat changes due to temperature rises.

3 INDIVIDUAL ESTUARY SURVEYS

The following sections describe the results of the aerial surveillance on the fourteen estuaries. Each issue described in Section 2 is discussed individually, before conclusions are drawn on the major findings. The estuaries are dealt with alphabetically.

3.1 THE DEBEN ESTUARY

3.1.1 Background Description

3.1.1.1 The Deben Estuary is located on the Suffolk coast to the north of the major ports of Felixstowe and Harwich. Figure 2 illustrates the estuary, which extends approximately 12 km from the tidal limit near Melton to the mouth at Felixstoweferry. The total catchment serves a population of over 20,000 people, of whom the majority live in Woodbridge. This figure also shows that the majority of the Deben Estuary is designated as a Site of Special Scientific Interest (SSSI).

3.1.1.2 Three creeks join the estuarine reaches between Woodbridge and the mouth: Martlesham Creek, Kirton Creek and Shottisham Creek. Both Kirton Creek and Martlesham Creek have short tidal reaches. There is a major sewage treatment work discharge to Martlesham Creek from Woodbridge, in addition to discharges at Melton and Kirton (see figure 4).

3.1.1.3 The true colour composite image of the estuary (figure 3), collected at low water on the 5th August 1996, shows the meandering nature of the estuary. The inter-tidal zone is extensive in comparison with the width of the channel, being in excess of 70%, with ground cover types varying from mudflat to saltmarsh. The imagery also illustrates the plume of estuarine waters to the coastal zone, which causes turbulence around the sandbars at the mouth of the estuary.

3.1.2 Discussion of major issues

3.1.2.1 The Deben Estuary is a highly important conservation resource, particularly due to the presence of major saltmarsh. The saltmarsh within the Deben accounts for 40% of the saltmarsh of Suffolk, and is an important haven for migratory birds. This has led to the majority of the estuary being classified as a Site of Special Scientific Interest (SSSI).

3.1.2.2 Water quality within the estuary has been assessed in recent years as part of a regional estuarine study, to assess the degree of eutrophication in the estuary. Water samples were analysed for chlorophyll-*a*, dissolved oxygen, turbidity and key nutrients. A slight sag in dissolved oxygen concentration was noted close to outfall from Woodbridge sewage treatment works. The Deben was found to have higher concentrations of chlorophyll-*a* in Summer than in Winter, although these remained moderate with no occurrence of noxious algal blooms (Elliott *et al.*, 1994).

3.1.2.3 The water quality study did not involve monitoring of the mudflats for the growth of inter-tidal vegetation. A further study has been implemented during 1996, in which the Deben Estuary has been investigated using a combination of aerial surveillance and ground based surveying. The results of this study on the Deben are described in section 3.1.5.

3.1.3 Discharge mixing zones

3.1.3.1 The Deben was surveyed on 5th August 1996, at four tidal states throughout the day, with collection of both CASI and thermal imagery. The true colour composite illustrated in figure 3 shows the quality of the CASI imagery. The thermal imagery clearly showed variations in water depth between the creeks and the main channel, with higher temperatures in the shallow waters of the creeks.

3.1.3.2 The area was covered by two flightlines, one over the upper reaches and the other covering the majority of the estuary. The positions of consented sewage effluent discharges within the Deben Estuary are shown in figure 4. There are no consented trade effluent discharges to this estuary.

3.1.3.3 The CASI and thermal imagery did not reveal the presence of any discharge mixing zones from the three sewage treatment works at Woodbridge, Melton and Kirton. Variations in both the CASI signal and the thermal imagery were due mainly to variations in sediment loading and water depth between the main estuary and the adjoining creeks.

3.1.3.4 There are a number of possible explanations for the absence of mixing zones within the imagery. Firstly, the consented volumes for each discharge are low, with the Woodbridge sewage treatment works having the highest volume at 4,800 m^3/day. Secondly, the estuarine waters had been warmed by insolation by August making it difficult to distinguish incoming waters. Aerial surveillance for thermal outfall plumes should in future be carried out in Winter or Spring. Finally, the discharges are mainly to smaller creeks which themselves have a higher temperature relative to the main channel meaning that thermal differentiation will be difficult.

3.1.4 Saltmarsh and beaches

3.1.4.1 The presence of saltmarsh and beaches within an estuary acts as a defence against coastal flooding, both purely as a physical barrier and as a means of dissipating wave and tidal energy. Additionally, the saltmarsh may act as an important resource for conservation, with high species diversity. These regions often provide an important haven for migratory birds.

3.1.4.2 CASI imagery collected at low water on 5th August 1996 was used to classify the extent of saltmarsh and beach within the Deben Estuary. The classification procedure relies upon the variation in near infrared signal between vegetated and non-vegetated surfaces over the entire inter-tidal zone. A false colour composite image, which displays the near-infrared channel as red, is shown in figure 5, with the results of the digital classification being shown pictorially in figure 6. Table 2 shows the percentage of the inter-tidal zone covered by each land cover class. The identification of the classes derived from the classification was facilitated by a ground survey in August 1996, which investigated major land cover types along the length of the Deben Estuary.

Land Cover Class	Area (ha)	Percentage cover
Saltmarsh	297	40
Mud	216	29
Wet mud	71	9
Brown algae/saltmarsh	69	9
Sparse green algae	56	8
Sand	25	3
Dense green algae	14	2
Total	**748**	**100**

Table 2: Inter-tidal land cover classification in the Deben Estuary, 5th August 1996

3.1.4.3 There are extensive areas of saltmarsh within the estuary, extending throughout the tidal reaches. The widest areas of saltmarsh are located in the middle reaches to the south of Waldringfield. The areal coverage compares well with that shown on the Ordnance Survey map of the region, suggesting that the marshes are well established. The upper reaches of the estuary are narrower and support less saltmarsh.

3.1.4.4 The marshes show a typical profile, with mudflats at the toe, where the marsh meets the water line. This area of mud serves to dissipate tidal energy, such that the marshes are protected against the force of the incoming tide. The marshes, in particular those that are well established, show a complex pattern of drainage channels. Younger saltmarsh, generally on the western side of the estuary, has less drainage channels.

3.1.4.5 To the landward side of the marsh there is a typical zonation of cover type, moving from saltmarsh species through to terrestrial vegetation. The digital classification produces a class which is saltmarsh or brown algae depending on the section of the estuary in which it occurs. These regions are not included in the percentage cover of saltmarsh recorded in table 2.

3.1.4.6 In the lower reaches of the estuary, south of 238,000, there is an area of sandy beach on both sides of the estuary. The inter-tidal zone in this area is narrow and the tidal energy will be high. These conditions are not conducive to the formation of a saltmarsh environment.

3.1.5 Inter-tidal vegetation

3.1.5.1 The presence of algae on inter-tidal mudflats may be indicative of eutrophic conditions. The Deben Estuary is currently being proposed as a Sensitive Area under the provisions of the Urban Waste Water Treatment Directive. The presence of extensive macro-algal cover is one indicator of the sensitivity of the estuary to eutrophication. Figure 6 shows classes representing varying concentrations of algae.

3.1.5.2 The main areas of mud are located to the seaward side of saltmarsh, as discussed above. Downstream of Waldringfield, these muds are bare with little or no algal cover. Further upstream, the mud tends to be covered to varying degrees by algae.

3.1.5.3 Close to the area known as The Tips, the algal cover is sparse (grey/green class), although there are small areas of more dense cover, shown as the bright green class. The most dense cover is found around Stonner Point. In this area there is a further class which signifies the presence of brown macro-algae.

3.1.5.4 Figure 7 shows an enlargement of Martlesham Creek. This is the region to which the Woodbridge sewage treatment works discharges. The classification shows that there is no algal growth in this creek. Opposite the mouth of Martlesham Creek there is algal growth on the mudflats. There is no evidence to support a causal link between this algae and the sewage discharge, although this may warrant further investigation.

3.1.5.5 Previous water quality surveys carried out by the Anglian Region of the Environment Agency recorded little sign of algal mat growth. This aerial study would seem to support the findings of these previous surveys, with little algal growth apparent in this estuary.

3.1.6 Summary of estuary

3.1.6.1 Investigation of the aerial surveillance imagery collected during 1996 reveals the rural nature of the estuary, with very little indication of urban development. The farmland surrounding the estuary is predominantly arable, with no evidence of forestry in the imagery. The low level of industry is signified by the absence of any consented trade effluent discharges in this estuary.

3.1.6.2 The key regional interest in the Deben Estuary has been in the establishment of the trophic status of the estuary. As stated in section 3.1.2, the Region has undertaken water quality surveys of the estuary, but has not to date carried out a full survey of the inter-tidal mudflat vegetation.

3.1.6.3 The work described above shows that there is no dense growth of macro-algae on the inter-tidal mudflats. Moreover, the small areas of algal cover recorded do not appear to be directly linked to the input of sewage from the major sewage treatment works on the estuary, in particular at Woodbridge sewage treatment works in Martlesham Creek.

3.1.6.4 There are no consented trade effluent discharges to this estuary. The discharges from sewage treatment works were not evident within either the CASI or the thermal imagery collected in August. This can probably be accounted for by the low thermal variability encountered in this season, and by the low suspended solids loading of such small discharges.

3.1.6.5 Recent reports predict a sea level rise of 37 cm on average across the UK by the year 2050 (DoE, 1996). When combined with the sinking land level of this section of the UK coast, an increase of 50 cm may be expected in this estuary. The highly rural nature of the estuary means that there are few assets which will require hard defences against flooding, except in the Woodbridge region.

3.1.6.6 The saltmarsh within the Deben Estuary is designated SSSI, with the estuary containing 40% of the saltmarsh resource of Suffolk. This saltmarsh currently covers an area of 297 ha, but the seaward margin will be under threat from the effects of sea level rise. However, there is great potential in such a rural estuary to consider the use of managed retreat to enable the maintenance of the extent of this ecologically important resource, by the landward migration of the marsh. The digital classification will provide a basis against which to assess changes in the saltmarsh location and extent.

3.1.6.7 The report by the Department of the Environment (1996) also predicts an increase in temperature in the south of Britain, and a subsequent increase in tourism. This may increase the pressures on sewage effluent disposal systems, and may in future alter the trophic status of this estuary.

3.1.6.8 The digital classification produced from the surveillance data provides a numerical estimate of the cover of saltmarsh and other vegetation types within the Deben estuary. Maps such as these may be integrated into a Geographical Information System, and inter-annual comparisons made. Moreover, classifications may be made of the land cover types surrounding the estuary in order to assess more fully the pressures placed upon the estuary.

Figure 2.
The Deben Estuary
Lower Ufford
Eyke
Hasketon
Melton
Bromeswell
Woodbridge
Norwich
Great Yarmouth
Ipswich
Felixstowe
Harwich
Colchester
Southend-on-Sea
Area of Detail
Martlesham Creek
Martlesham
River Deben
Sutton
Waldringfield
Shottisham
Hollesley
Brightwell
Newbourne
Shingle Street
Hemley
Bucklesham
Kirton Creek
Ramsholt
Alderton
Kirton
Bawdsey
Falkenham
Trimley Heath
Felixstoweferry
Walton
Old Felixstowe
Felixstowe
Tidal Limit of Estuary
Coastal Waters
Estuarine Waters
Land (above mean high sea level)
Site of Special Scientific Interest
River or Stream
0
1.5
3 km

Deben Estuary
5th August 1996, Low Water

True colour composite of two CASI images

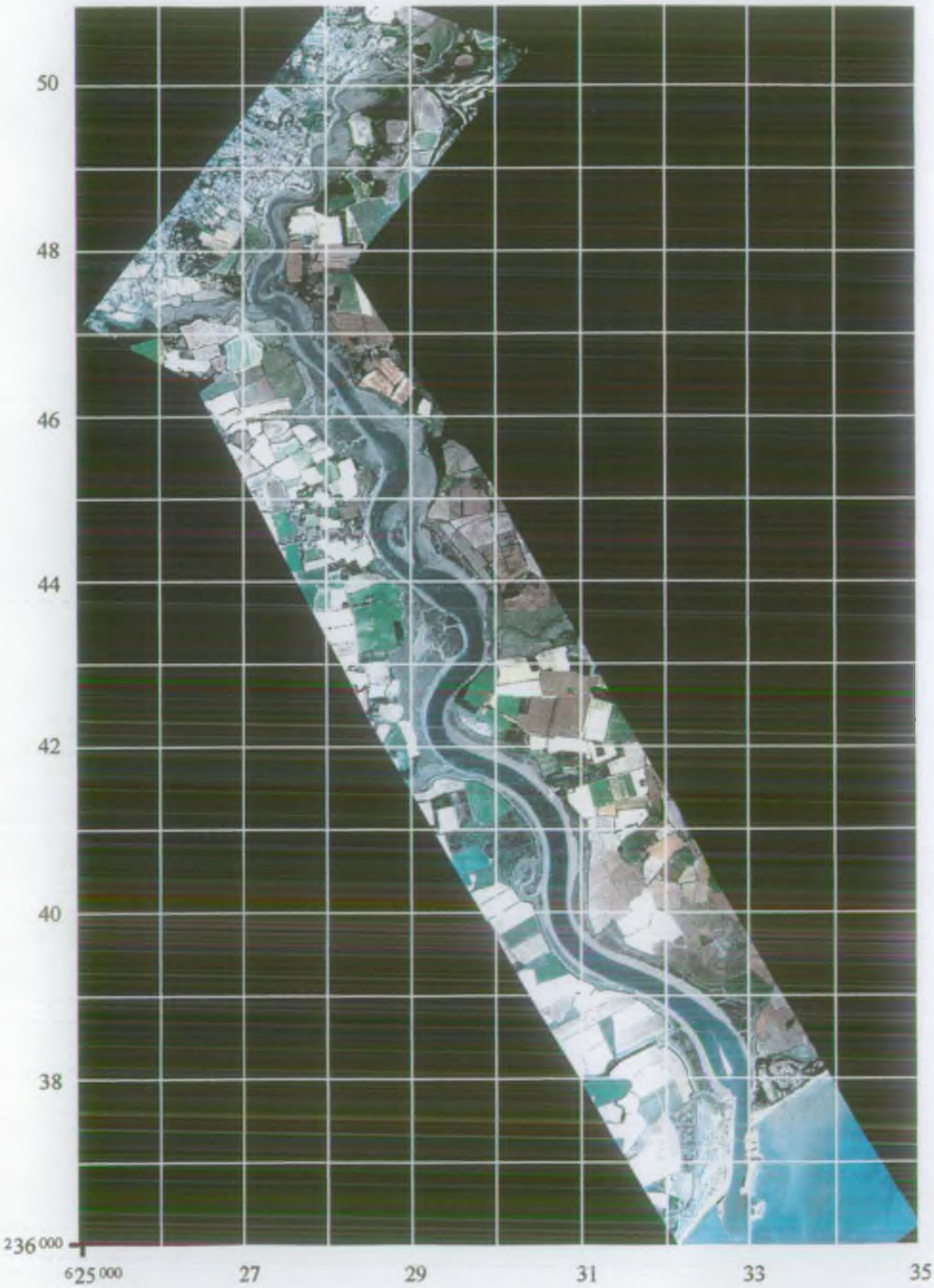


Figure 3

Figure 4. Selected Discharges, The Deben Estuary

Deben Estuary
5th August 1996, Low Water

False colour composite of two CASI images

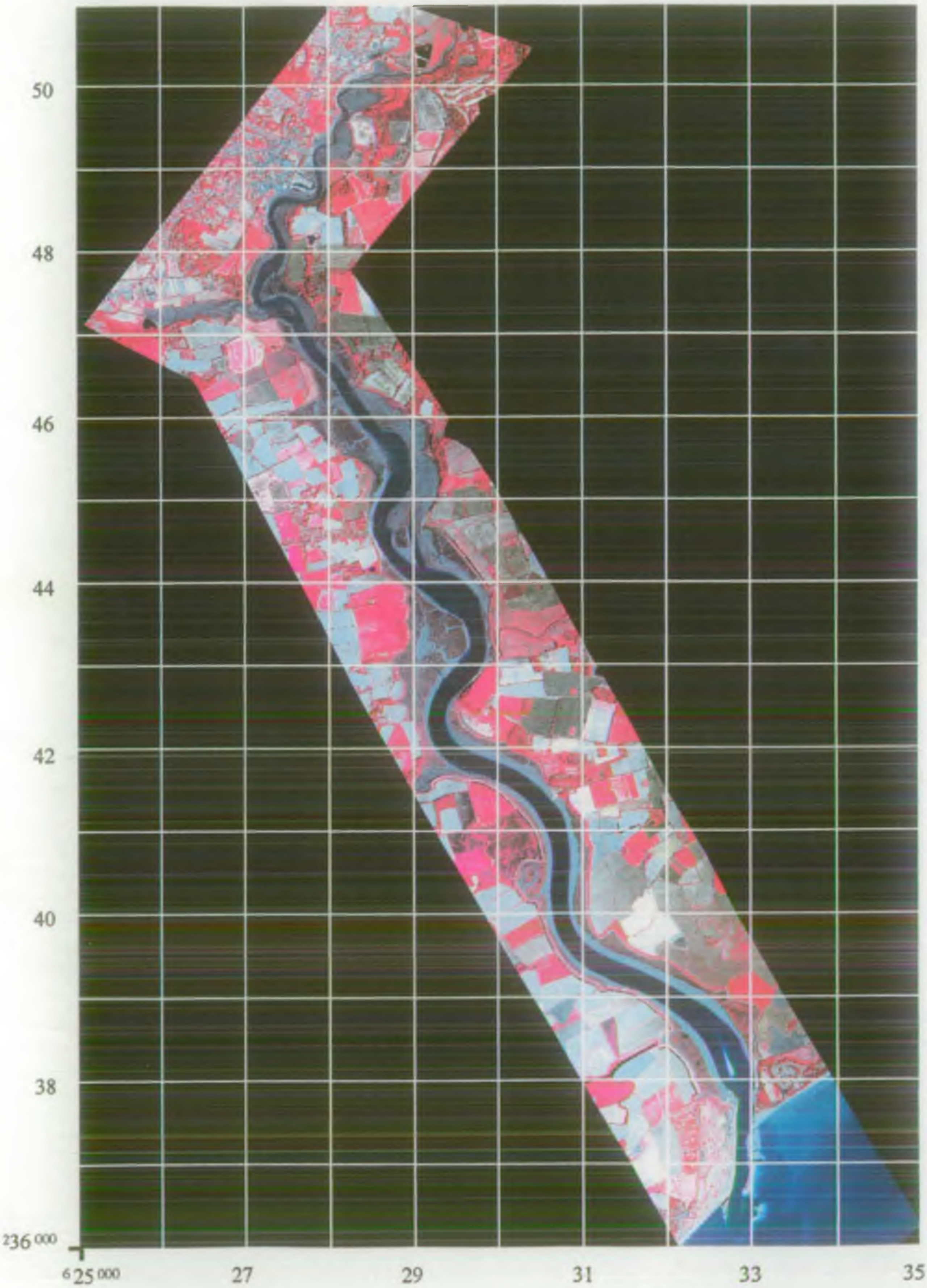


Figure 5

Deben Estuary
5th August 1996, Low Water

Unsupervised classification of inter-tidal areas

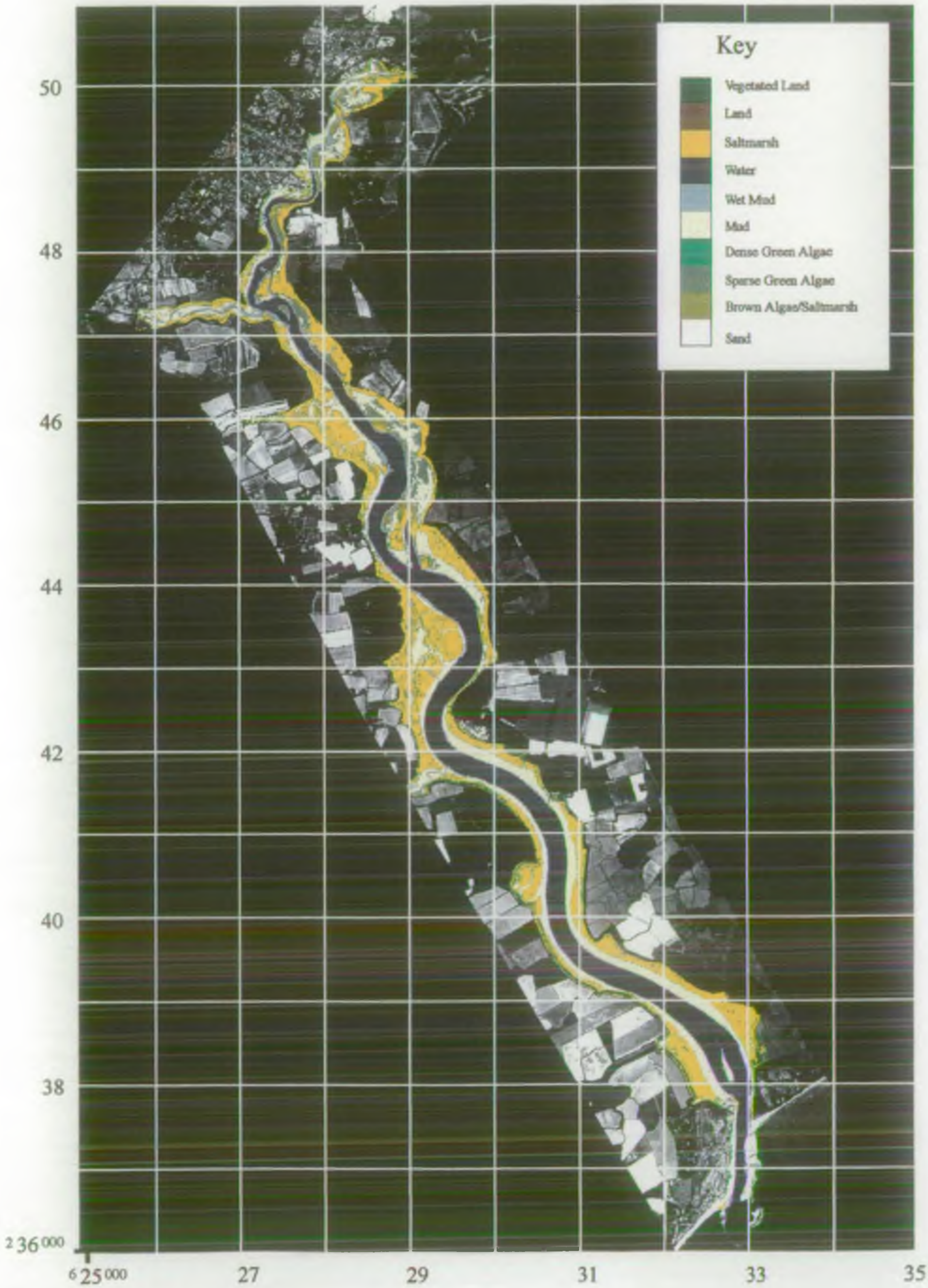


Figure 6

Deben Estuary
5th August 1996, Low Water

Unsupervised classification
- Martlesham Creek

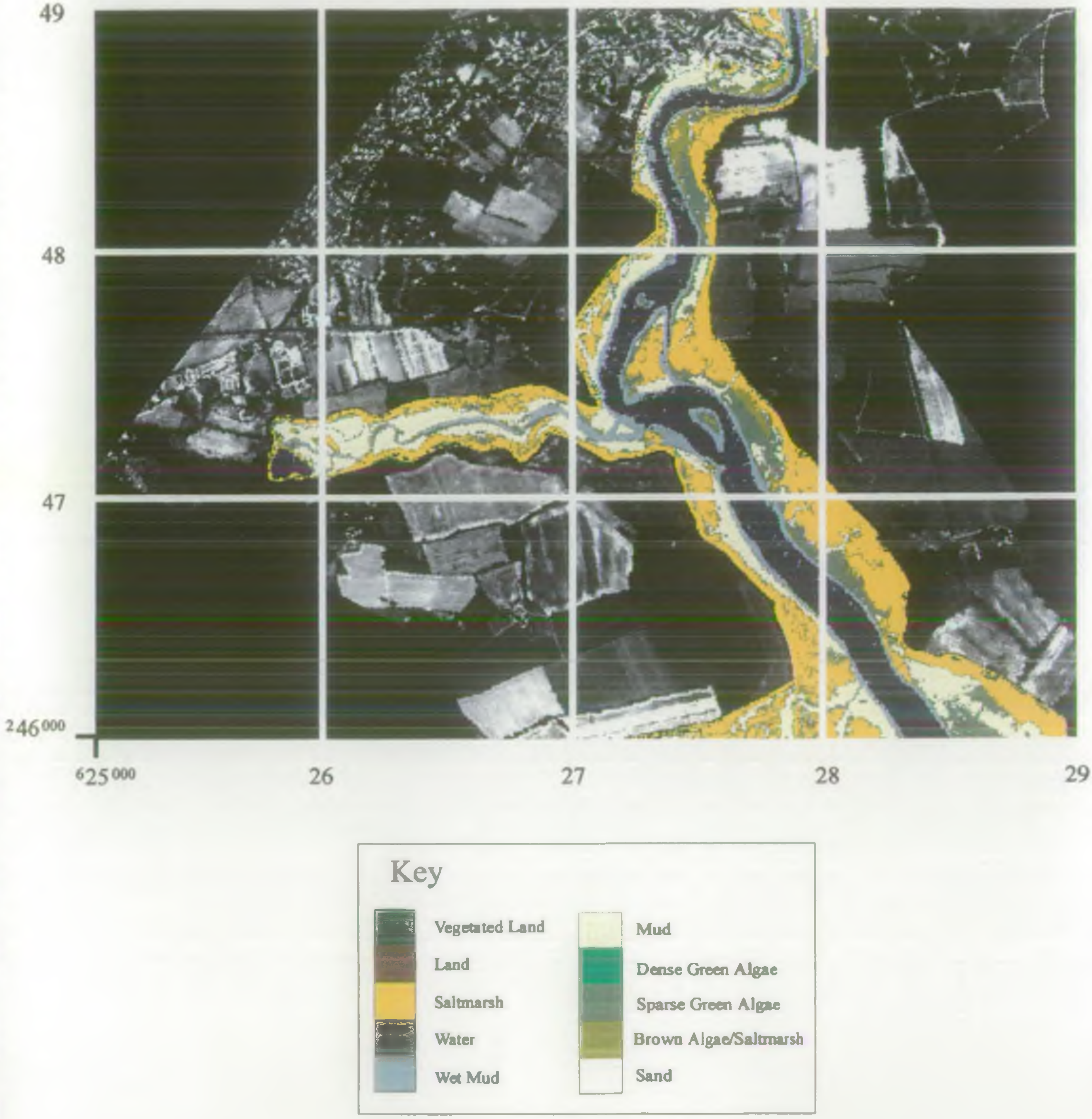


Figure 7

3.2 THE FAL ESTUARY

3.2.1 Background Description

3.2.1.1 The Fal Estuary in Cornwall is a complex system comprising four major branches, the rivers Truro and Tresillian, the River Fal and the Restronguet Creek, which join together in the water course known as the Carrick Roads. The estuarine area is shown in figure 8. This map also shows the locations and extents of Sites of Special Scientific Interest (SSSI) within this estuary.

3.2.1.2 Figure 9 shows a mosaic of the three CASI images recorded at low water on 14th September 1996. This image covers the estuarine reaches of the Truro and Tresillian rivers and show extensive inter-tidal mud flats with indications of green algal growth.

3.2.1.3 The major historical influence on this area has been the presence of metals mining, which has been carried out since 2000 BC. Extensive mining began in the 17th Century, with the group of mines in the Carnon Valley (upstream of Restronguet Creek) being the largest copper producer in the world by the 1850s. This has resulted in pollution of the surrounding water courses over the years.

3.2.2 Discussion of major issues

3.2.2.1 The Fal Estuary is a major region for shell fisheries, with the water quality at Turnaware and Percival being measured against the provisions of the EC Shellfish Water Directive (79/923/EEC). Additionally, the EC Shellfish Hygiene Directive (91/492/EEC) is used to determine which areas may be used for shellfish cultivation. Although there are no Class A shell fisheries in the estuary, there are a large number of Class B and C fisheries. Some sections have shown a decline in water quality in recent years, in particular in the upper Carrick Roads region, and harvesting is prohibited in the Truro River. Although no link has yet been established between this decline and the effects of sewage discharges from Ladock and Newham sewage treatment works, an investigation has been carried out using bacteriological tracking to fully assess this (Environment Agency, 1997*a*), the results of which will be available in 1997.

3.2.2.2 The growth of macro-algae on the mudflats of this estuary is being assessed by the Environment Agency South West Region, in relation to the Urban Waste Water Treatment Directive (91/271/EEC). A combination of aerial surveillance and ground based studies is being used to assess changes in growth of macro-algae in 1995 and 1996. Additionally the presence of toxic blooms of *Alexandrium tamarense*, occurring in both 1995 and 1996, indicate eutrophic conditions. If current studies show this region to be subject to eutrophication, then further treatment will be required at the sewage treatment works (Environment Agency, 1997*a*).

3.2.2.3 After the closure of the Wheal Jane copper mine in 1991 there was an unavoidable release of mine waters in 1992. These contained high concentrations of dissolved metals which were discharged into Restronguet Creek. This resulted in the commissioning of a major report into possible ways of avoiding this in future (NRA South Western, Knight Piésold, 1992). The report concluded that various techniques should be employed to minimise releases from Wheal Jane, but pointed out that metals concentrations in this region would remain high due to diffuse pollution from the large number of other abandoned mine workings in the region.

3.2.2.4 The past use of the Fal Estuary for mining activities has resulted in high dissolved metals concentrations being recorded during water quality surveys, when for example compared against the Environmental Quality Standards of the Dangerous Substances Directive (76/464/EEC). The impact of these metalliferous mining activities is considered in the Local Environment Agency Plan, which is due for publication in Spring 1997.

3.2.3 Discharge mixing zones

3.2.3.1 The Fal Estuary was surveyed at high water on 18th June 1996, with a series of 5 flightlines. The thermal imagery was of high quality with a very different surface temperature in the main estuary compared with that of the adjoining creeks. This is probably due to the presence of more shallow water in these creeks, which will have warmed up more rapidly than the deeper water in the main channel.

3.2.3.2 The CASI data shows a high suspended solids loading in the region, signified by an increased reflectance recorded by the sensor. Higher concentrations were found in the smaller creeks, with the least turbid waters in the Carrick Roads.

3.2.3.3 Investigation of both the CASI and the thermal data showed no distinct discharge mixing zones at the time of measurement.

3.2.3.4 The high suspended solids loading of the area means that sewage discharges, which would typically have a high solids loading, would be less easily distinguishable in the CASI imagery.

3.2.3.5 The data were collected in June when the temperature of the receiving waters should be cooler than that of the discharges. Most of the larger discharge points are within the creeks adjoining Carrick Roads which have an overall higher temperature than the main channel. The discharges may be raising the temperature of these creeks, but this is being masked by the effects of shallow water and high suspended solids loading.

3.2.4 Saltmarsh and beaches

3.2.4.1 The presence of saltmarsh and beaches within an estuarine environment acts as a natural defence against the actions of coastal flooding, both by providing a physical barrier and by dissipating tide and wave energy. Saltmarsh is a highly diverse habitat supporting a wide variety of wildlife.

3.2.4.2 The Truro and Tresillian rivers have been identified by Regional and Area staff as potentially prone to eutrophication. This area was therefore studied in both 1995 and 1996 using a combination of aerial imagery and ground truth studies.

3.2.4.3 Figure 11 shows a mosaic of three false colour composite images of the estuarine reaches of the Truro and Tresillian rivers. This mosaic shows vegetated surfaces as red, as these have a higher infrared signal. The CASI imagery has also been used to produce a digital classification of the region. This technique relies on the variation in all channels of the CASI, and is particularly sensitive to changes in vegetation cover. The results of both the 1995 and 1996 classifications are displayed in terms of percentage cover of the inter-tidal zone in table 3. Figures 12 and 13 give a pictorial display of the results from both surveys.

Land Cover Class	Area (ha) 1995	% Cover 1995	Area (ha) 1996	% Cover 1996
Mud	120	80	**104**	**72**
Sparse green algae	5	3	**20**	**14**
Wet mud	12	8	**14**	**9**
Dense green algae	4	3	**5**	**4**
Saltmarsh	-	-	**1**	**1**
Sand	2	1	-	-
Null	8	5	-	-
Total	**151**	**100**	**144**	**100**

Table 3: Inter-tidal and cover classification in the Truro and Tresillian rivers in 1995 and 1996

3.2.4.4 There is only one area of saltmarsh in this region of the estuary, close to Calenick. Saltmarsh vegetation was not included in the 1995 classification, but observation of the false colour composite colour imagery for this year reveals that this region was again saltmarsh, which is in agreement with ground truth studies.

3.2.4.5 The small area of saltmarsh in this estuary is verified by the numerical results which show that saltmarsh accounts for only 0.68% of the inter-tidal zone. The majority of the inter-tidal zone consists of muds which will themselves act to dissipate the wave and tide energy, thus providing a barrier against flooding.

3.2.5 Inter-tidal vegetation

3.2.5.1 The quantity of macro-algae such as *Enteromorpha* and *Ulva* growing on inter-tidal mudflats may be enhanced by excessive nutrients from sewage effluent discharges. These algae are used as an indicator when assessing whether an estuary is prone to eutrophication, and whether qualifying discharges should be stripped of nutrients under the provisions of the Urban Waste Water Treatment Directive (91/271/EEC). Interpretation of the results from this estuary should take into consideration the elevated metals loadings which will inhibit the growth of macro-algae.

3.2.5.2 The Truro and Tresillian rivers were considered by Environment Agency Regional and Areas staff to be potentially prone to eutrophication and are currently being proposed as a Sensitive Water under the provisions of the Urban Waste Water Treatment Directive. The presence of algae is shown in imagery from 1995 and 1996 in the digital classifications (figures 12 and 13).

3.2.5.3 The classifications show varying concentrations of algae on the inter-tidal mudflats. Figure 14 shows the main region of algae in greater detail. In both the 1995 and the 1996 imagery, there was an area of dense algae, marked A on the figure 13. This area is comparable in the two images, indicating that it has remained fairly constant, although there is slightly more dense cover in the 1996 data. The area is close to the small discharge of untreated sewage from Victoria Point outfall and is downstream of the more major sewage effluent discharge from Newham sewage treatment works which serves Truro.

3.2.5.4 In the lower reaches of the River Tresillian there is greater cover by algae in 1996 than in 1995. In 1996 some patches show dense algae with much of the inter-tidal zone covered by sparse algae. In 1995, this area had only small areas sparsely covered by algae. The percentage cover of dense algae has only increased from 4% to 5% from 1995 to 1996, but the percentage of the inter-tidal zone showing sparse algal cover has increased from 5% to 20%.

3.2.5.5 It is the percentage cover of dense algae which is particularly indicative of eutrophic conditions. The macro-algal presence does not suggest that the area should be considered as a Sensitive Area although other factors mean that the estuary is still being considered. The classification, however, shows such a large increase in algal cover between the two years that it may be considered worthy of further investigation in future years, to assess whether the inter-annual variability is simply natural variation.

3.2.6 Summary of estuary

3.2.6.1 The aerial surveillance of the Fal Estuary carried out in 1996 has revealed information on the environmental quality of this estuary. The land surrounding the estuary is almost entirely rural, with major urban development only at Falmouth and Truro, accounting for about 10% of the estuary shoreline. The land use is mainly agricultural with some forestry evident.

3.2.6.2 Recent reports predict a sea level rise due to global warming of 37 cm on average throughout the UK (DoE, 1996) by the year 2050. This rise will be exacerbated in the south of England by the effects of falling land levels. This rise in sea level will result in increased flooding of estuarine environments such as the Fal. The low level of industrial and urban development means that there will be few assets to protect through hard coastal defences. Moreover, the present hard coastal defences have been designed to account for such a sea level rise (Environment Agency, 1997).

3.2.6.3 Although there are no major regions of saltmarsh in the upper Fal estuary, many of the mudflats have protected SSSI status. These will be potentially under threat through an increase in sea level.

3.2.6.4 The aerial surveillance data did not reveal the presence of any mixing zones associated with the discharges of sewage or trade effluent to the Fal Estuary. This may be explained by the characteristics of the receiving water. The majority of discharges are to the narrow, shallow creeks which have elevated temperatures and suspended solids concentrations compared to the main channel. This makes the presence of discharges more difficult to distinguish. Regional investigations into the fate of discharges from Newham sewage treatment works have used bacteriological surveys, which may prove more suitable than remote sensing technique in this highly turbid environment.

3.2.6.5 The data collected at high water showed iron staining of the mud banks in the mouth of Restronguet Creek, which is a result of historical mine water discharges, and specifically may be linked to the release of mine waters from Wheal Jane in 1992, although imagery was not collected prior to this event in order to compare changes. Re-suspension of sediment from this and other banks may adversely affect the water quality, as metals will be re-introduced to the water column.

3.2.6.6 The presence of macro-algal growth on the inter-tidal mudflats of the Truro and Tresillian rivers was shown to have increased between 1995 and 1996. Although the levels do not presently signify the region to be subject to eutrophication, it may be worthy of further investigation in future years.

3.2.6.7 The Fal Estuary was subject to blooms of *Alexandrium tamarense*, in both 1995 and 1996. This red alga can potentially lead to toxic shellfish poisoning. Aerial imagery collected in July 1996 detected the presence of algae and showed that it affected the entire Carrick Roads region of the estuary. The continued occurrence of such algal blooms would potentially affect the use of this estuary for shellfish cultivation and for tourism, although shellfish harvesting is only performed outside of the bloom season.

3.2.6.8 There is a predicted temperature rise for the south of England, which will result in increased tourism within this region (DoE, 1996). This may place extra pressures on the sewage disposal systems, with corresponding changes to the trophic status of the estuary.

3.2.6.9 The results of the above investigations, in particular, the digital classification, may be integrated into a Geographical Information System to allow comparisons of change to be made. This will be of particular benefit is assessing long term change, for example the increase in sea level discussed above.

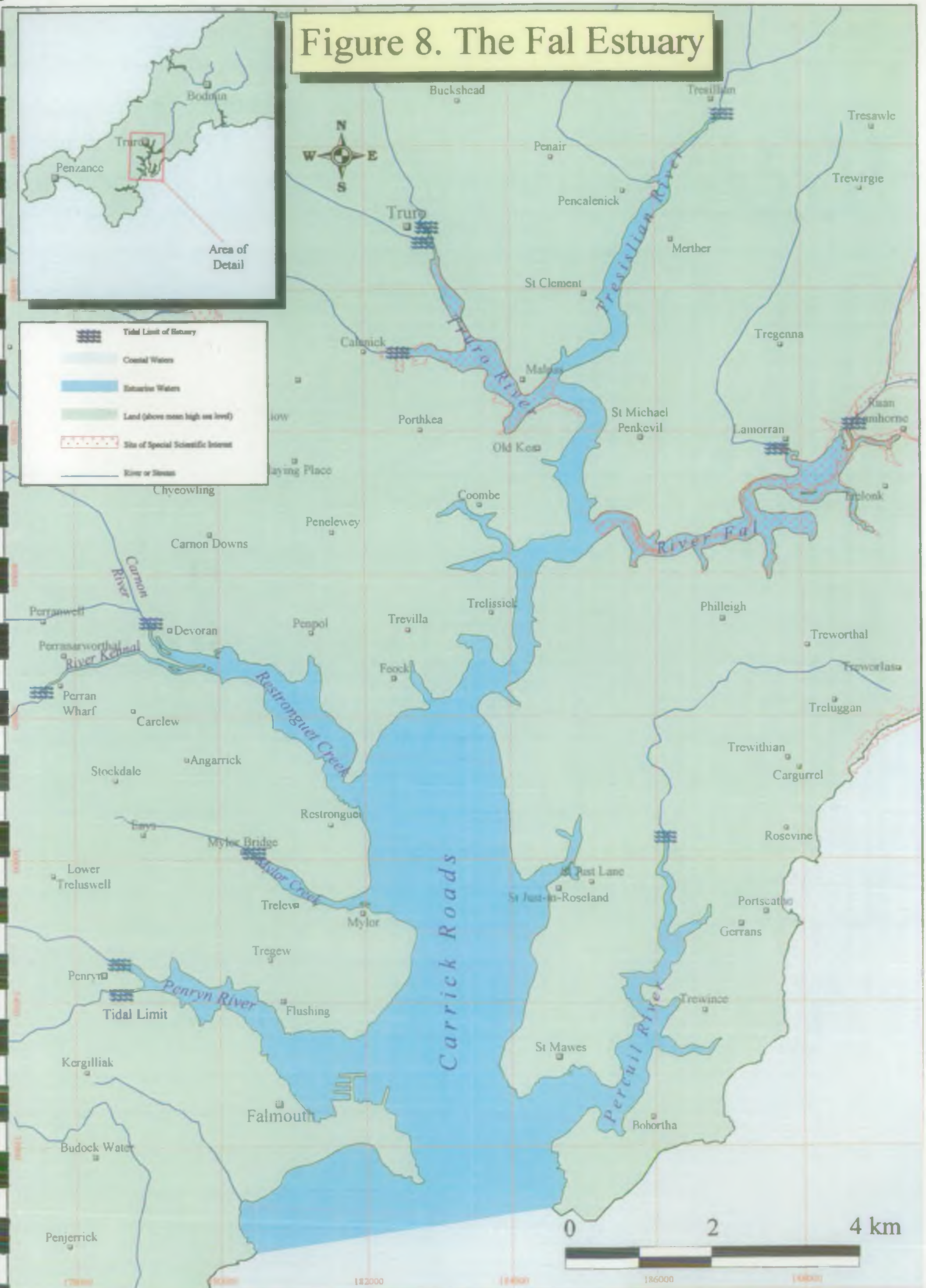


Figure 8. The Fal Estuary

Truro and Tresillian Rivers
14th September 1996, Low Water

True colour composite of three CASI images

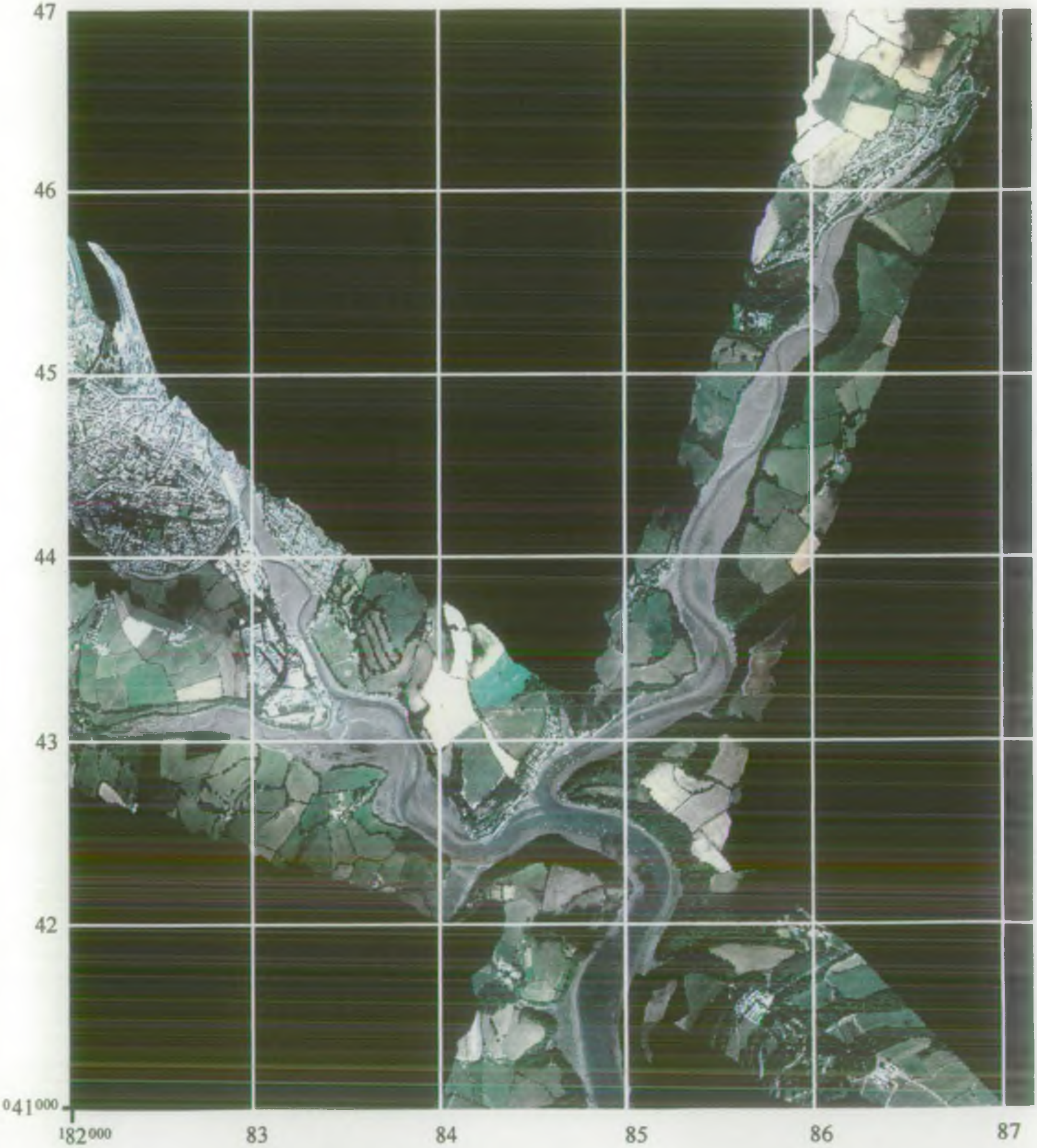


Figure 9

Figure 10.
Selected Discharges,
The Fal Estuary

Truro and Tresillian Rivers
14th September 1996, Low Water

False colour composite of three CASI images

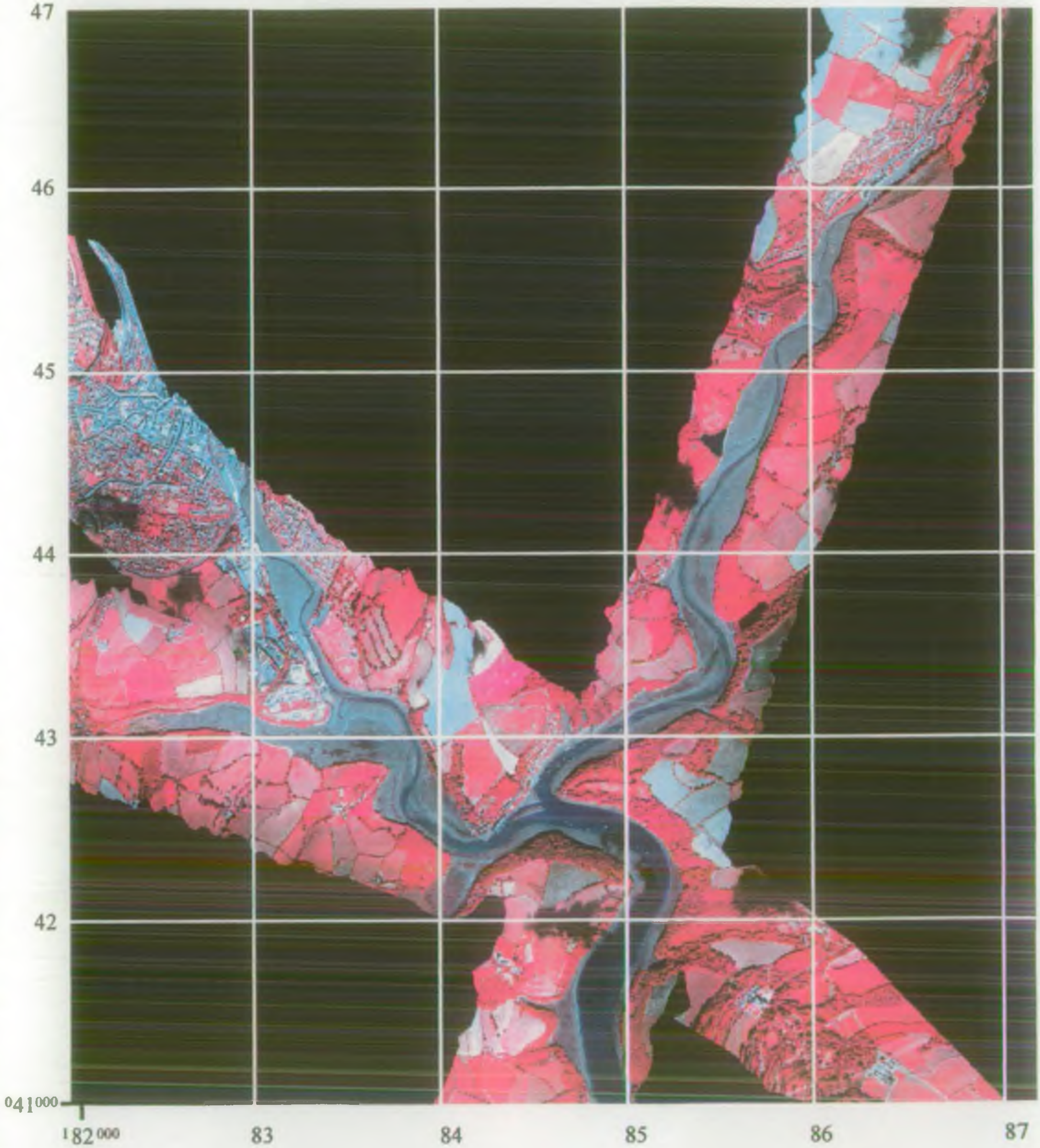


Figure 11

Truro and Tresillian Rivers
16th August 1995, Low Water

Unsupervised classification of inter-tidal areas

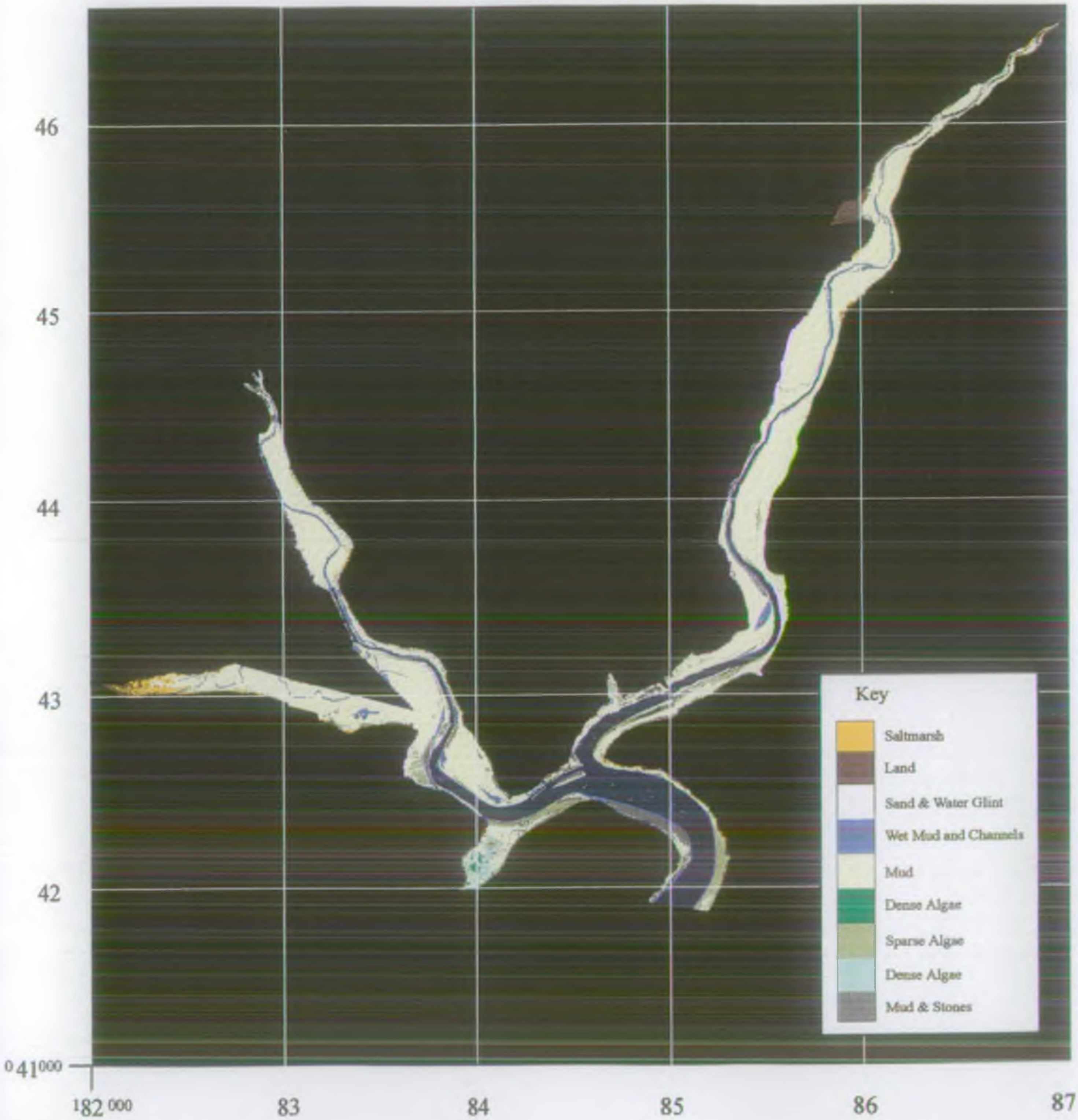


Figure 12

Truro and Tresilian Rivers
14th September 1996, Low Water

Unsupervised classification of inter-tidal areas

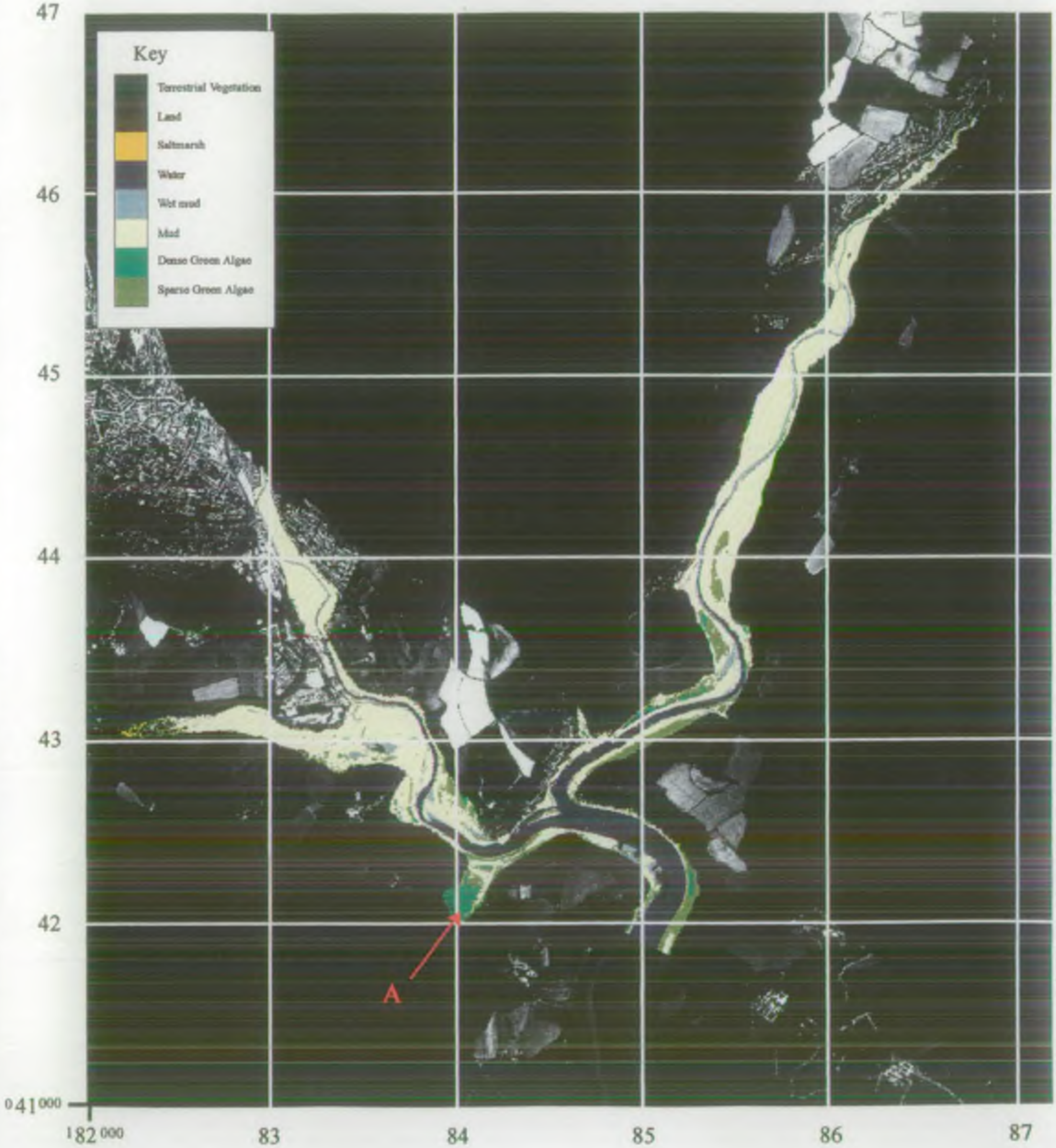


Figure 13

Truro and Tresillian Rivers
14th September 1996, Low Water

Unsupervised classification - Malpas Region

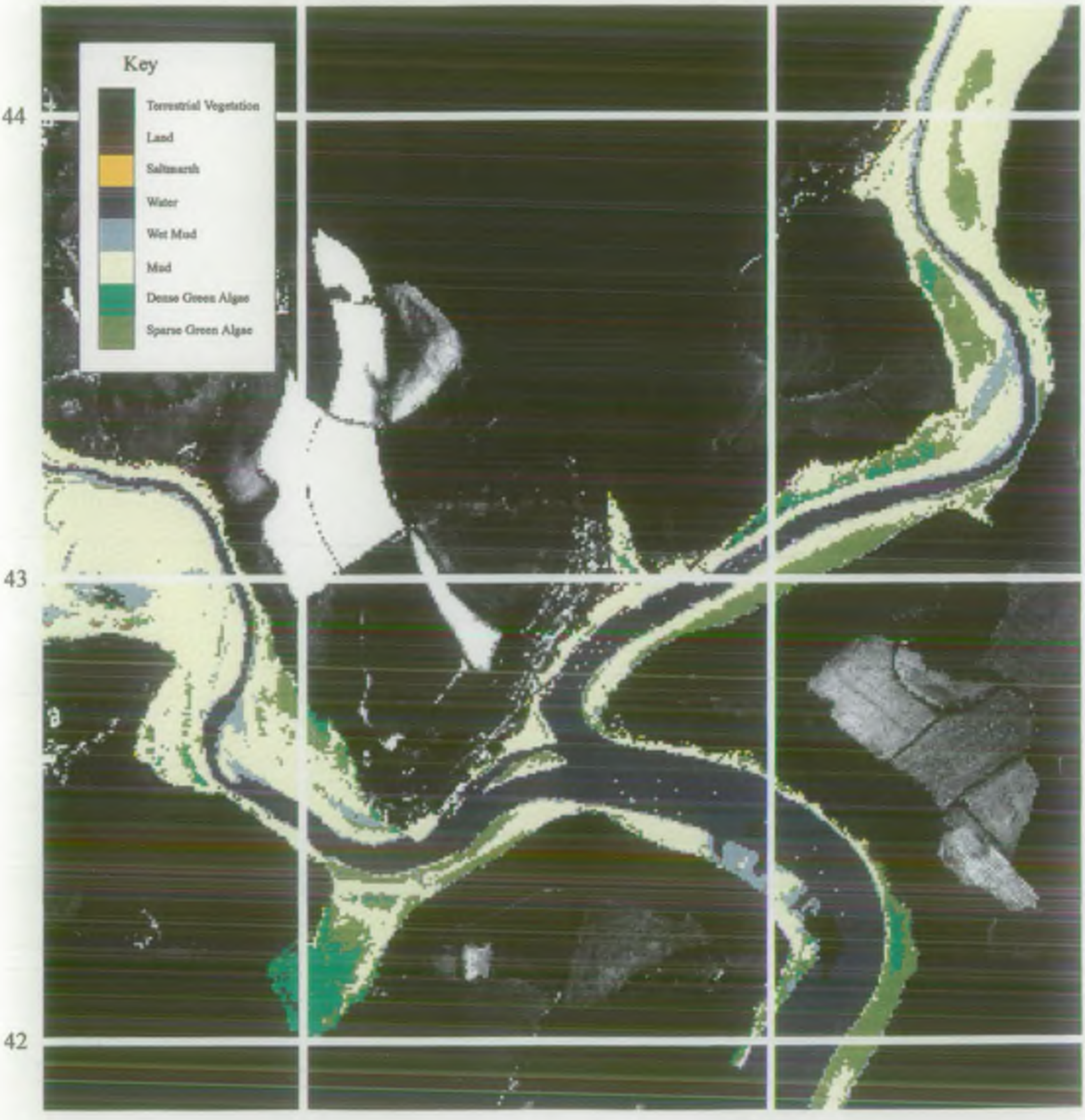


Figure 14

3.3 THE HUMBER AND TRENT ESTUARIES

3.3.1 Background Description

3.3.1.1 The Humber Estuary is formed from the combined discharges of the rivers Trent, Yorkshire Ouse, Don and Hull, representing a catchment covering about one fifth of England (Davidson, 1995*b*). This estuary represents a major input of fresh water and associated terrestrial pollutants to the North Sea. The direction of residual flow from the estuary is to the south along the Lincolnshire coast, before it is deflected to the north east offshore of north Norfolk (de Ruiter *et al.*). The estuary is macrotidal with a spring tidal range of 6 m.

3.3.1.2 The estuarine region is shown in figure 15. Major population centres are found at Hull, Grimsby and Immingham, with the majority of industry also found close to these centres. This figure also shows the location of Sites of Special Scientific Interest (SSSI) within the estuary.

3.3.1.3 Industrial development on many of the shorelines has led to a reduction in the size of the inter-tidal zone, with artificial shoreline extending along much of the central and lower reaches of the estuary.

3.3.1.4 Figures 16 and 17 present two mosaics of CASI data collected at low water for the Humber Estuary. Figure 16 shows the upper reaches of the estuary, as a mosaic of six images. Figure 17 shows the lower reaches as a mosaic of six images. Both sets of data were collected close to low water to show the maximum extent of the inter-tidal zone.

3.3.1.5 The images clearly illustrate the high suspended solids loading within the Humber Estuary, with the presence of solids causing enhanced reflection to the sensor.

3.3.2 Discussion of major issues

3.3.2.1 The estuary is heavily industrialised with large numbers of both sewage and industrial outfalls. Recent legislation has resulted in the definition of the Humber downstream of Hull as an estuary in terms of the provisions and requirements of the Urban Waste Water Treatment Directive. This will result in the need for more stringent treatment being applied to many outfalls.

3.3.2.2 The sand spit at the mouth of the estuary, Spurn Head, has historically been artificially maintained. In 1995 this maintenance ceased, which is resulting in the movement of the spit, and will probably result in the spit becoming separated from the mainland which may have potential implications on the movement of suspended sediment within the estuary.

3.3.2.3 The River Humber has extremely high suspended sediment concentrations. This may lead to the concentration of contaminants from industrial sources within the sediment. One example of this is iron staining, which is a by-product of the titanium dioxide process at two outfalls within the estuary. In this instance, the problem has been alleviated by moving the outfalls to deeper water, where the tidal flow is stronger, and thus better able to disperse the effluent.

3.2.2.4 The water quality of the Humber Estuary is Grade B or Fair when compared against the National Water Council (NWC) Estuary Water Classification Scheme. The north shore, downstream of Hull, is of Good quality.

3.3.3 Discharge mixing zones

3.3.3.1 The main areas of industrial development are found at Hull, Grimsby and Immingham, and consist of manufacturing industry and port developments. This is reflected in the distribution of consented discharges to the region, the positions of which are shown in figure 18.

3.3.3.2 Two key EC directives apply to the trade effluent discharges to the estuary. Most are covered by the Dangerous Substances Directive (76/464/EEC), which regulates controlled substances using Environmental Quality Standards. Two discharges, from Tioxide UK Ltd and SCM Chemicals, are covered by the Titanium Dioxide Directive (78/176/EEC). Only one other discharge in the UK is covered by this directive, this being Tioxide UK Ltd in Teesmouth.

3.3.3.2 Thermal imagery collected from the Humber Estuary on 25th July 1996 shows high thermal variability. This variability was mainly associated with interactions between different water bodies. For example, tributaries such as the River Trent show different temperatures in comparison with those of the main estuary. Higher temperatures were also found where the water was more shallow over sand banks.

3.3.3.3 The imagery recorded only one discharge of warmer water associated with an effluent outfall, this being from the Keadby Power Station on the River Trent (see figures 20 and 21). The absence of thermal mixing zones from outfalls is probably due to the date of data collection. Seasonal warming of the estuary has resulted in less thermal contrast between incoming and receiving waters.

3.3.3.3 The CASI imagery shows the presence of many effluent discharges which show a significant change in water colour due mainly to the characteristics of industrial output. In addition, the extremely high suspended solids loading of the River Humber means that discharges of clear water, for example from rivers and docks, are easy to detect in the CASI imagery.

3.3.3.5 Data were collected from the Humber estuary at three tidal states, on the rising tide, at high water and on the falling tide, allowing the variation in position of any discharge mixing zones to be mapped. The region was overflown at 10,000 ft, with 11 images at each tidal state.

3.3.3.6 Figure 19 represents the positions of discharge mixing zones recorded in the CASI imagery. The CASI sensor does not identify the mixing zone in terms of its definition for statutory sampling, as this is often defined in terms of dissolved metals concentration which may not be measured by remote sensing techniques. However, the system provides a true measure of the area of influence of the discharge at the time of data collection which may be integrated into models of the mixing processes within an estuary. The shaded areas represent the mixing zone extent, with the area influenced at different tidal states being shown as a different colour. This allows comparisons of the maximum extent of the mixing zone at different tidal states.

3.3.3.7 The most clearly marked discharge within the Humber is from the titanium dioxide factory of Tioxide UK Ltd, located 2.2 km offshore from Grimsby (see figure 18). This outfall was relocated to the deep water channel in 1988 to decrease pollution impacts from the acidic discharge, and iron staining on the surrounding coastline. The discharge has a distinct bright yellow signal at all tidal states. Although the characteristic colour of discharges from titanium dioxide plants is white to the human eye, the higher spectral sensitivity of the CASI, and the means by which the imagery has been enhanced, result in the effluent appearing yellow.

3.3.3.8 The mixing zone is directed upstream on both the rising tide and at high water. At both times it has an elongate structure, suggesting low mixing perpendicular to the tidal stream, which has strong flow either upstream or downstream. On the falling tide the mixing zone is less clearly defined, which suggests greater dispersion by the strong tidal currents.

3.3.3.9 The SCM Chemicals titanium dioxide plant has a discharge point marked on figure 18, inshore of the Oil Jetty at Immingham. The CASI imagery records a clear mixing zone close to this point on the rising tide and at high water, both shown in figure 19. The signal from this discharge is not, however, spectrally similar to that from Tioxide UK Ltd., suggesting that the source of this mixing zone is from one of the other discharges close to the Oil Jetty. However, local knowledge would accept this plume as originating from SCM Chemicals under certain wind and tide conditions.

3.3.3.10 Figure 19 also shows the position and extent of the mixing zone related to the Courtaulds effluent outfall (trade effluent discharges 35 and 36). This discharge is evident at all states of the tide. On the rising tide and at high water, the orientation of the mixing zone is upstream, with a downstream orientation on the falling tide. There is no apparent onshore flow from this discharge at any of the tidal states at which data were collected.

3.3.3.11 Further downstream there is a discharge mixing zone recorded from the Anglian Water (Pyewipe) sewage treatment works (sewage effluent discharge 28). This discharge does not appear to impinge on either the north or south shoreline at the time of image collection. However, field data and model predictions have shown that under certain wind conditions the discharge does affect the shoreline

(Ashcroft, *pers. comm.*).

3.3.3.12 There are two sources of water low in suspended solids from Grimsby, one emanating from the Fish Dock at high water, and one from Grimsby Main Dock at both high water and on the falling tide. On the falling tide the discharge from Grimsby Dock is detectable up to 4 km downstream. Although the presence of clearer water is not in itself a hazard, this clearly illustrates the direction of transport of any waterborne pollutants from the dock.

3.3.3.13 Two small discharges are recorded from Hull Dock on the north bank of the Humber, both on the rising tide. These are not associated with any discharges in the regional consents register, and probably represent the inflow of less turbid water from the dock (marked on figure 19, inset 1).

3.3.3.14 Hull Eastern outfall of crude sewage is clearly delineated in the CASI imagery at both high water and on the falling tide. At both tidal states the effluent flows downstream, following the line of the bank for approximately 600 m (see figure 19).

3.3.3.15 The Hull Western sewage treatment works is also marked in the CASI imagery at high water but the mixing zone is not visible at any other tidal state (see figure 19). This is potentially due to the action of tidal currents in dispersing the effluent. At high water the currents are slack, resulting in the collection of effluent around the discharge point.

3.3.3.16 The Hull Eastern and Hull Western discharges are the only ones within the estuary whose mixing zones appear to have an effect on the neighbouring coastline, although there is no indication of flow across the estuary towards the bathing beach at Cleethorpes. Under the provisions of the Urban Waste Water Treatment Directive, this sewage treatment works will be upgraded to secondary treatment by the end of the year 2000.

3.3.3.17 The mixing zones of the discharges around Grimsby and Immingham are characterised by their elongate nature. This reflects the direction of the tidal stream in this estuary, with strong tidal currents flowing parallel with the shore. This results in mixing along the axis of flow, with little diffusive mixing across the estuary.

3.3.3.18 The discharge of effluent from outfalls within the Humber estuary tends to form plugs of effluent with only a small amount of mixing. It is vital that this is considered during the consenting procedure, and that efficient dispersion is not assumed. Equally, collection of post consenting samples should be concentrated either directly upstream or downstream of the discharge position, depending on tidal state.

3.3.3.19 The River Trent, which joins with the Humber Estuary at Trent Falls, shows little variation in water colour, signifying a low contrast in suspended solids concentration between the two water bodies. There is one clearly defined thermal mixing zone within this region, associated with the discharge from Keadby Power Station. The position and extent of this mixing zone is shown in figure 20.

3.3.3.20 The tidal regime within the Trent differs markedly from that at Immingham with a longer falling tide than a rising tide. Thus two of the images collected from this area were collected on falling tides, and one close to high water. At high water the mixing zone extends upstream from Keadby towards Gunness for a distance of approximately 1.1 km. This warmer water extends across the majority of the width of the river. The mixing zone is deflected downstream on both images collected on the falling tide, with effects detected furthest from the discharge in the image collected one hour before low water.

3.3.3.21 Figure 21 shows classified thermal data for this outfall. In the first image, collected on the falling tide, the temperature of the plume is shown to be 6°C above ambient at its maximum, extending downstream, with a temperature difference of 3°C at a distance of 2 km. In the second image the temperature difference between the outfall and the receiving waters is similar, with a plume of water some 3°C higher, extending upstream to Gunness. Collection of this data may be one method of assessing compliance with the temperature EQS applied to Keadby power station, although other techniques such as static remote sensing devices are being considered.

3.3.3.22 The lower Humber estuary region around Immingham was overflown in previous years as part of the National Coastal Baseline Survey. The discharge mixing zones recorded within these images have been compared with those recorded in 1996.

3.3.3.23 In the 1994 imagery the Courtaulds effluent outfall also occurs as a red signal with a downstream flow direction. The Tioxide UK Ltd outfall is shown as a small white signal. Downstream of here there are two further mixing zones, one which corresponds with the Anglian Water (Pyewipe) sewage treatment works. The spectral signature of the second mixing zone indicates that this is a plug of discharge from Tioxide UK Ltd. This is consistent with the direction of the tidal stream at the time of data collection.

3.3.3.24 In the 1995 imagery the discharge mixing zones visible within the imagery were again from Courtaulds, Tioxide UK Ltd and the Anglian Water (Pyewipe) sewage treatment works. Each mixing zone was directed downstream at the time of data collection, which is consistent with data collection half an hour before low water at Immingham. In both the 1994 and the 1995 data the discharge mixing zones were again elongate in nature, with no apparent movement towards the shoreline on either occasion.

3.3.4 Saltmarsh and beaches

3.3.4.1 The presence of saltmarsh and beaches in the inter-tidal zone of an estuary acts as a defence against the actions of coastal flooding, by dissipating the wave and tide energy and by providing a physical barrier against the passage of water towards the shore.

3.3.4.2 Saltmarsh is a highly diverse habitat, supporting a rich variety of flora and fauna. Marshes provide havens for migratory birds, acting both as feeding and breeding grounds. The importance of maintaining these environments is therefore recognised by the designation of many as Sites of Special Scientific Interest (SSSI).

3.3.4.3 The mosaics of CASI imagery collected at low water are shown in figure 16 and 17. Meteorological conditions meant that the two data sets were collected on different days, those for the lower estuary being collected on 19th August 1996, and those of the upper estuary on 16th September 1996. These mosaics have also been displayed as false colour composites, which use a near-infrared channel to distinguish between vegetated and non-vegetated surfaces (figures 22 and 23).

3.3.4.4 A digital classification procedure has been applied to the inter-tidal zone recorded by the CASI imagery. This relies on the variation in all spectral channels of the CASI to distinguish between different land cover types. The results of this are shown in figures 24 and 25. The numerical results are recorded in tables 4 and 5.

Land Cover Classes	Area (ha)	% Cover
Dense algae	2493	31
Sand	2229	28
Mud	1938	25
Saltmarsh	642	8
Sparse algae	600	8
Total	**7902**	**100**

Table 4: Inter-tidal land cover classification in the Lower Humber Estuary, 19th August 1996

Land cover classes	Area (ha)	% Cover
Saltmarsh	635	39
Mud	381	23
Wet mud	273	17
Sparse algae	186	12
Dense algae	147	9
Total	**1622**	**100**

Table 5: Inter-tidal land cover classification in the Upper Humber Estuary, 16th September 1996

3.3.4.5 The percentage of the inter-tidal zone covered by saltmarsh is much greater for the upper reaches of the Humber Estuary than the lower reaches, although the spatial cover is similar between the two sections. There are four key areas of saltmarsh development within the Humber, these being at Blacktoft Sand, Read's Island, around Tetney High Sands and towards the mouth of the estuary at Sunk and Hawke Channels.

3.3.4.6 The National Saltmarsh Survey (Burd 1989 *a&b* in Hill 1995*b*) showed that saltmarsh extended as a discontinuous fringe along both shores of the estuary. This survey recorded approximately 650 ha of saltmarsh, which is 50% of the resource recorded in the CASI data. The two surveys were carried out by different techniques, and as such are not directly comparable. Additionally the saltmarsh area around Tetney High Sands may be considered to be outside the estuarine confines. Any key differences will be discussed below.

3.3.4.7 The Blacktoft Sand nature reserve is shown in more detail in figure 25. The classification shows this area to be a mixture of saltmarsh and land vegetation. The land vegetation probably corresponds to marshland which has been managed, for example by grazing, which has resulted in an alteration in spectral characteristics. Whitton Sand, an island downstream of the nature reserve, has been classified as saltmarsh, although Ordnance Survey maps show this area to be inter-tidal mud and sand. This region may therefore have been recently colonised by saltmarsh vegetation. Published maps and charts are often out of date, and the regular collection of aerial data would allow the assessment of changes in cover in this dynamic environment.

3.3.4.8 The Read's Island area shows a small area of saltmarsh vegetation within the inter-tidal mudflats (figure 25).

3.3.4.9 Figure 26 shows a small area of marsh to the north of Sunk and Hawke channels on the northern side of the estuary towards the mouth. This marsh is well established, being semi-enclosed by terrestrial vegetation. There is a region of dense green algal growth at the toe of the marsh, adjacent to the mudflat.

3.3.4.10 The estuary shows a mixture of mud and sand beaches. For much of the length of the estuary the shoreline has been extensively modified by industrial development, resulting in a narrow inter-tidal zone. This is particularly evident between Immingham and Chowder Ness (opposite Hull).

3.3.5 Inter-tidal vegetation

3.3.5.1 The presence of macro-algae on the inter-tidal mudflats and beaches of an estuarine environment may signify the presence of eutrophic conditions. This has therefore been defined as one of the indicators to be used in the determination of Sensitive Areas requiring further sewage treatment under the provisions of the Urban Waste Water Treatment Directive.

3.3.5.2 The digital classification shows the presence of algal growth on the inter-tidal mudflats of the Humber Estuary. The major areas of algal cover in the upper estuary are shown in figure 25.

3.3.5.3 The classification shows the mudflats of Read's Island are extensively covered in green algae of varying densities. This area is just downstream of the sewage effluent outfall at Winteringham (see figure 18). This outfall has primary treatment applied and is consented to discharge between 1,000 and 10,000 m^3/day. It is possible that the nutrients in the effluent from this outfall are enhancing the algal growth at this point. There were no ground surveys carried out to identify the algae within the Humber Estuary, with the spectral signatures being compared with those recorded over algae in a number of other estuaries.

3.3.5.4 In the lower estuary there is an extensive area of algal cover on the mudflats between Spurn Head and Sunk Island Sands. There is a further area on the southern shore to the north of Grimsby. This is close to the Anglian Water (Pyewipe) sewage effluent discharge, which has a consented volume of between 10,000 and 100,000 m^3/day. Discharge mixing zone studies showed no onshore flow of effluent from this discharge (see section 3.3.3.11), although previous studies have shown some impact on the shoreline.

3.3.5.5 There is a very small area of dense algal growth on the northern shore of the estuary downstream of Hull (see figure 26). This growth may be being enhanced by the effluent from Hull Eastern sewage treatment works, which discharges just upstream of this point, although the area of cover is not large in comparison to other sites within the estuary.

3.3.6 Summary of estuary

3.3.6.1 The aerial surveillance data of the Humber Estuary collected throughout 1996 has revealed information on the environmental quality of this estuary. The estuary is rural for much of its length, with industry being mainly confined to a small area around Hull and between Immingham and Grimsby.

3.3.6.2 The discharge mixing zones of the Humber Estuary are characterised by their elongate nature, with little apparent mixing across the estuary. This is most probably due to the strong tidal streams experienced within this estuary. The implications of this are that although the water quality of the estuarine waters may be adversely affected by the effluent discharged, this will not affect the quality of the shoreline. This is of particular relevance to the discharge of sewage effluent.

3.3.6.3 The saltmarsh area recorded by the CASI imagery was considerably greater than that reported in the National Saltmarsh Survey (Burd 1989 *a&b* in Hill 1995*b*), with a total area for the estuary of 1277 ha. This discrepancy may be due to the different techniques used to determine land cover. However, one area has clearly altered recently, this being Whitton Sand. The classification shows that this mudflat has been colonised by saltmarsh vegetation. The saltmarsh classification may be used to update the maps of the inter-tidal zone for this estuary.

3.3.6.4 Recent estimates predict a sea level rise across the UK of 37 cm by the year 2050 (DoE, 1996). The position of the Humber on the East coast of the UK will further exacerbate this rise by the additive effect of sinking land. This may result in increased flooding of the estuary, which may effect the saltmarsh resource. The protected status of much of the saltmarsh shows its ecological importance. In order to allow maintenance of this resource consideration should be given to managed retreat, allowing the saltmarsh to progress naturally landwards.

3.3.6.5 There are large areas of extensive algal cover within the inter-tidal zone, particularly in the lower Humber Estuary. Although there is no direct causal link between this algal growth and sewage effluent, the large expanses of algae may make this area worthy of further investigation. The high suspended solids loading within the estuary tends to inhibit the growth of nuisance algal blooms, meaning that this estuary is unlikely to become eutrophic.

3.3.6.6 The imagery collected may be integrated into a Geographical Information System to allow comparison with future data. This will allow the investigation of long term changes, such as those related to sea level rise. Additionally, more short time scale changes may be investigated, for example, the anticipated movement of Spurn Head shingle ridge.

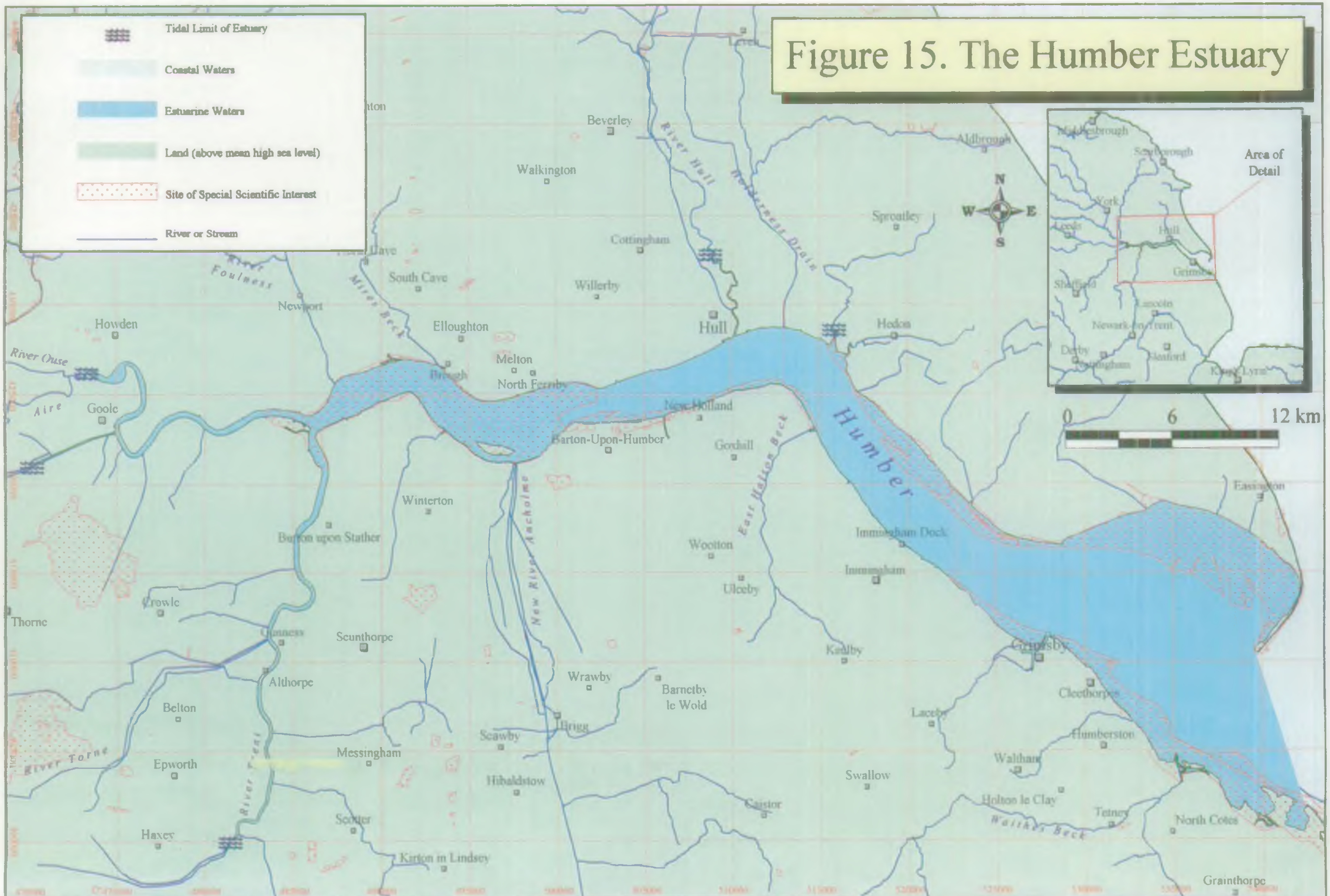


Figure 15. The Humber Estuary

Upper Humber Estuary
16th September 1996, Low Water

True colour composite of five CASI images

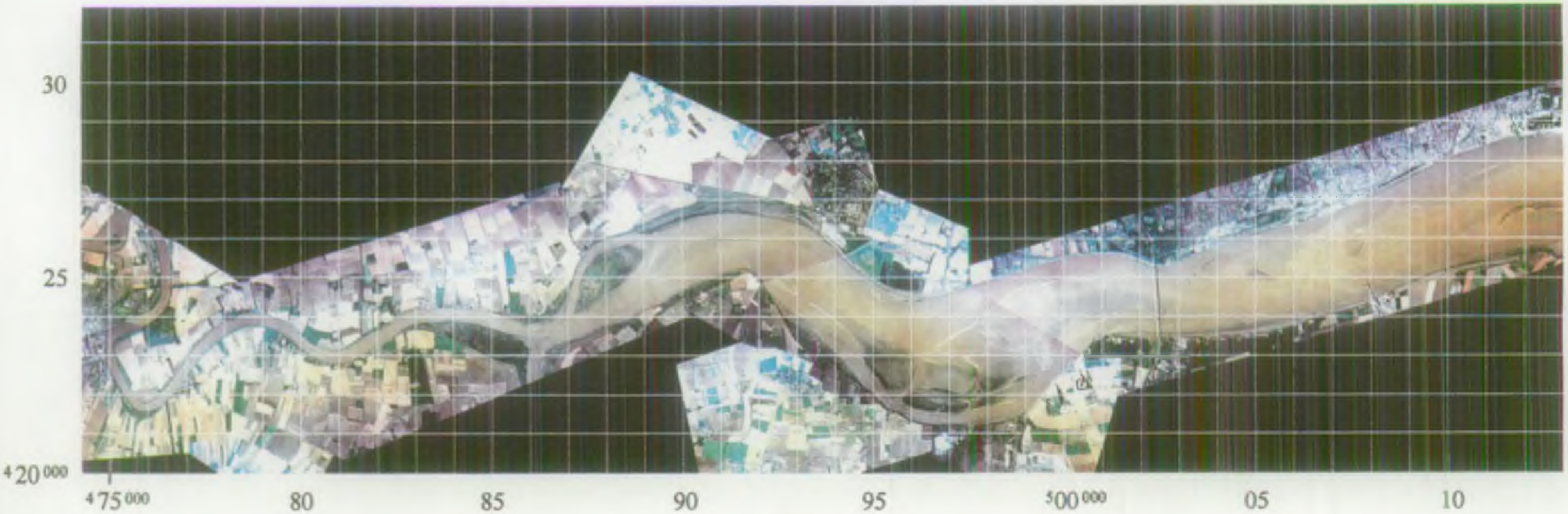


Figure 16

Lower Humber Estuary
19th August 1996
Low Water

True colour composite of six CASI images

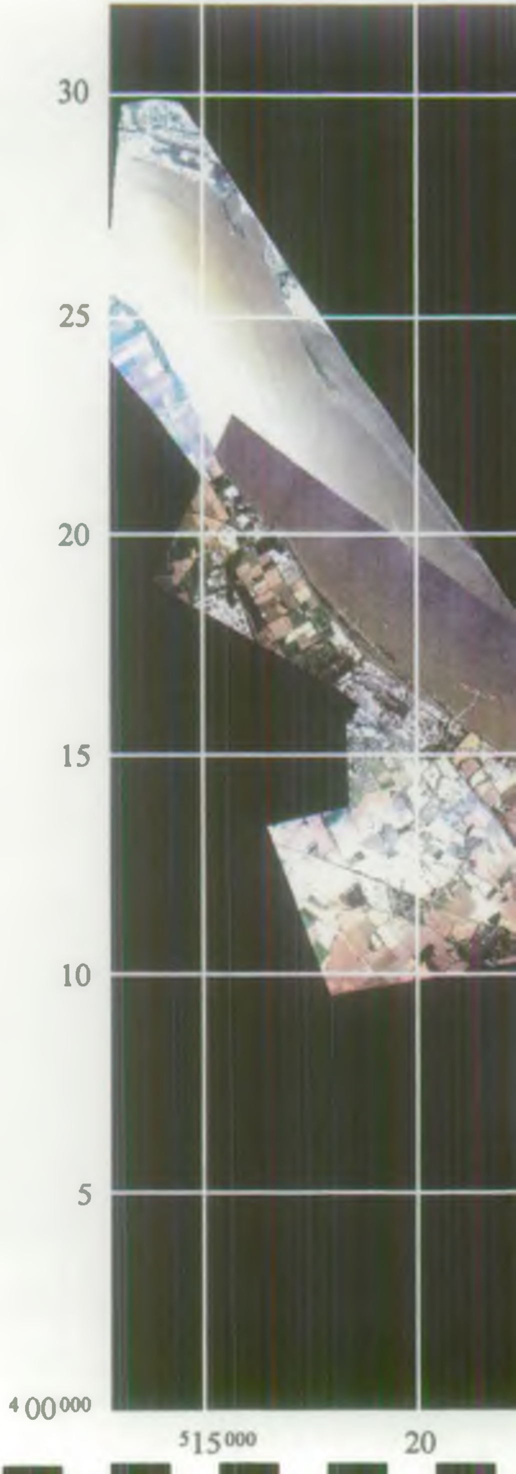
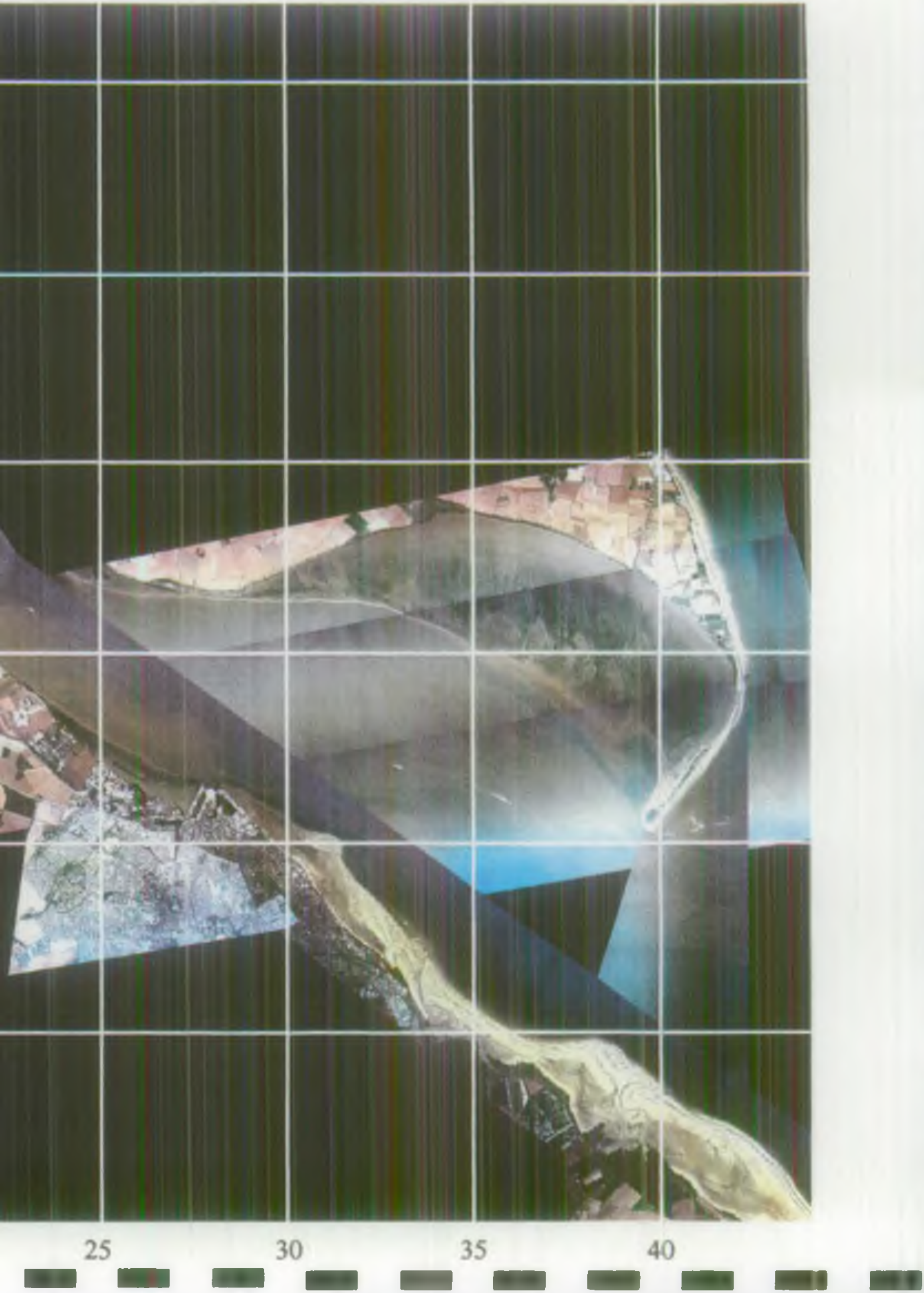


Figure 17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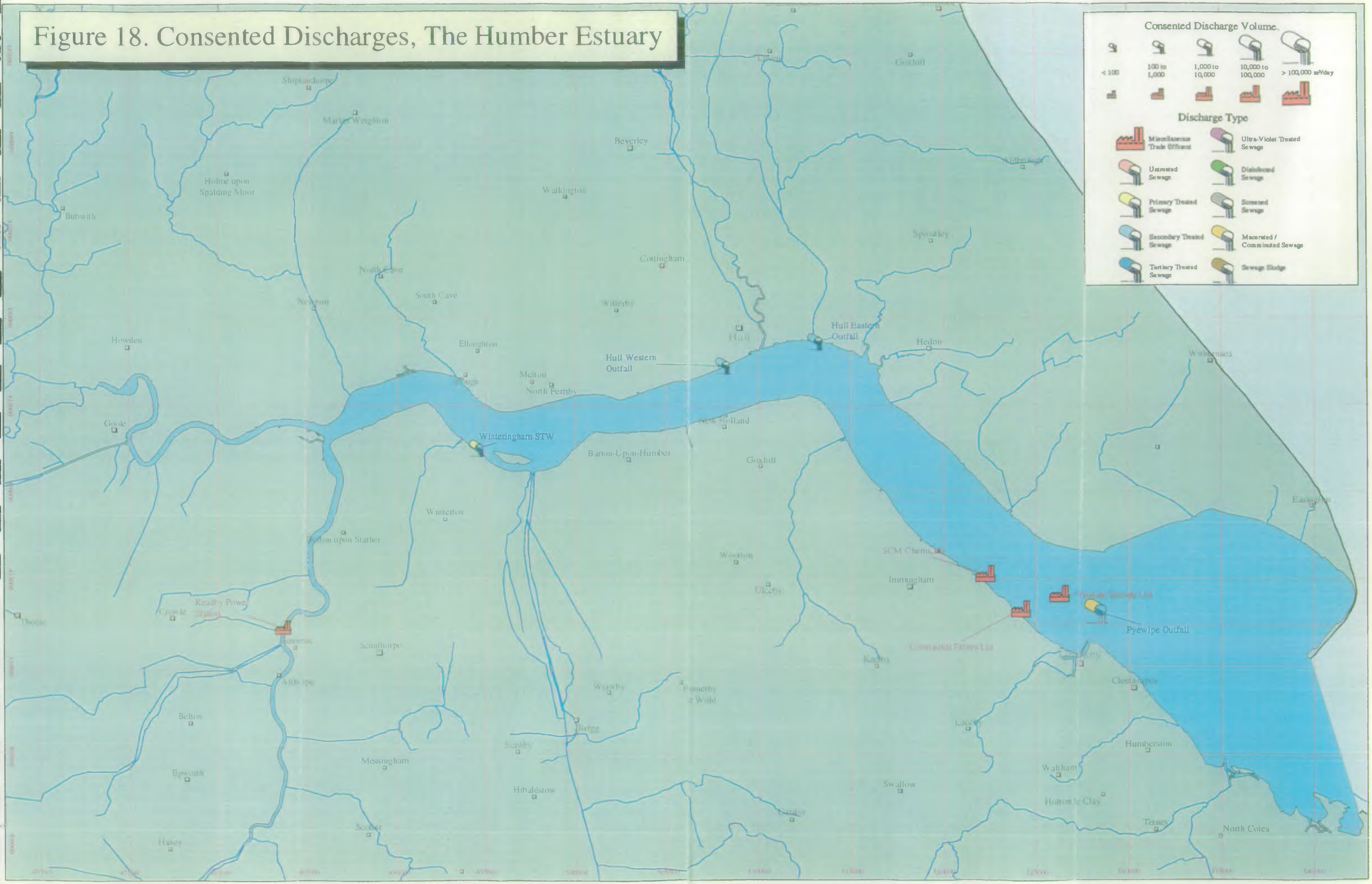


Figure 18. Consented Discharges, The Humber Estuary

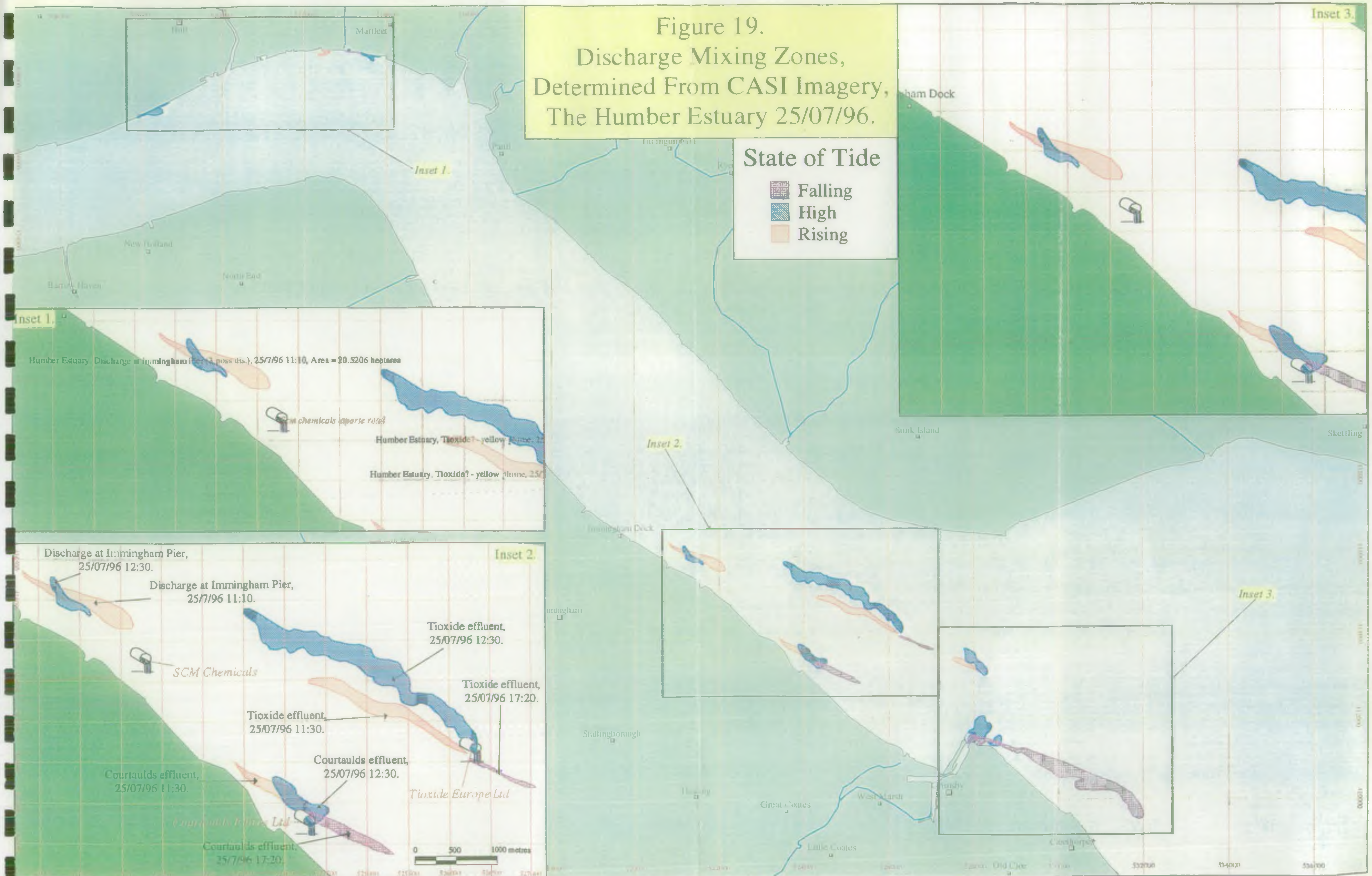
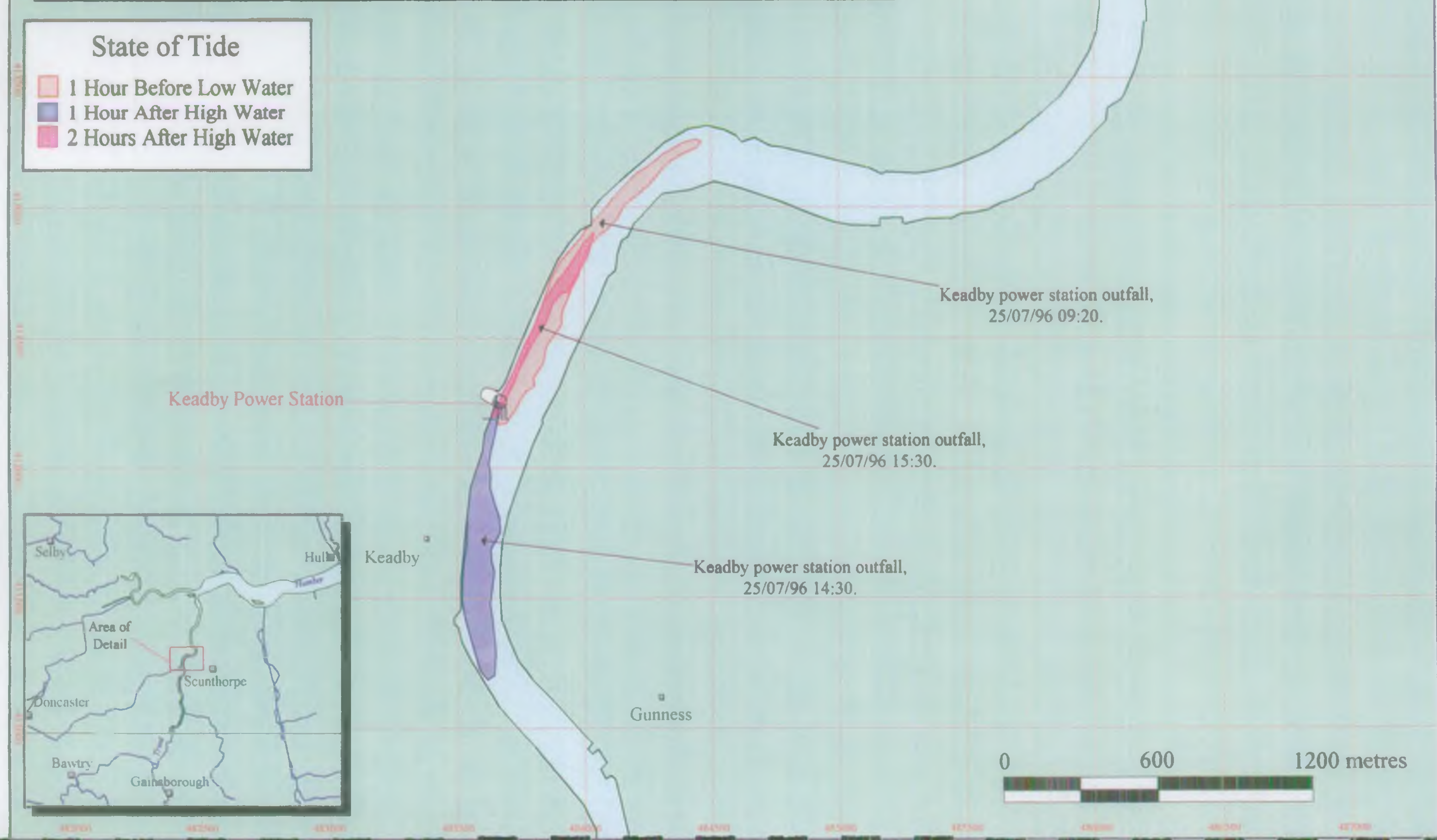


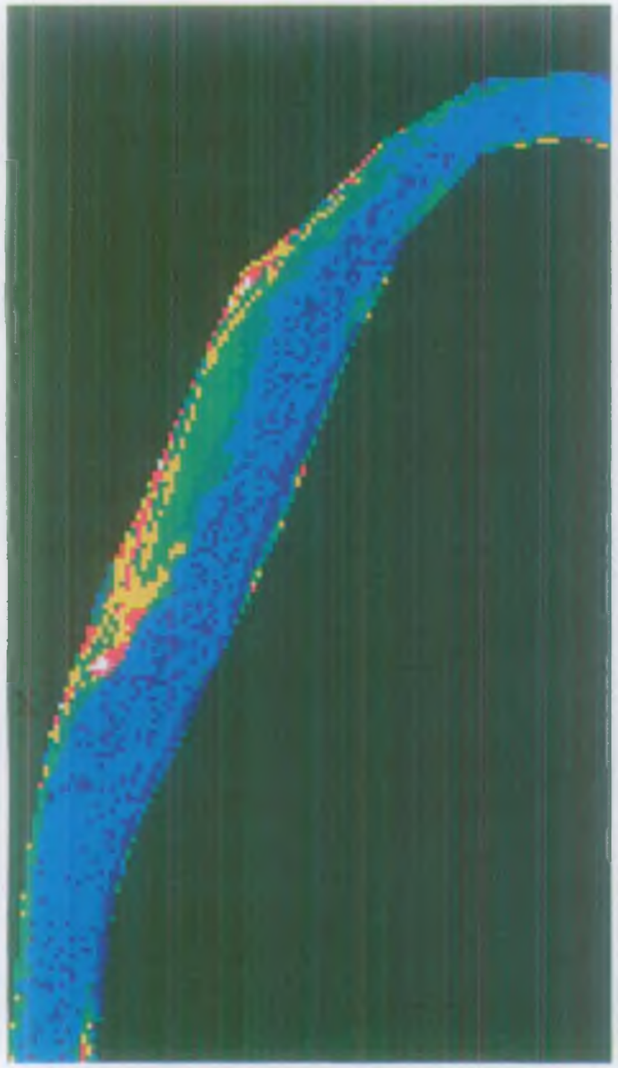
Figure 19.
Discharge Mixing Zones,
Determined From CASI Imagery,
The Humber Estuary 25/07/96.

Figure 20. Discharge Mixing Zones Determined From CASI Imagery, The Trent, 25/07/96.



River Trent - Keadby Power Station Outfall (marked as X)
25th July 1996

Digital thermal images calibrated for temperature



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14:30 GMT

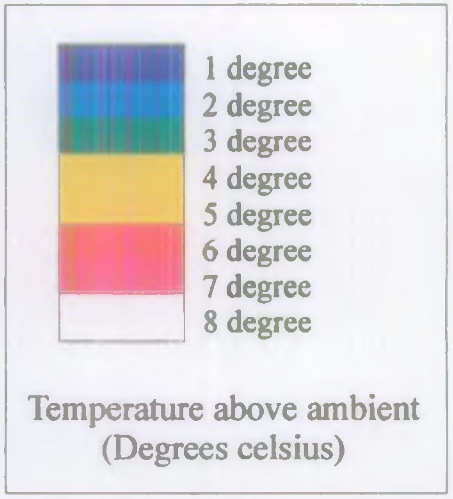


Figure 21

Upper Humber Estuary
16th September 1996, Low Water

False colour composite of five CASI images

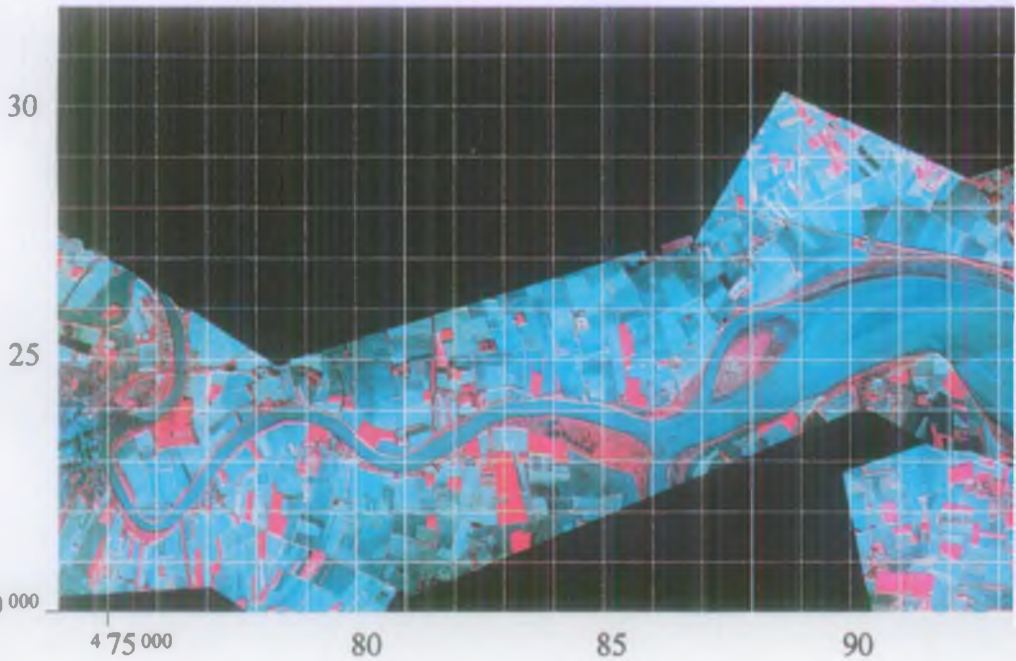
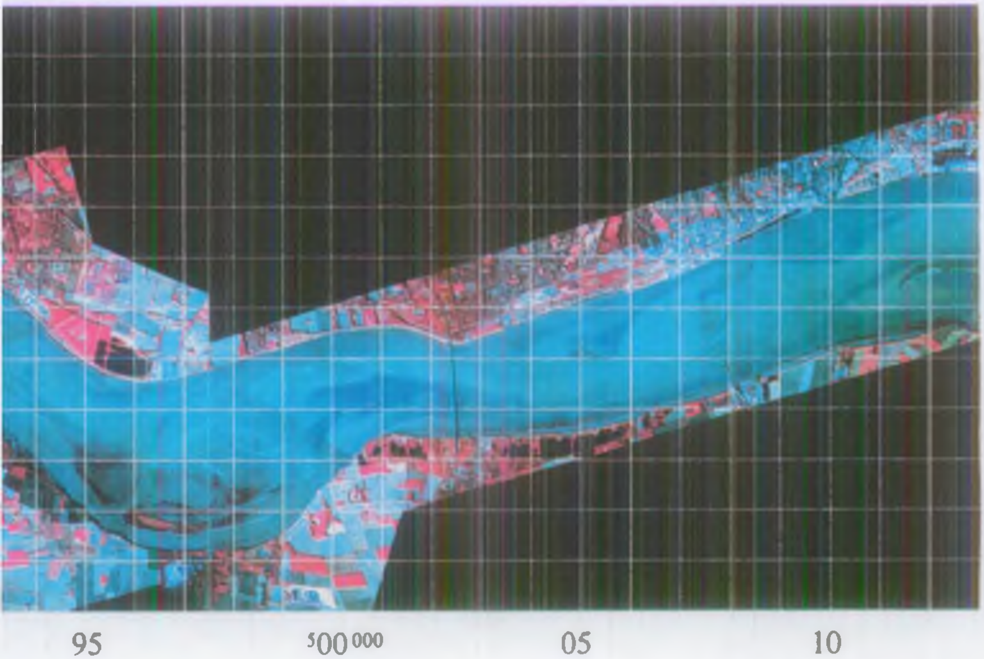


Figure 22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Lower Humber Estuary
19th August
Low Water

False colour composite of
six CASI images

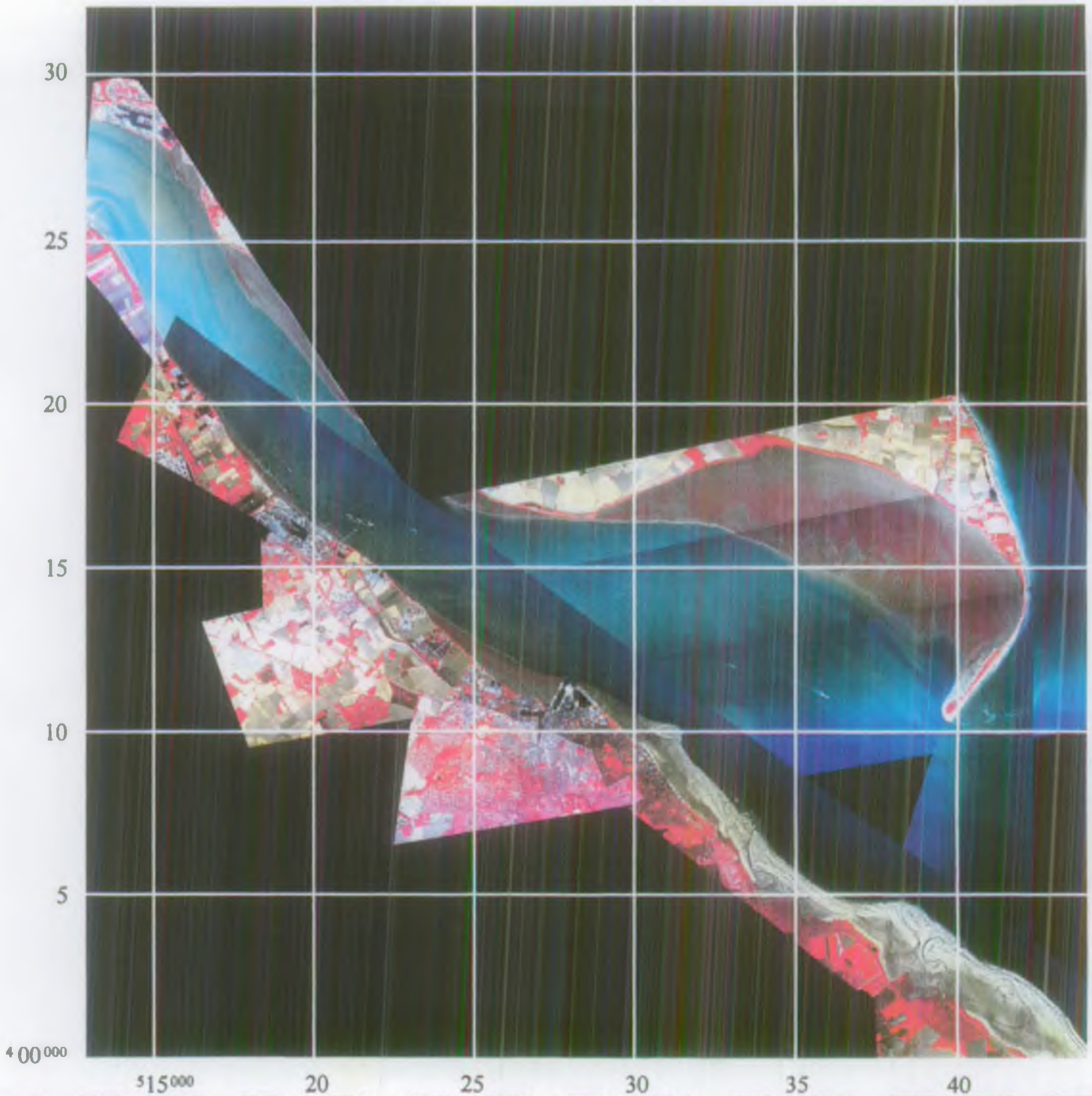

Figure 23

Upper Humber Estuary
16th September 1996, Low Water

Unsupervised classification of inter-tidal areas

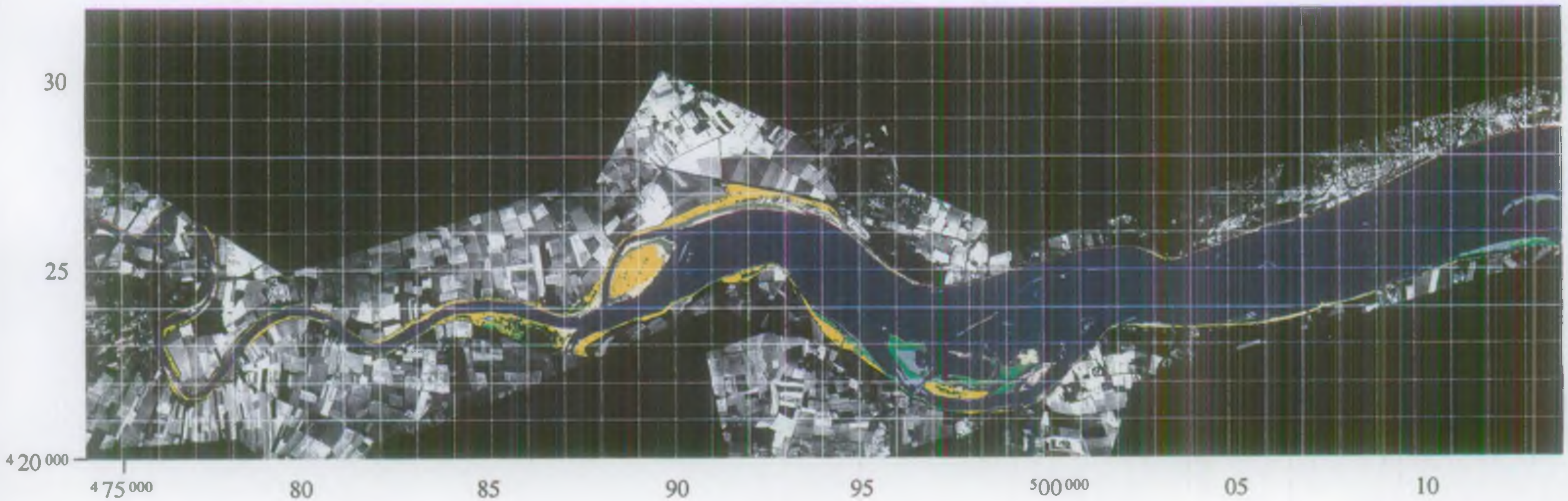

Figure 24

Upper Humber Estuary
16th September 1996, Low Water

Unsupervised classification - regions of interest

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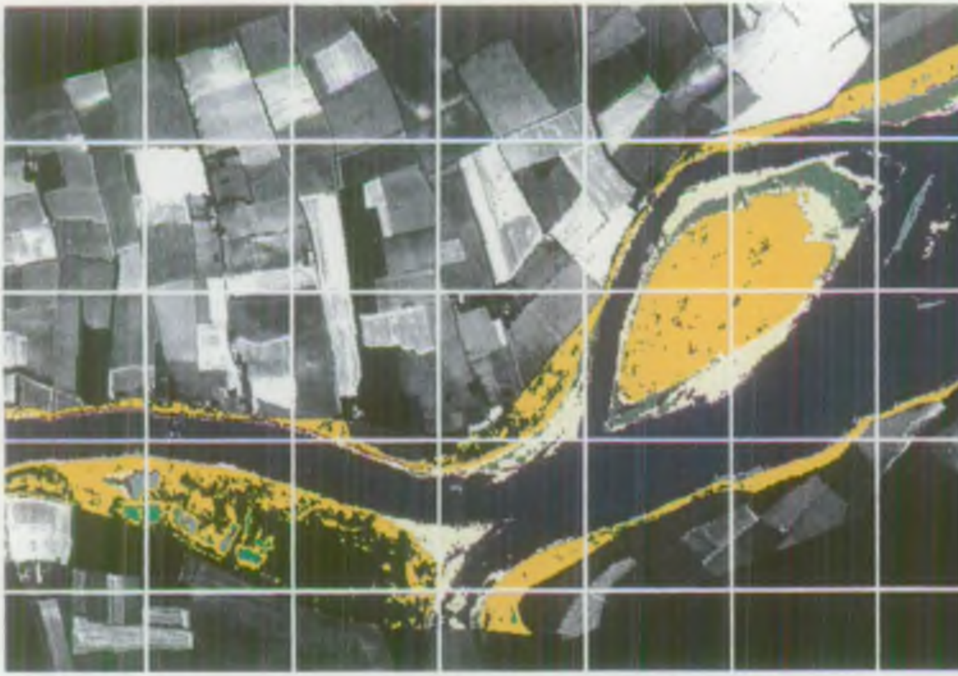

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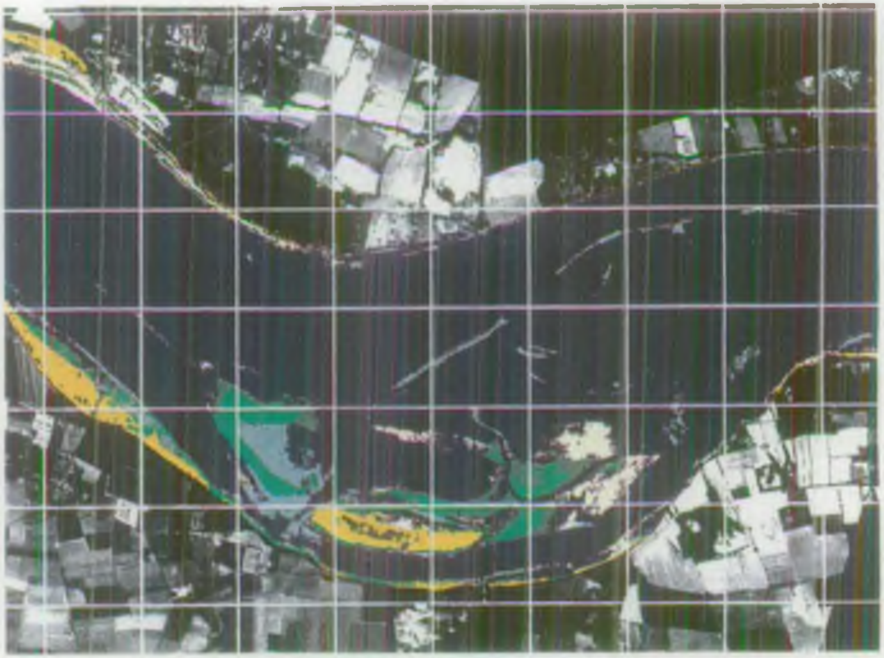
Blacktoft Sand Area

Key

- Terrestrial Vegetation
- Land
- Saltmarsh
- Water
- Wet Mud
- Mud
- Dense Algae
- Sparse Algae
- Sand

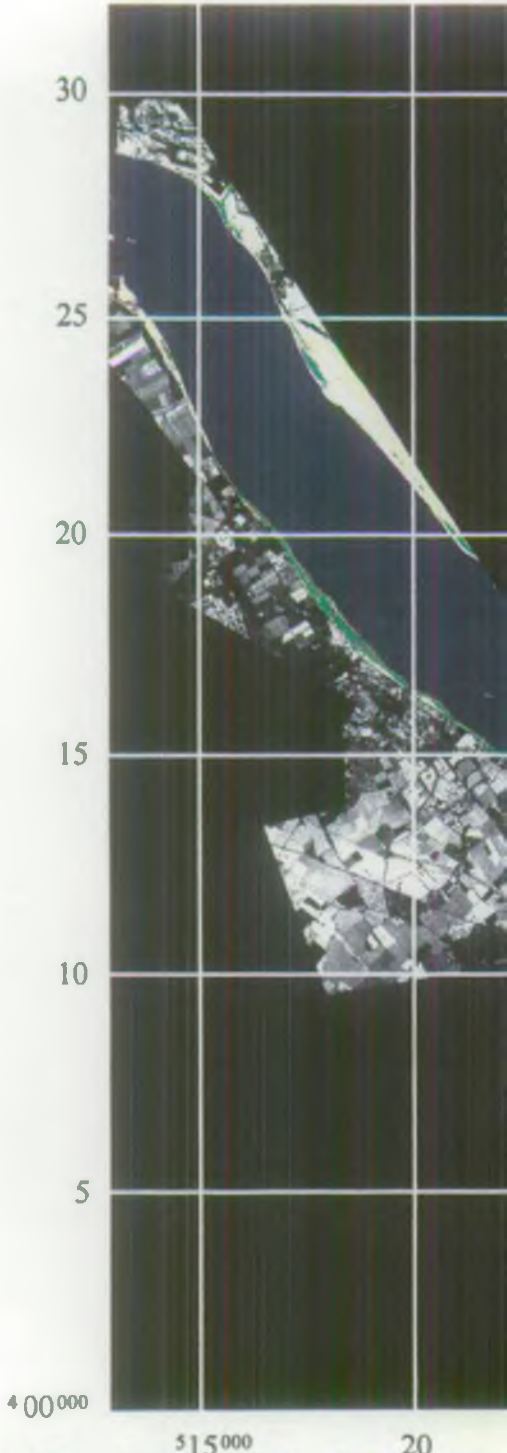
Figure 25



Read's Island Area

Lower Humber Estuary
19th August 1996
Low Water

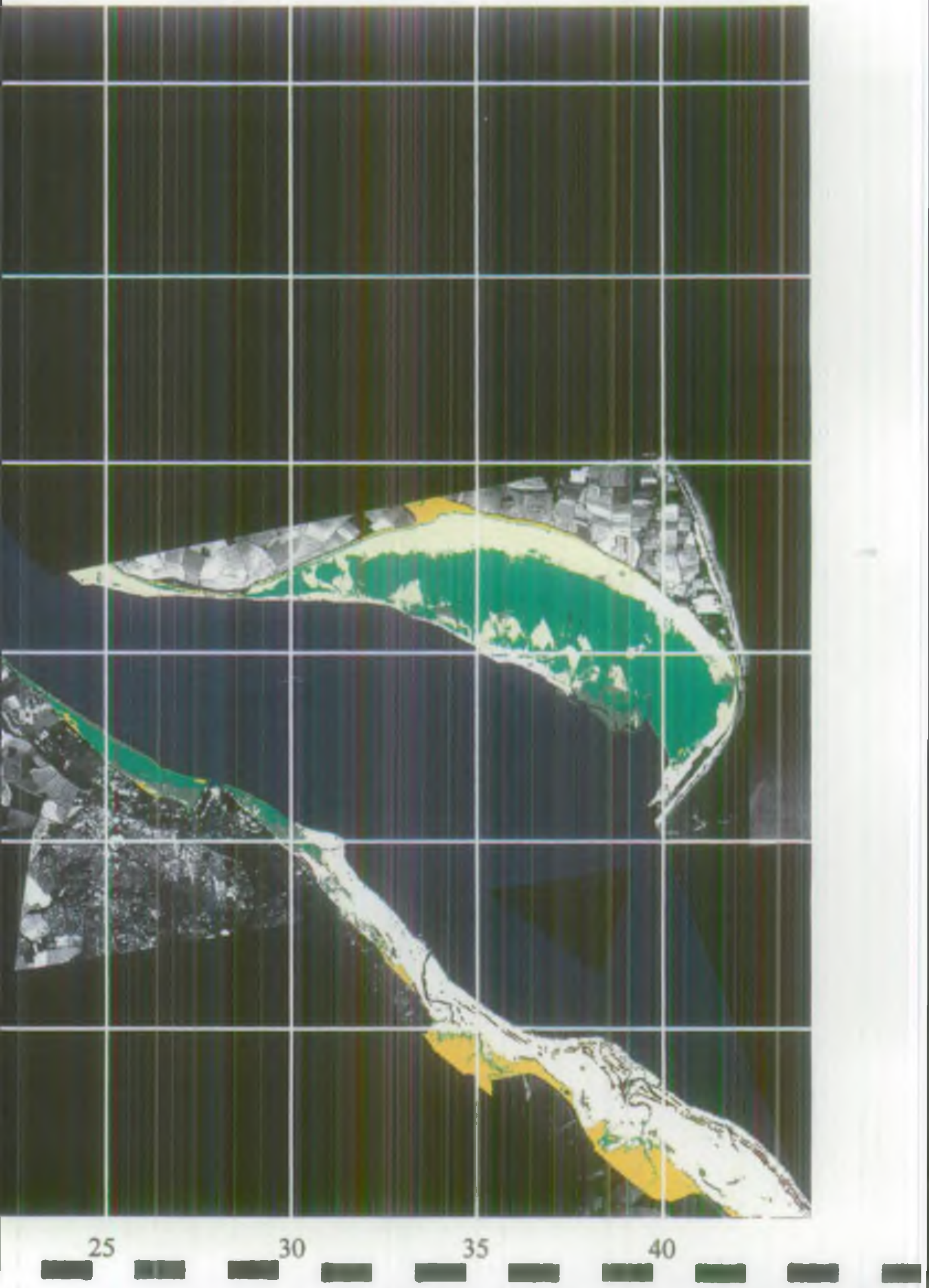
Unsupervised classification of inter-tidal areas



Key

- Land Vegetation
- Land
- Saltmarsh
- Water
- Wet Mud
- Mud
- Dense Green Algae
- Sparse Green Algae
- Sand

Figure 26



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3.4 LANGSTONE AND CHICHESTER HARBOURS

3.4.1 Background description

3.4.1.1 Langstone and Chichester harbours, although often defined as two separate estuaries, are physically linked, forming a biological continuum. For the purposes of this report they will be treated as one estuarine region. Located on the south coast of England, the estuaries are both bar built, being protected from the sea by multiple ridge sand and shingle spit systems (Randall, 1995*c*). Figure 27 shows the estuarine area at high water. This map also includes the positions and extents of Sites of Special Scientific Interest (SSSI).

3.4.1.2 There is little inflow of fresh water to the region, resulting in a strong marine influence. The total inter-tidal area of the two estuaries is approximately 4000 ha, with extensive mudflats and saltmarsh cover.

3.4.1.3 Figure 28 is a mosaic of three true colour composite CASI images flown at low water on 4th August 1996. This illustrates the extensive mudflats and saltmarshes. Moreover, the highly vegetated nature of the mudflats is immediately apparent, with expanses of intense green seen in the imagery. The imagery also shows the development of the sand bars at the estuary mouths.

3.4.2 Discussion of major issues

3.4.2.1 Langstone Harbour is being reviewed as a potential sensitive area under the provisions of the EC Urban Waste Water Treatment Directive (91/271/EEC). Langstone Harbour is currently a eutrophic problem area under investigation, with detailed studies being carried out into the trophic status of the estuary. In the past, these have consisted of interpretation of false colour composite aerial photography. More recently, a feasibility study was undertaken using the CASI system to provide a digital classification of vegetation cover type.

3.4.2.2 The main sewage effluent discharge in Langstone Harbour is from Budds Farm sewage treatment works which enters the northern end of the harbour. Increases in the cover of macro-algae, particularly *Enteromorpha* and *Ulva* spp in the late 1950s and early 1960s was considered to be potentially due to increased discharge volume resulting from the increase in population at this time.

3.4.2.3 Recent water quality surveys have measured the nutrient concentrations within the harbours and in the surrounding coastal waters. The coastal waters were found to be hyper-nutrified in winter months. However, there was no sustained algal blooms activity in spring and summer. Additionally, both Langstone and Chichester harbours were fully flushed on each tide. These two factors have led to a preliminary conclusion that the high nutrient concentrations in coastal waters are responsible for the macro-algal growth within Langstone Harbour.

3.4.2.4 Both Langstone and Chichester harbours are extensively used for recreational purposes, with a large network of leisure marinas. The harbours also attract visitors for passive recreation; Farlington Marshes, part of Langstone Harbour in particular receives a large number of visitors. Both harbours are Sites of Special Scientific Interest (SSSI).

3.4.2.5 The saltmarsh communities of Chichester Harbour provide an important habitat resource for migratory birds, recognised by the establishment of much of the region as a SSSI (see figure 27). The wet grasslands of Langstone harbour have been declared a Special Protection Area in recognition of their importance to the dark bellied Brent goose. The maintenance of these marsh resources is an important issue in this region.

3.4.3 Discharge mixing zones

3.4.3.1 Figure 29 shows the positions of selected consented sewage discharges to Langstone and Chichester Harbours. There are four significant discharges at Budds Farm, Thornham, Bosham and Chichester sewage treatment works. Trade effluent discharges, have a minor impact being associated with gravel washing and are located on the northern shore of Langstone Harbour close to Havant.

3.4.3.2 Langstone and Chichester harbours were overflown on 22nd July 1996 at high water and on the rising and falling tide. The area was covered in three east to west flightlines.

3.4.3.3 The CASI and thermal data collected were of high quality. The CASI data shows variation in suspended solids loading between the harbours and the offshore waters, and, in addition, marked the presence of shallow water. Shallow water causes a more intense signal to the CASI because of the effects of bottom reflection.

3.4.3.4 The thermal data shows high variability but again this was mainly due to the presence of more shallow water. This shallow water heats up faster than deeper waters, increasing the surface temperature recorded by the sensor.

3.4.3.5 The thermal and CASI imagery did not reveal any discharges. The three trade discharges to the harbours are of low volume, which explains why they are not evident in the imagery. However, the three sewage effluent discharges have consented volumes in excess of 10,000 m^3/day and some indication of flow from these might have been expected in the imagery.

3.4.3.6 The characteristics of the receiving waters are such that discharge mixing zones are not easily distinguishable using the aerial techniques. The sewage effluent discharged to Langstone and Chichester Harbours has received secondary treatment making it difficult to distinguish from the low turbidity receiving waters. Similarly, the shallow waters of the harbour will have a warm ambient temperature, which will make thermal discharges less easy to distinguish.

3.4.4 Saltmarsh and beaches

3.4.4.1 Saltmarsh is an important resource in an estuarine environment. It is a highly diverse habitat, providing a haven for migratory birds. Saltmarsh and beaches also protect the shoreline from flooding, both by acting as a physical barrier and by dissipating tide and wave energy.

3.4.4.2 The importance of saltmarsh in Langstone and Chichester Harbours is reflected in their status as SSSI (see figure 27). Additionally, the wet grasslands have been declared a Special Protection Area in recognition of their importance for migratory birds, particularly the Brent Goose.

3.4.4.3 The CASI data collected at low water on 4th August 1996 have been displayed as a false colour composite (figure 30). This composite shows vegetation in red, signifying that it has high infrared reflectance. These data have also been used to produce a digital classification of the land cover types in the harbours. This classification is based on the variation in all channels of the CASI system, but is particularly sensitive for detecting vegetation. Figure 31 shows the digital classification, the mathematical results of which are held in table 6.

Land cover class	Area ha	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**

Table 6: Inter-tidal land cover classification in Langstone and Chichester harbours, 4th August 1996

3.4.4.4 The classification shows saltmarsh to be concentrated in three main areas, these being to the north of Hayling Island, to the east of Thorney Channel and at East Head.

3.4.4.5 Figure 32 shows enlargements of two of these areas, these being Hayling Island and Thorney Channel. The saltmarsh is shown to be interspersed by drainage channels, which are supporting algal growth. The extent of the saltmarsh is not large in comparison with other estuaries surveyed, accounting for only 11% of the inter-tidal zone.

3.4.4.6 The area of wet grassland at Farlington Marshes, to the north west of Langstone Harbour, is presently enclosed. These wet grasses support 5-10% of the world population of the dark bellied Brent goose (Gee, 1995*c*). This area is managed, in order to preserve the grassland, with hay cropping being the designated land type.

3.4.4.7 The state of disrepair of the seawalls in Langstone and Chichester Harbours means that wet grasslands are increasingly subject to encroachment of marine waters. The digital classification produced may be used to provide a baseline against which any future data can be compared. The area of saltmarsh may decrease if algal growth increases and this can also be mapped against the above classification.

3.4.5 Inter-tidal vegetation

3.4.5.1 The growth of algae on inter-tidal mudflats may be indicative of eutrophic conditions. This indicator is used in part to define an estuary as a Sensitive Area under the provisions of the Urban Waste Water Treatment Directive. The nutrient budget and vegetation cover of Langstone and Chichester Harbours are being investigated by Regional staff to define whether nutrient stripping should be applied to the discharges from qualifying sewage treatment works at Budds Farm, Thornham and Chichester.

3.4.5.2 The digital classification shows the presence of algae on the mudflats of Langstone and Chichester Harbours (figure 31). The major area of dense algal growth is at the north of Langstone Harbour, shown in more detail in figure 32. This region is close to the Budds Farm sewage treatment works shown on figure 29.

3.4.5.3 Ground truth surveys in 1995 showed this area to be dominated by *Enteromorpha* and *Ulva* spp, with some patches of *Fucus* and *Zostera*.

3.4.5.4 The upper reaches of Chichester Harbour are densely covered by algae. No ground truth data was collected at the time of the survey to identify this algae. Subsequent investigations have shown green algae of the *Enteromorpha* type to be present on the mudflats, at the seaward edge of the saltmarsh, even during winter months.

3.4.5.5 Much of the remaining inter-tidal mudflats are sparsely covered by algae, again mainly *Enteromorpha* and *Ulva*. This leads to a total algal cover of 40% of the inter-tidal area, which is high in comparison to the other estuaries surveyed.

Although this percentage cover is in excess of the 25% level indicative of sensitivity to eutrophication, the sparsity of cover must be considered when interpreting this figure.

3.4.5.6 Surveys carried out in 1996 by Environment Agency Southern Region have, however concluded that the presence of macro-algae and associated physical, chemical and biological impacts indicate that the harbours should be proposed as Sensitive Areas (Lowthian, *pers. comm.*).

3.4.6 Summary of estuary

3.4.6.1 The aerial surveillance data collected during 1996 has provided information on the environmental quality of Langstone and Chichester Harbours. Imagery of the harbours shows a mixture of rural land and urban development, with low levels of industry evident. Urban development is concentrated along the northern and western shores of Langstone Harbour, with the remaining estuary being mainly rural in nature.

3.4.6.2 The low consented volumes of the trade effluent discharges and the characteristics of the secondary treated discharged waters mean that the differentiation of discharge mixing zones was not possible within the aerial data. Similarly, there was no indication of mixing zones from the sewage effluent discharges, although these are of greater volume.

3.4.6.3 The extent of macro-algal cover on the inter-tidal mudflats is immediately apparent in the imagery, particularly close to the discharge from Budds Farm sewage treatment works. The trophic status of Langstone Harbour is currently being investigated by Regional staff.

3.4.6.4 Recent studies predict an increase in temperature in the south of England, with a corresponding increase in tourism (DoE, 1996) which may have effects on the environmental quality of Langstone and Chichester harbours. A combination of some increase in tourism and the new urban development planned for this area will result in additional pressures on the sewage disposal systems. This may further increase the eutrophic status of the harbours. The use of the harbour for water sports will also increase, placing extra strains on the saltmarsh and beaches fringing the harbours.

3.4.6.5 The effects of macro-algal growth on the spatial extent of saltmarsh within the two harbours is of key importance, with increasing algal growth impeding the growth of saltmarsh. The saltmarsh of Langstone and Chichester harbours is an important ecological resource, with SSSI status, due to its importance as a haven for migratory birds.

3.4.6.6 Additionally, the saltmarsh is under threat from the effects of sea level rise. Recent studies predict a rise of 37 cm across the UK by the year 2050 (DoE, 1996). The southerly location of Langstone and Chichester harbours means that the surrounding land is presently sinking, further increasing this rise to approximately 40 cm, which will cause flooding of the present inter-tidal zone. The ability of saltmarsh to progress landwards may be impeded by the presence of hard defences at the landward edge of present saltmarshes, particularly at the northern edge of Langstone Harbour.

3.4.6.7 Langstone and Chichester harbours will therefore be particularly susceptible to the effects of global warming. The digital classifications produced from the aerial data may be integrated into a Geographical Information System to add a contextual layer to future investigations of these harbours which have such high ecological status.

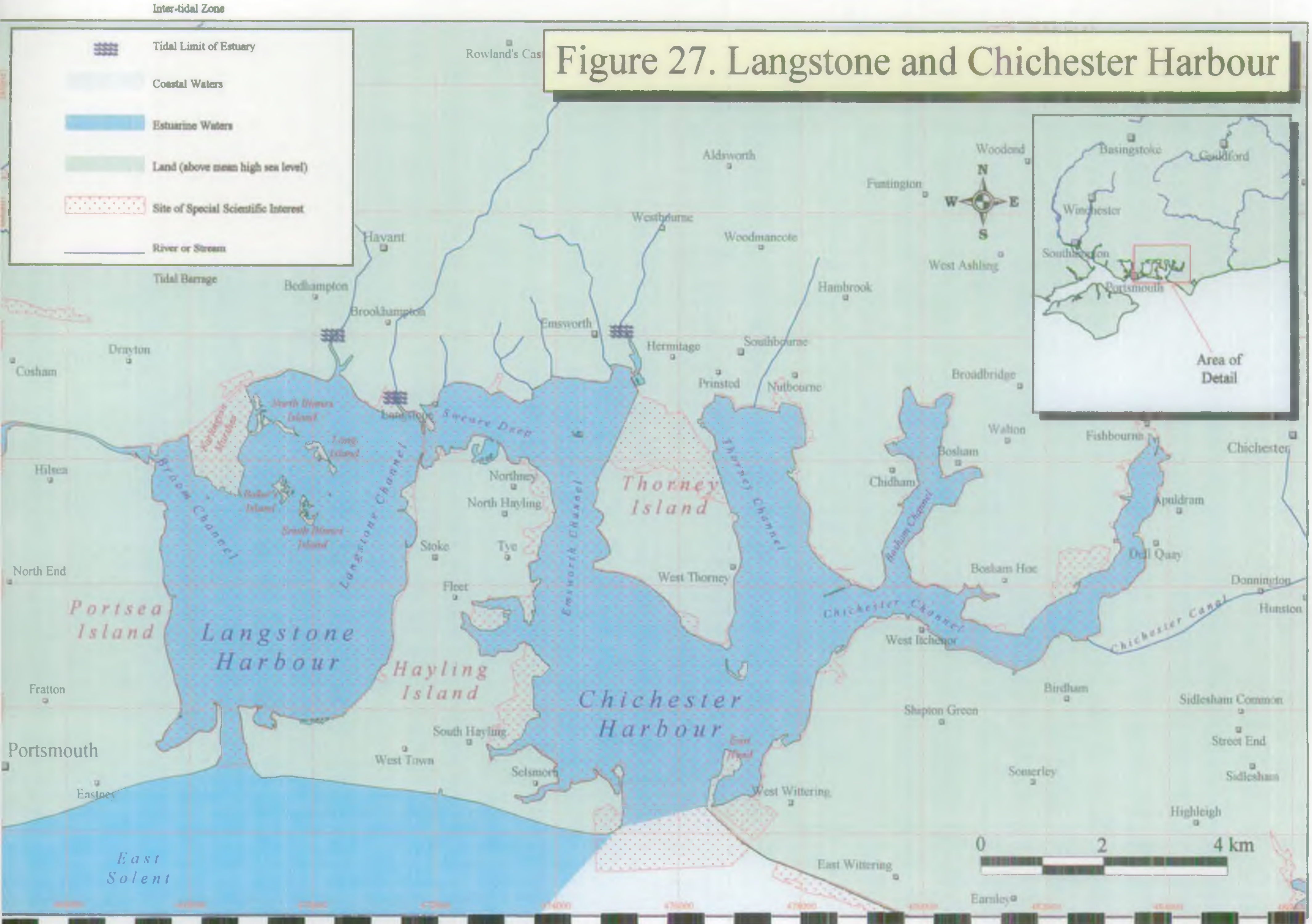


Figure 27. Langstone and Chichester Harbour

Langstone and Chichester Harbours
4th August 1996, Low Water

A true colour composite of three CASI images

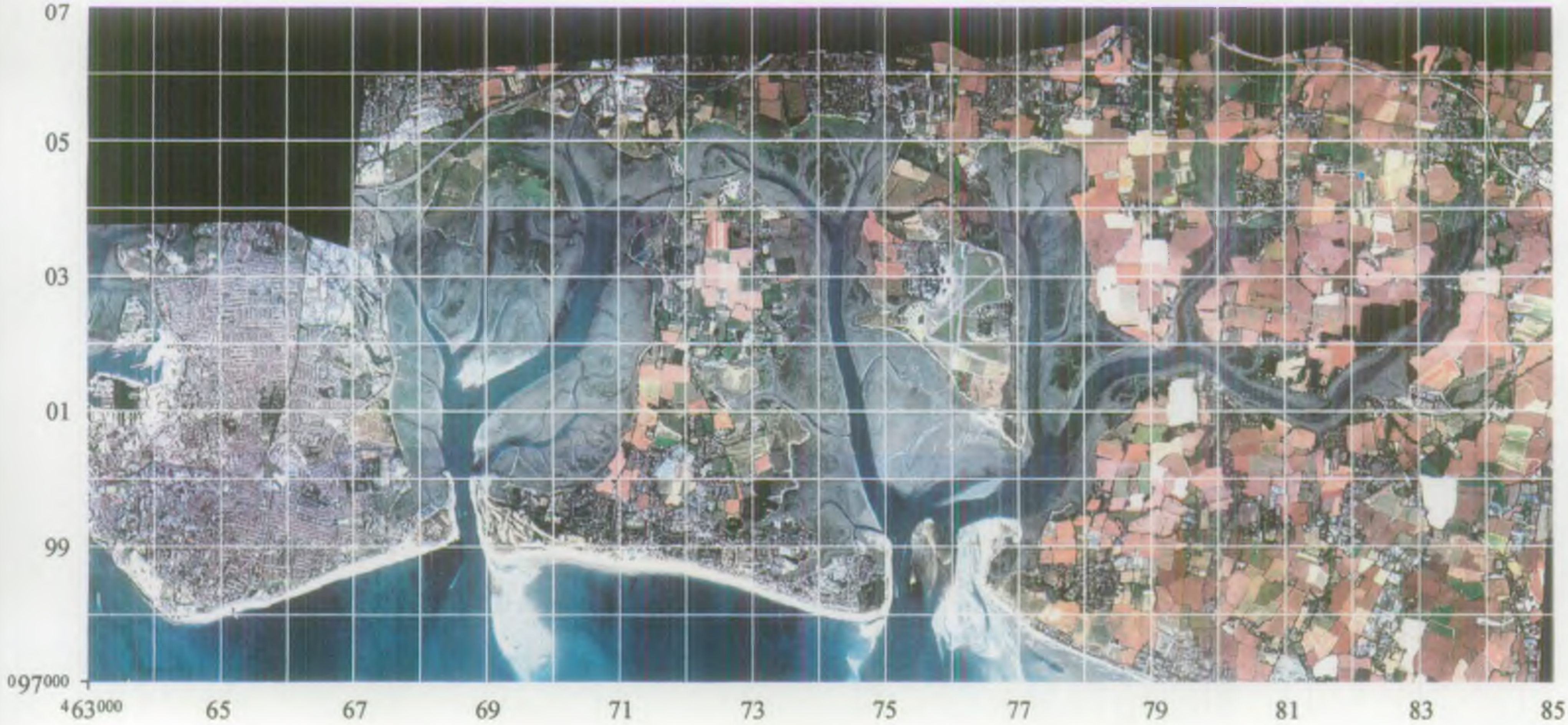
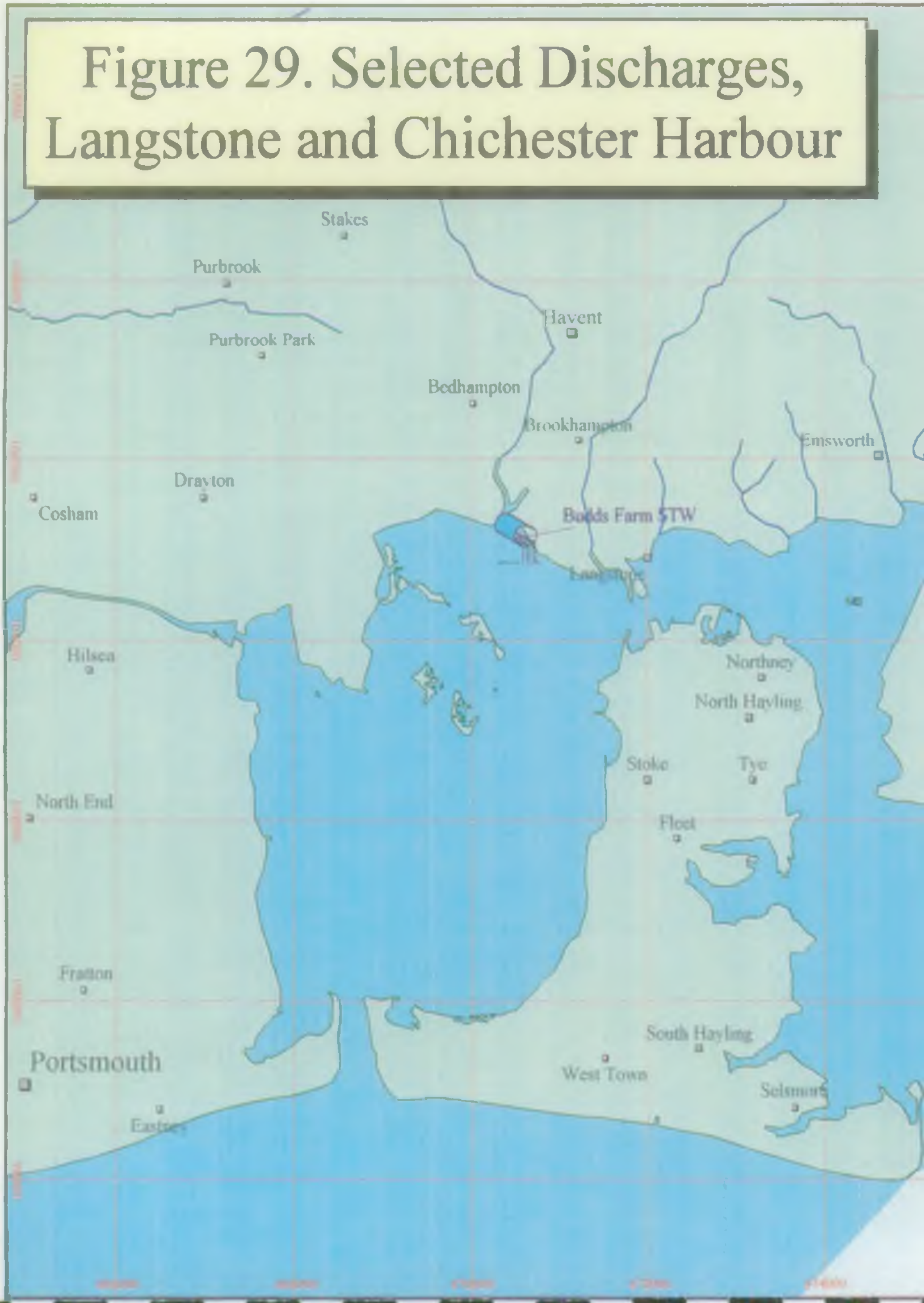


Figure 28

Figure 29. Selected Discharges, Langstone and Chichester Harbour



Consented Discharge Volume
< 100
100 to 1,000
1,000 to 10,000
10,000 to 100,000
> 100,000 m³/day
Discharge Type
Miscellaneous Trade Effluent
Ultra-Violet Treated Sewage
Untreated Sewage
Disinfected Sewage
Primary Treated Sewage
Screened Sewage
Secondary Treated Sewage
Macerated / Comminuted Sewage
Tertiary Treated Sewage
Sewage Sludge
Walderton
Lordington
Aldsworth
Funtington
Westbourne
Woodmancote
Hambrook
Hermitage
Southbourne
Prinsted
Nutbourne
Thornham STW
Walton
Fishbourne
Chichester
Bosham
Chidham
Chichester STW
Apuldram
Bosham STW
Dell Quay
Bosham Hoe
West Thorney
Donnington
Hunston
West Itchenor
Birdham
Sidlesham Common
Shipton Green
Street End
Somerley
Sidlesham
West Wittering
Highleigh
East Wittering
Earnley

Langstone and Chichester Harbours
4th August 1996, Low Water

A false colour composite of three CASI images

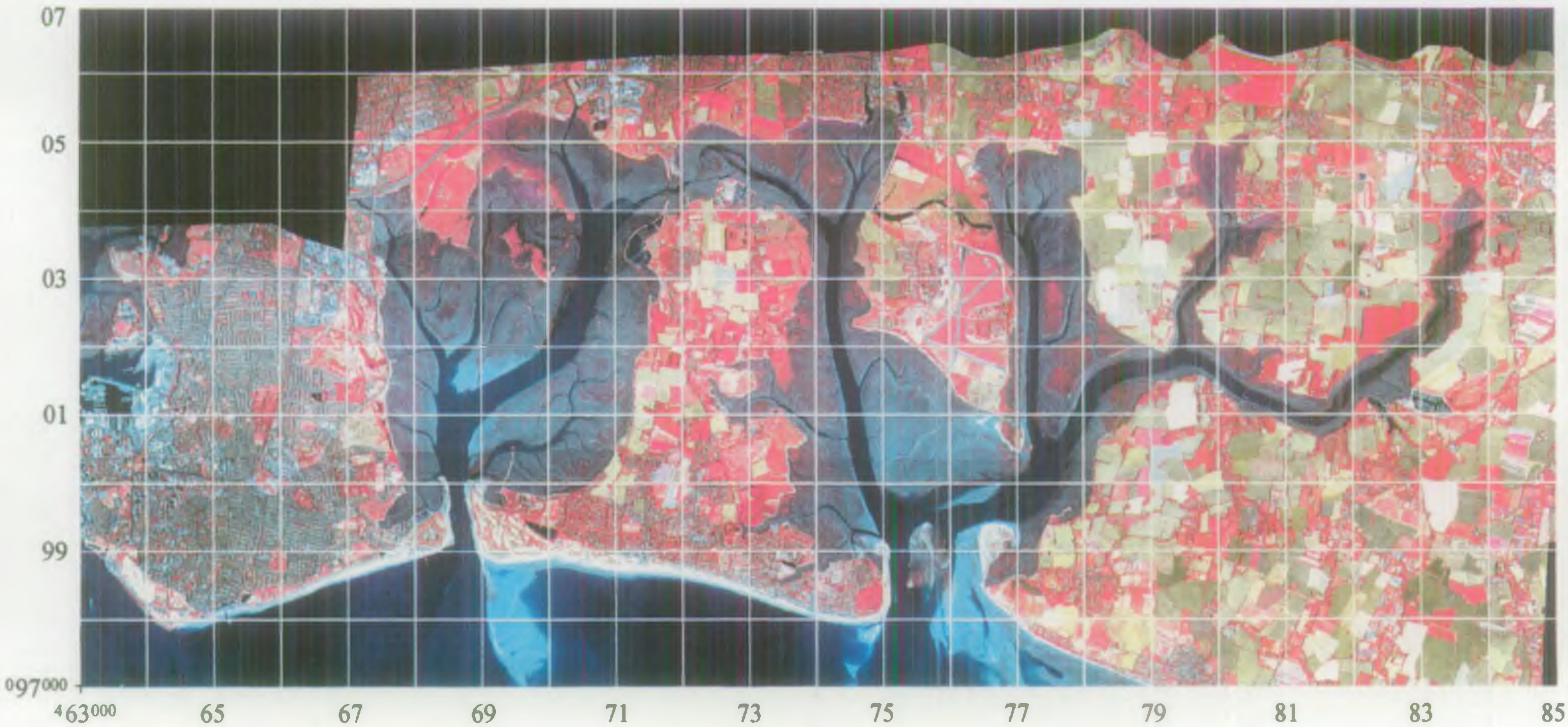


Figure 30

Langstone and Chichester Harbours 4th August 1996, Low Water

An unsupervised classification of inter-tidal areas.

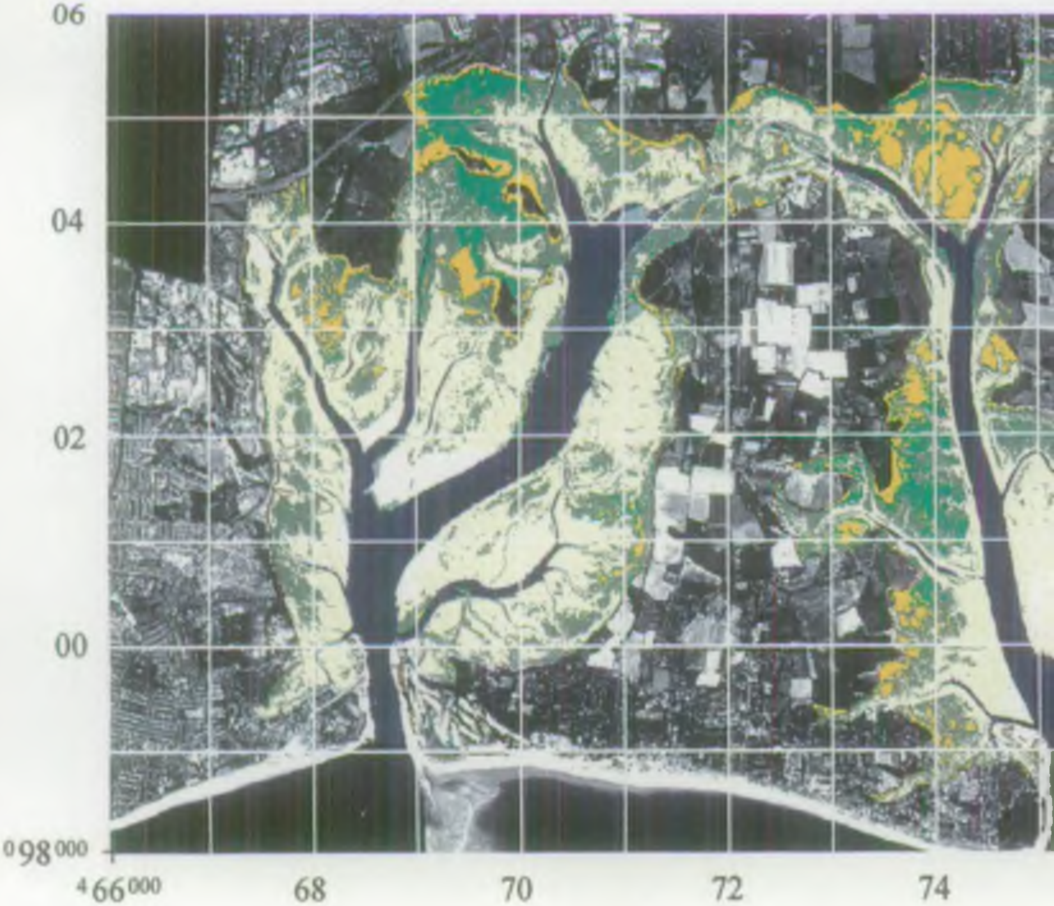
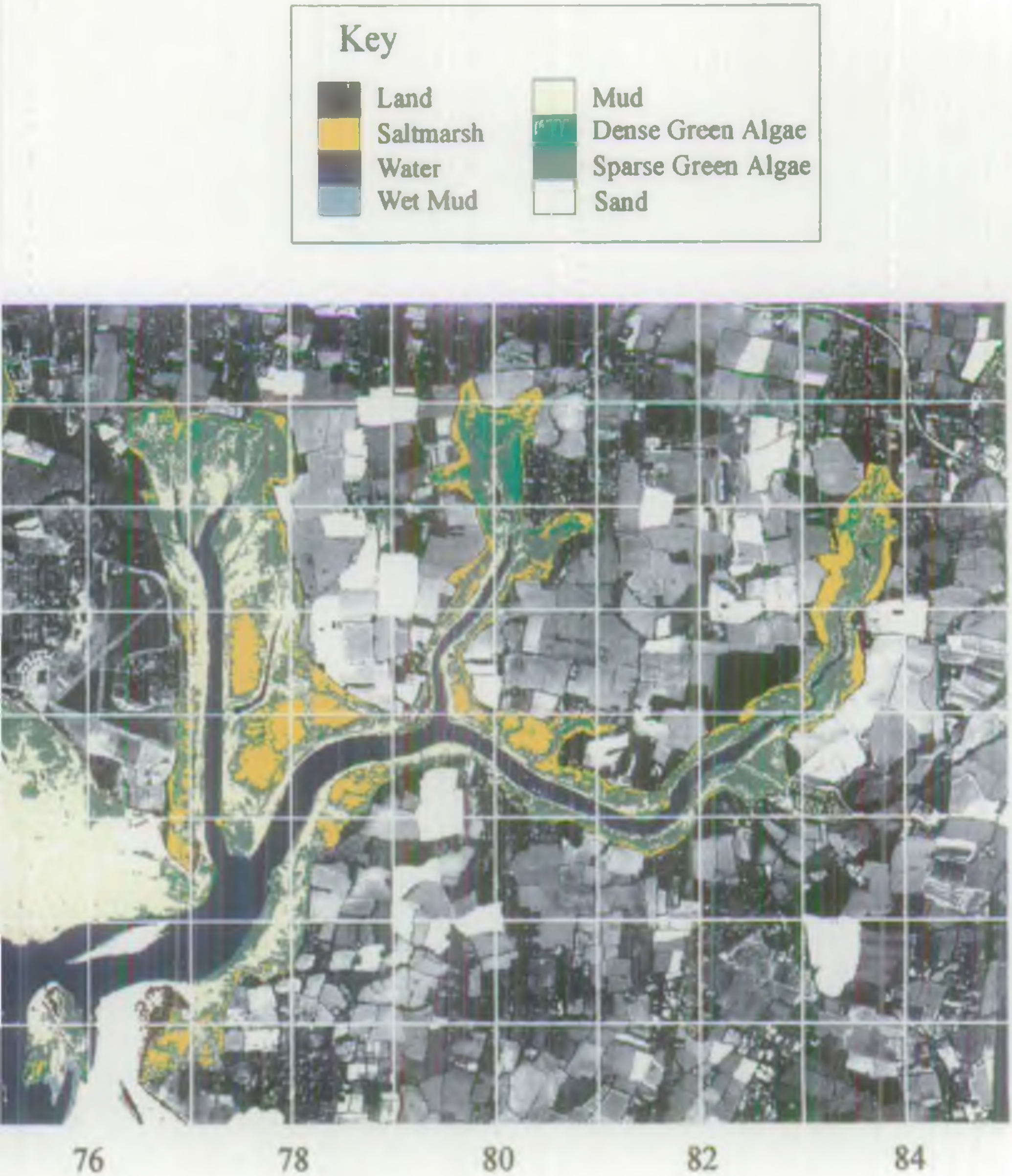


Figure 31


Key
Land
Saltmarsh
Water
Wet Mud
Mud
Dense Green Algae
Sparse Green Algae
Sand
76
78
80
82
84

Langstone and Chichester Harbours
4th August 1996, Low Water

Unsupervised classification - regions of interest

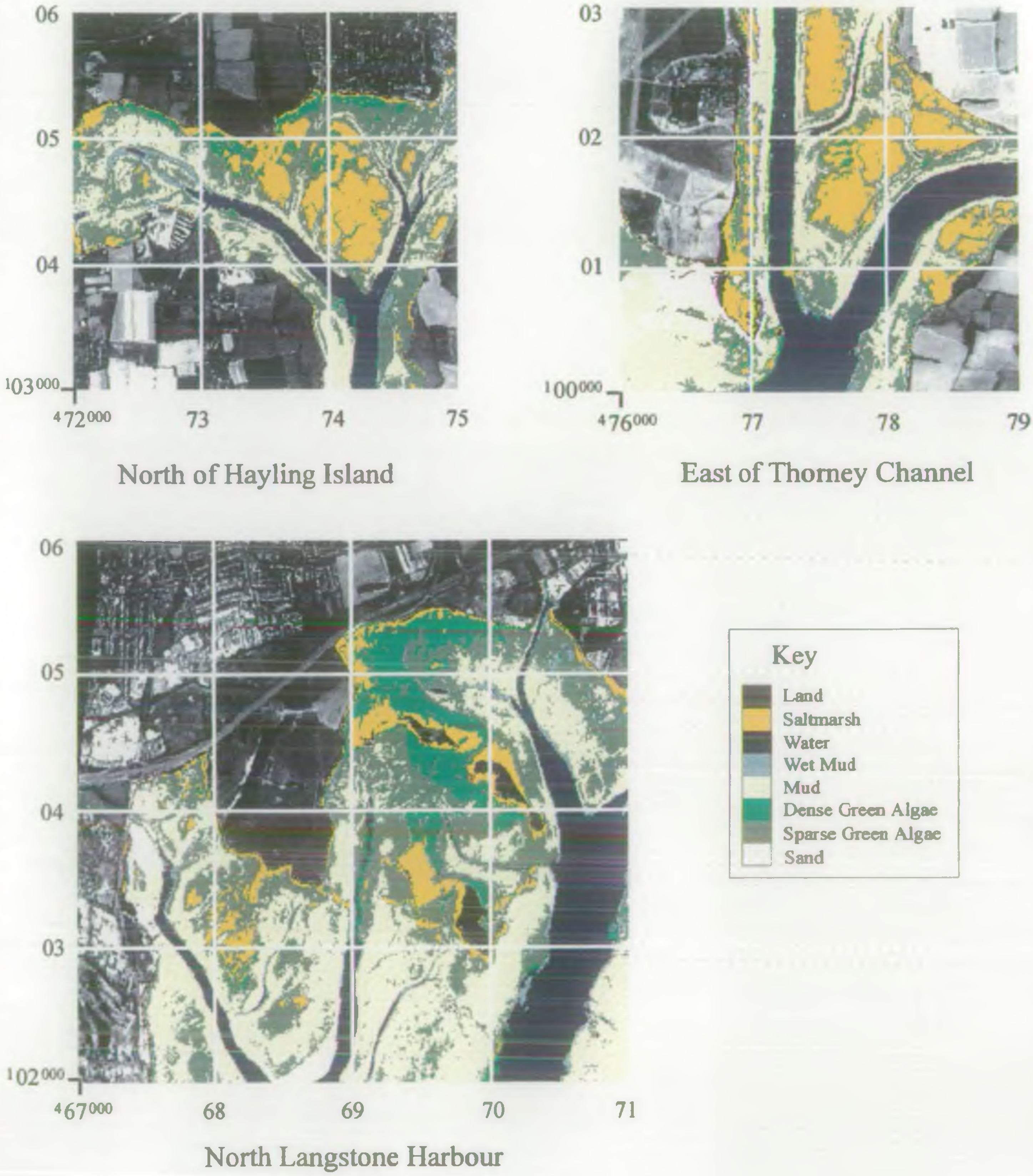


Figure 32

3.5 THE LEVEN ESTUARY

3.5.1 Background Description

3.5.1.1 The Leven Estuary forms part of the larger estuary of Morecambe Bay on the North West coast of Britain. The Leven drains from Lake Windermere to join Morecambe Bay through Lancaster Sound.

3.5.1.2 The estuarine area is illustrated in figure 33, which also shows the major populations centres and physical features. The major centre of both urban and industrial development within the estuarine area is at Ulverston, on the western shore. The entire of the Leven Estuary is designated as a Site of Special Scientific Interest (SSSI) as shown on figure 33.

3.5.1.3 The estuary is dominated by the presence of extensive mudflats, with high exposure at low water. Public rights of way exist across the estuary, with historical reports of troop movements and a coach road in this area.

3.5.1.4 The low lying nature of the estuary means that the area is under threat from sea level rises, predicted as a result of climate change (DoE, 1996).

3.5.2 Discussion of major issues

3.5.2.1 The Leven Estuary forms part of Morecambe Bay which has been proposed to the European Union as a candidate Special Area of Conservation (SAC) and is already designated as a Special Protection Area (SPA) under the EC Birds Directive. The maintenance of natural resources such as saltmarsh are of key interest. Such habitats may be mapped using aerial techniques, with the results being integrated into a Geographical Information System.

3.5.2.2 At low water the Leven Estuary is mainly exposed, with only a small number of navigation channels. The positions of these channels are known to change over time. Possible effects on the transport of effluent from discharges means that the positions of the channels should be accurately known. Remote sensing has been suggested as a means of regularly monitoring the positions of the channels.

3.5.2.3 Changing positions of deep water channels can lead to the development of new saltmarsh communities. The deposition of contaminants such as heavy metals in this saltmarsh may lead to bio-accumulation of toxic substances.

3.5.2.4 The main industrial centre is at Ulverston, where the majority of industry is due to Glaxo Pharmaceuticals. There is also a discharge of sewage effluent at this point. The mixing zone of effluent from the main discharge was studied using a dye release in 1995. This involved releasing Rhodamine dye into the discharge and tracking the direction of flow using aerial surveillance. The dye was seen to flow towards the coast to the south of Ulverston at Aldingham.

3.5.2.5 The water quality of the estuary is generally good consisting mainly of overflow from Lake Windermere. The Ulverston sewage treatment works, which is the major cause of localised low water quality, is likely to receive secondary treatment by the year 2000 under the provisions of the Urban Waste Water Treatment Directive (Wither, *pers. comm.*).

3.5.3 Discharge mixing zones

3.5.3.1 Figure 34 shows the positions of the major consented sewage and trade effluent discharges to the Leven Estuary. Trade effluent discharges are associated with Glaxo Chemicals. The largest sewage effluent discharge is at Canal Foot serving the population of Ulverston which receives primary treatment, with a further ultra-violet treated sewage discharge at Newbiggin.

3.5.3.2 The Leven Estuary was overflown on 15th June 1996 close to high water. The area was covered by three flightlines, flown at an altitude of 10,000 ft.

3.5.3.3 The imagery showed high variability in the CASI signal which was mainly indicative of differing depths. Deep water absorbs more light and therefore returns a lower signal to the sensor. Variations in the thermal imagery were also mainly caused by the depth of the water, with shallow water being warmed faster, and thus returning a higher signal.

3.5.3.4 Neither the CASI nor the thermal imagery revealed any sign of the discharges detailed above. The imagery was collected between 11:20 and 11:30 GMT, with high water being at 11:04 GMT. The consent for the Glaxo discharge, which is the largest in the estuary, allows discharge for only 20 minutes after High Water. Thus the timing of the flights means that the imagery may have been collected outside the discharge window.

3.5.3.5 Further data collection could be carried out to study the fate of the discharges in this estuary. However, the high suspended solids loading of the estuary and the relatively warm temperatures caused by shallow water at the date and time of data collection, mean that the use of dye tracers may again be necessary to ensure detection of the effluent flow. This technique was highly successful is delineating the flow of effluent in studies in 1995.

3.5.4 Saltmarsh and beaches

3.5.4.1 The presence of saltmarsh and beaches in the inter-tidal zone of an estuary acts to protect the shoreline against the actions of waves and tides. Saltmarsh is also a highly diverse habitat supporting a wide variety of flora and fauna and providing both a feeding and a breeding ground for migratory birds, in particular waders.

3.5.4.2 The importance of the saltmarsh communities of Morecambe Bay has been recognised in the proposal to the EC of Morecambe Bay as a Special Area of Conservation (SAC). The saltmarsh of Morecambe Bay has been accreting over recent years, with a growth in the abundance of common cord grass being particularly apparent. The majority of marshes in this area are grazed throughout the year (Hill, 1995*a,b,c&d*).

3.5.4.3 Data collection from aerial surveys may be used to produce a digital classification of land cover types in the inter-tidal zone of an estuary.

3.5.4.4 Numerous attempts were made throughout 1996 to collect aerial surveillance data at low water on the Leven Estuary. Meteorological conditions, however, precluded the collection of any data of high enough quality to interpret land cover in the inter-tidal zone.

3.5.4.5 The presence of the large saltmarsh to the east of the estuary is evident in the data collected at high water on 15th June 1996. Similarly, the main navigation channels are evident in this data set. The data is not suitable, however, for mapping the full extent and accurate positions of such features, because of the partial cover of this zone by the tide when the data were collected.

3.5.5 Inter-tidal vegetation

3.5.5.1 The presence of macro-algae on the inter-tidal mudflats of an estuary may indicate that this estuary is subject to eutrophic conditions. This may lead to the classification of the estuary as a Sensitive Area under the provisions of the Urban Waste Water Treatment Directive. This subsequently requires additional treatment to be applied to sewage effluent discharges.

3.5.5.2 The Leven Estuary was not considered by Environment Agency Regional staff to be potentially subject to eutrophication, although the fate of effluent from the Canal Foot sewage discharge has been the subject of investigation. This has led to the proposal for implementation of secondary treatment to this discharge by the year 2000.

3.5.5.3 As stated above it was not possible to collect data of the Leven Estuary at low water during 1996. It is not therefore possible to make any conclusions on the presence of macro-algae on the mudflats.

3.5.6 Summary of estuary

3.5.6.1 Collection of aerial surveillance data of the Leven Estuary has been made difficult by poor weather conditions in the region throughout 1996. In particular, the weather conditions during August and September, when the area was being surveyed for algal growth on the inter-tidal mudflats were so poor as to preclude the collection of any good quality data.

3.5.6.2 The data collected just after high water on 15th June 1996 did not show the presence of any discharge mixing zones associated with either trade and sewage effluent. This may have been due to the time of data collection having missed the effluent discharge. However, the high suspended solids loading of the estuary and the presence of shallow water mean that this estuary is not ideal for the detection of discharge mixing zones from aerial surveillance, unless dye tracers are added to the effluent.

3.5.6.3 Recent studies predict an increase in sea level due to global warming of 37 cm on average across the United Kingdom (DoE, 1996). The geographical location of the Leven Estuary means that the sea level rise will be slightly lower than average, and has been estimated at approximately 30 cm. The low lying nature of the estuary will result in extensive flooding of the present inter-tidal zone. Possible implications of this are the re-suspension of contaminants from saltmarsh and mudflats, and the requirement for additional hard defences for asset protection.

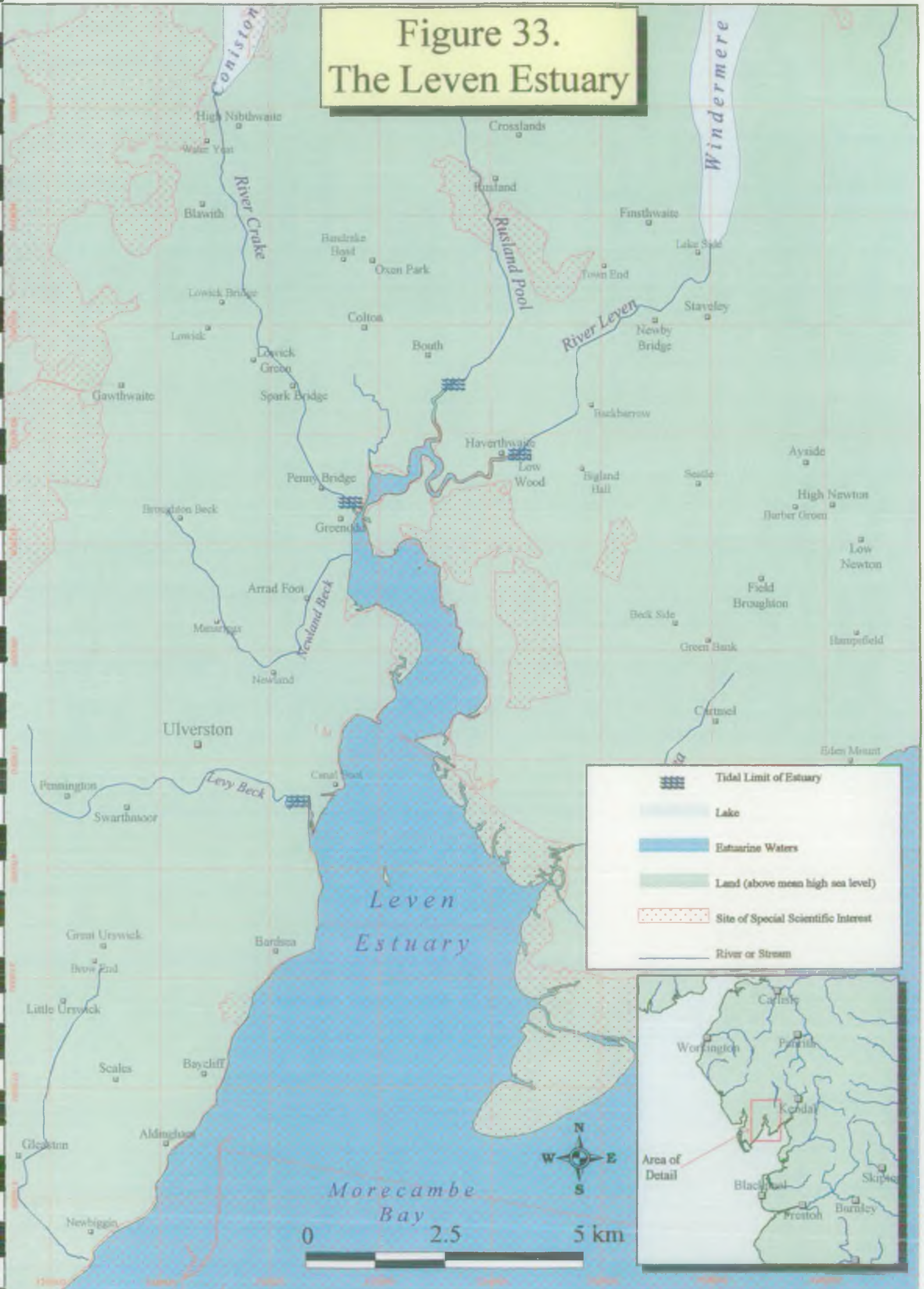


Figure 33. The Leven Estuary

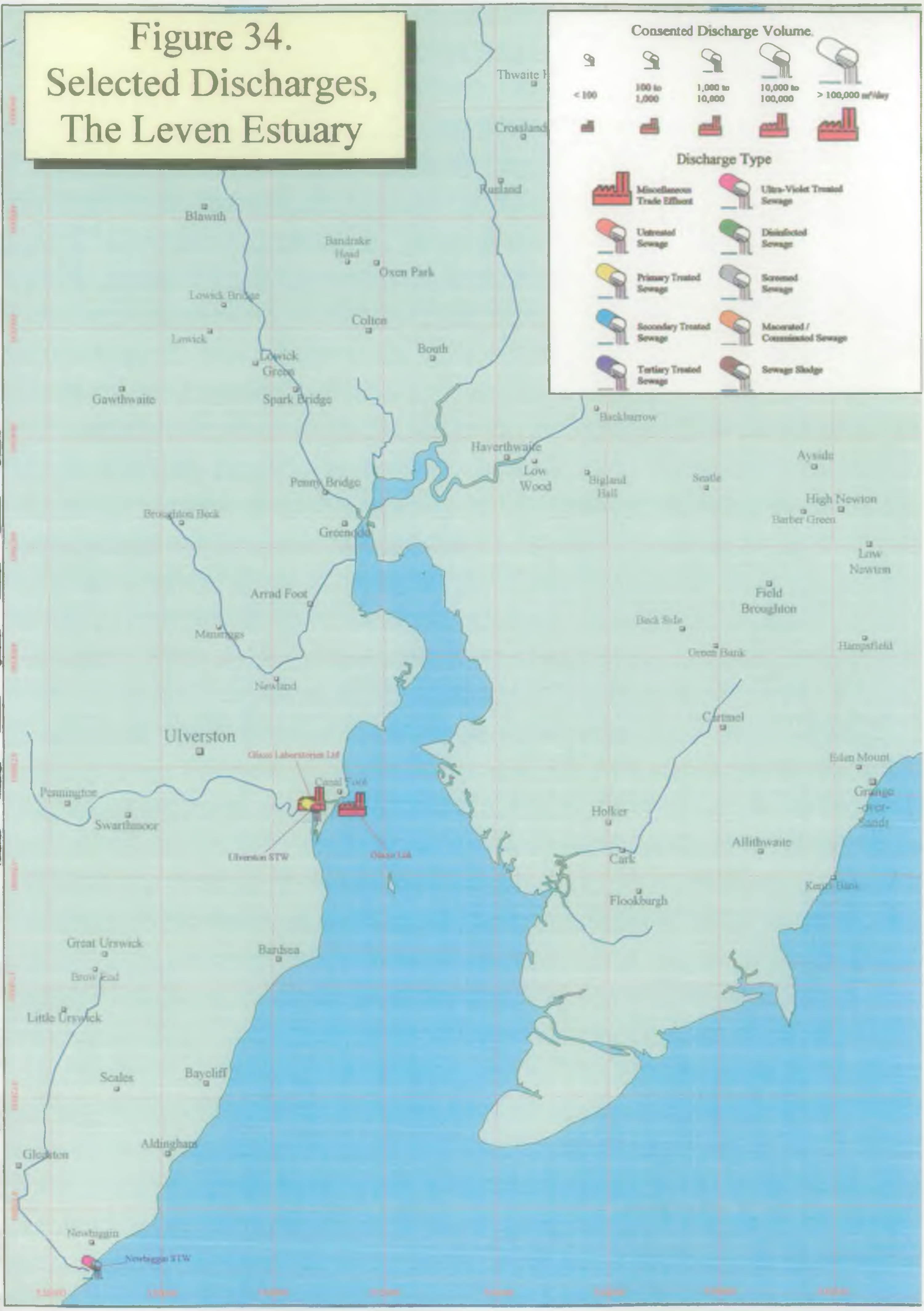


Figure 34. Selected Discharges, The Leven Estuary

3.6 THE LUNE ESTUARY

3.6.1 Background Description

3.6.1.1 The Lune Estuary forms part of the larger estuary of Morecambe Bay, on the north west shore of the United Kingdom. The catchment is generally rural, with the exception of the city of Lancaster. Major industry is concentrated on the outer estuary, within the main part of Morecambe Bay.

3.6.1.2 Figure 35 shows the estuarine area, extending from the tidal limit at Skerton Weir, out into Morecambe Bay. This figure also shows the major population centres within the estuarine region, at Lancaster, Glasson and Overton. The majority of the Lune Estuary is designated as a Site of Special Scientific Interest (SSSI) as shown in figure 35.

3.6.1.3 Figure 36 shows a mosaic of two true colour composite CASI images taken at low water on 19th October 1996, covering the inner Lune Estuary. This mosaic clearly illustrates the presence of extensive mudflats at the mouth of the estuary, with a single dredged deep water channel. The imagery also highlights the large areas of marshland within the estuary.

3.6.2 Discussion of major issues

3.6.2.1 The Lune Estuary was proposed as a Sensitive Water under the provisions of the Urban Waste Water Treatment Directive (91/271/EEC). Historically, algal blooms have been reported within the Lune estuary and red blooms can occur on the mudflats. In order to establish whether these are linked with the discharge of sewage effluent, a monitoring programme was established, measuring nutrient levels at 6 sites within the estuary, including the direct discharge of sewage effluent from Lancaster sewage treatment works at Stodday.

3.6.2.2 This study revealed no biological or conservation related reasons for the establishment of the Lune Estuary as a Sensitive Area. In particular, ground based surveys revealed no sewage related debris on the mudflats. Additionally, there was no enhanced growth of diatoms and other algae which could be directly associated with the Stodday sewage treatment works. However, the discharge is scheduled for upgrading to secondary treatment by the year 2000 under the provisions of the Urban Waste Water Treatment Directive.

3.6.2.3 The general water quality of the estuary is good, with localised areas of lower quality, particularly close to the outfalls from Glasson Dock. These discharges are due for upgrading to secondary treatment in 2005 under the provisions of the Urban Waste Water Treatment Directive (91/271/EEC). .

3.6.2.4 Morecambe Bay has been proposed to the European Union as a candidate Special

Area of Conservation (SAC) and is already designated as a Special Protection Area (SPA) under the EC Birds Directive. This means that changes to the important inter-tidal resources should be carefully monitored. The saltmarsh within the Lune Estuary is a Site of Special Scientific Interest (SSSI) because of their importance as a habitat for over-wintering by migratory birds, in particular wader species.

3.6.2.5 A major new coastal defence has been built close to the mouth of the estuary, extending from Potts Corner on the seaward side to Trailhome and Overton on the inner side. This is an embankment which has rock armouring in places. The barrier is set to intercept freak storm conditions, positioned at the landward edge of the marsh, or within farmland. It should thus have little effect on the development of the saltmarsh, which is naturally accreting seawards in this region.

3.6.2.6 The upper reaches of the estuary are used extensively for recreational purposes, including water skiing, power boating and jet skiing. The dismantled railway from Glasson to Lancaster has been converted into a cycle way.

3.6.2.7 The Lune is a major salmonid river and there are commercial estuarine fisheries using draft nets and haaf nets.

3.6.3 Discharge mixing zones

3.6.3.1 The position of all consented trade and sewage effluent discharges within the Lune Estuary are shown in figure 37. There are six sewage effluent discharges within the inner estuary, the largest being Stodday sewage treatment works. This intermittent high water discharge currently receives primary treatment, but will be upgraded to secondary treatment by the year 2000.

3.6.3.2 Trade effluent discharges are restricted to the outer estuary, mainly associated with Heysham power station which was not covered by aerial surveillance. The Solrec outfall to the south of Heysham was overflown twice, at a time interval of approximately one hour.

3.6.3.3 The Lune Estuary was overflown close to high water on 15th June 1996. The inner estuarine region was encompassed by two flightlines. The thermal imagery shows a large number of inputs of warmer than ambient temperature water from the creeks within the saltmarsh zones, particularly in the upper estuary. The CASI data shows high suspended solids concentrations within the estuary compared with offshore waters, but does not show high variability within the estuary itself.

3.6.3.4 The thermal imagery records a significant discharge of warm water from a point downstream of Lancaster sewage treatment works at high water, which extends approximately 500 m downstream. The position and extent of this discharge has been digitised and is marked on figure 38. The temperature of this discharge is approximately 2°C above that of the receiving waters.

3.6.3.4 There are no further discharge mixing zones apparent within the inner estuary.

3.6.3.5 In the outer estuary, in Morecambe Bay, the CASI imagery highlights two discharges, each with a characteristic white surface signal. The position and extent of these has been marked on figure 38. At 11:05 GMT imagery showed two point sources of effluent, the first having a faint trailing signal to the south east, and the second being more concentrated. Approximately one hour later at 11:55 GMT the first discharge had rotated to the south, and the second had dispersed westwards. The new positions are again recorded on figure 38. The movement of the mixing zones is consistent with the tidal flow, with a change in current direction towards an offshore direction between the collection of the two images.

3.6.3.6 Consultation with Regional staff has suggested that these discharges are likely to be related to the surface water discharge for Solrec solvent recovery company, which has IPC authorisation, and as such may possibly be contaminated with solvents. This discharge has authorisation for storm water overflow and additionally receives pumped site drainage and storm waters from a former oil refinery site. As a surface signal would not have been expected during June, when the weather had been dry, this apparently anomalous discharge is being investigated internally by Regional staff.

3.6.4 Saltmarsh and beach

3.6.4.1 The presence of saltmarsh vegetation and beaches within estuarine environments acts as a natural defence against the action of coastal flooding. They act both as a physical barrier against the flooding and as a means of dissipating tidal and wave energy, and therefore protect artificial defences.

3.6.4.2 Saltmarsh is a diverse environment, which provides an important habitat for over-wintering of migratory birds, in particular wading species.

3.6.4.3 The Lune Estuary has extensive areas of established saltmarsh, which support a highly diverse community. The importance of these marshes for bird habitats has led to their establishment as Sites of Special Scientific Interest (SSSI). The marshes are also extensively grazed by cattle throughout the year.

3.6.4.4 Figure 39 shows a mosaic of two false colour composite CASI images recorded at low water on 19th October 1996. In this display, a near infrared channel has been used to show variations in vegetation cover. Vegetation has a high infrared response and shows up red in the image. Thus saltmarsh is easily distinguished from bare mudflats and beaches. Meteorological conditions in this region were poor throughout 1996, meaning that the area had to be flown at low level. This has resulted in the geographically limited coverage shown.

3.6.4.5 This CASI data has been digitally classified to produce a map of surface cover type in the inter-tidal region. The output of this classification procedure is shown in figure 40. A summary of the statistics is shown in table 7.

Land cover classes	Area (ha)	% Cover
Saltmarsh	575	43
Sand	514	38
Wet sand	136	10
Green algae	67	5
Mixed green and brown algae	49	4
Total	**1341**	**10**

Table 7: Inter-tidal land cover classification in the inter-tidal zone of the Lune Estuary, 19th October 1996

3.6.4.6 The classification shows extensive saltmarshes along the length of the estuary. The saltmarshes in the lower estuary have a characteristic profile, with sand and mud between the toe of the marsh and the water. This acts to protect the marsh from the worst effects of tide and wave energy. Drainage channels are seen within the marshes, which allow the passage of water to all parts of the marsh, preventing drying out.

3.6.4.7 The presence of the new hard coastal defence from Potts Corner to Overton could potentially affect the development of the marsh at this point. With increasing sea level, marshes naturally advance towards the land, encroaching on the dunes and terrestrial vegetation behind. The position of this particular defence has been chosen to intercept freak storm events and should not affect the development of the marsh, which is currently accreting into the channel.

3.6.4.8 Further upstream, the saltmarshes are directly at the edge of the deep water channel. This will make them more susceptible to rises in sea level and the resulting increases in wave and tide action.

3.6.4.9 This digital classification may be integrated into a Geographical Information System to allow comparisons of change in spatial extent. This may prove useful in assessing the degree of accretion of saltmarsh, particularly around Sunderland Point.

3.6.5 Inter-tidal vegetation

3.6.5.1 The digital classification delimits the extent of macro-algal growth on the beaches and mudflats (see figure 40). There have previously been occurrences of red algae on the mudflats, which are potentially due to eutrophic conditions caused by the discharge of sewage effluent. This has prompted a study into the algal growth in the Lune Estuary, particularly downstream of Stodday sewage treatment works, to determine whether the Lune should be proposed as a Sensitive Area under the provisions of the Urban Waste Water Treatment Directive (91/271/EEC).

3.6.5.2 The digital classification produced from the CASI data collected at low water on 19th October 1996 did not record the presence of any red algae on the mudflats. Areas of more common green algae were, however, delineated. The main area of green algae was found on the shingle banks around Plover Scar at the mouth of the estuary. This was dense in places, with the substrate showing through in others.

3.6.5.3 Other regions of algae were found at the edge of the saltmarsh at the boundary with the sand and mud. The classification shows the mudflats directly downstream of Stodday sewage treatment works to be free of algal growth. This is consistent with studies undertaken by Regional and Area staff.

3.6.5.4 In comparison with other estuaries studied using the aerial surveillance techniques, the Lune Estuary has very low algal cover. This reinforces the findings of Regional studies which have concluded that the Lune Estuary should not be defined as a Sensitive Area as part of the Urban Waste Water Treatment Directive, at this time.

3.6.5.5 The map of algal cover may be used as a baseline against which to compare future data. This will allow any increases in the areas affected by algal growth to be accurately assessed, and may aid Regional staff in future studies of the trophic status of this estuary.

3.6.6 Summary of estuary

3.6.6.1 The aerial investigation of the Lune Estuary has provided an overview of the major processes within the estuary. The information revealed could aid Regional staff in investigations into the environmental quality of this estuary, which is an ecologically sensitive area. The imagery shows the highly rural nature of the estuary, with only small areas of urban development. A visual estimate is that only 10% of the shoreline is developed.

3.6.6.2 The inner estuary has low levels of industry which is reflected in the small number of discharge mixing zones recorded in the imagery. A small thermal effect is seen from the Lancaster sewage treatment works at Stodday, although this effect extended only 500 m downstream. The imagery did, however, reveal the presence of a large effluent discharge from the Solrec solvent recovery outfall in Morecambe Bay, which is the subject of investigation by the Region.

3.6.6.3 Digital classification of the inter-tidal zone has provided a map of major cover types, from which the relative importance of each cover type may be extracted. Saltmarsh is the major cover type with an area of 575 ha, 43% of the inter-tidal zone. This classification may be integrated into a Geographical Information System to allow comparisons of spatial change to be made.

3.6.6.4 The ecologically important coastal grazing marshes within the estuary are clearly delineated by the CASI imagery. The seaward accretion of the marshes at the mouth of the estuary, close to Sunderland Point, may be studied by collection of similar data in subsequent years.

3.6.6.5 The effects of sea level rise due to global warming predicted by the year 2050 (DoE, 1996), will be lessened in the Lune Estuary by the north-westerly position of the estuary. Some flooding of the present inter-tidal zone may, however, be expected. This may result in removal of some saltmarsh environment, and may additionally require improvements to the hard defences to protect assets.

3.6.6.6 The imagery reveals where there is algae colonising the mudflats. The classification reveals low levels of algal cover in comparison to other estuaries surveyed in this study. This information reinforces the finding of Regional ground truth studies which showed there to be no enhanced algal growth on the mudflats. The map produced may be used as a baseline information for any further studies into the trophic status of the Lune Estuary.

3.6.6.7 The CASI imagery was collected from an altitude of 10,000 ft. The presence of the new coastal defence is therefore noted in this imagery, but details are not visible. Low level flights of this could be scheduled in future years to investigate the effects that the defence is having on the surrounding saltmarshes.

3.6.6.8 The upper reaches of the Lune Estuary are heavily used for recreational purposes, for example water skiing, jet skiing and power boating. The aerial data does not reveal any adverse environmental conditions which would affect this usage. For example, the levels of algae are not such that they would be aesthetically unpleasant to recreational users. Similarly, the aerial imagery did not reveal any large effluent discharges which would affect the water quality.

Figure 35. The Lune Estuary

The Lune Estuary
19th October 1996, Low Water

A true colour composite of two CASI images.

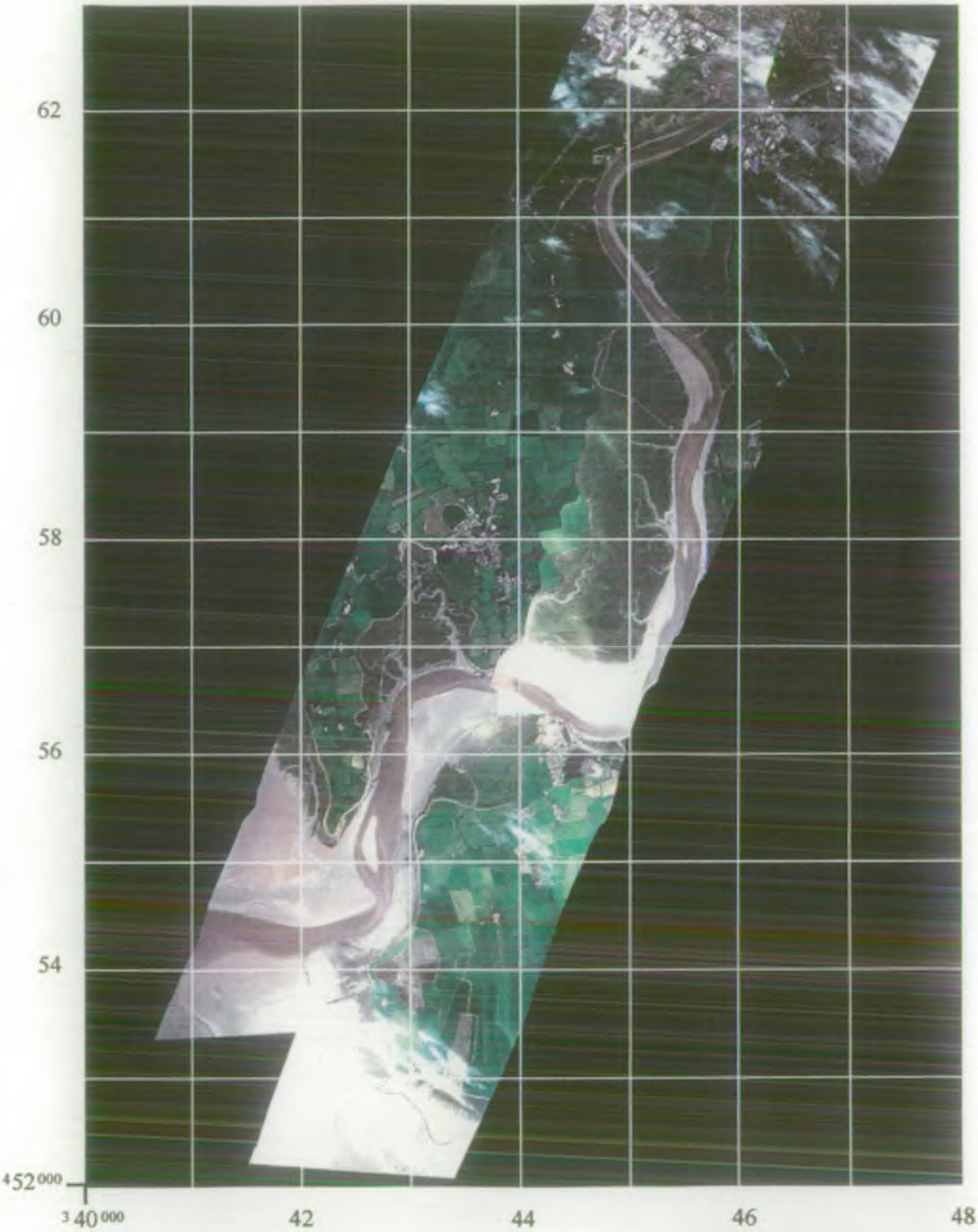
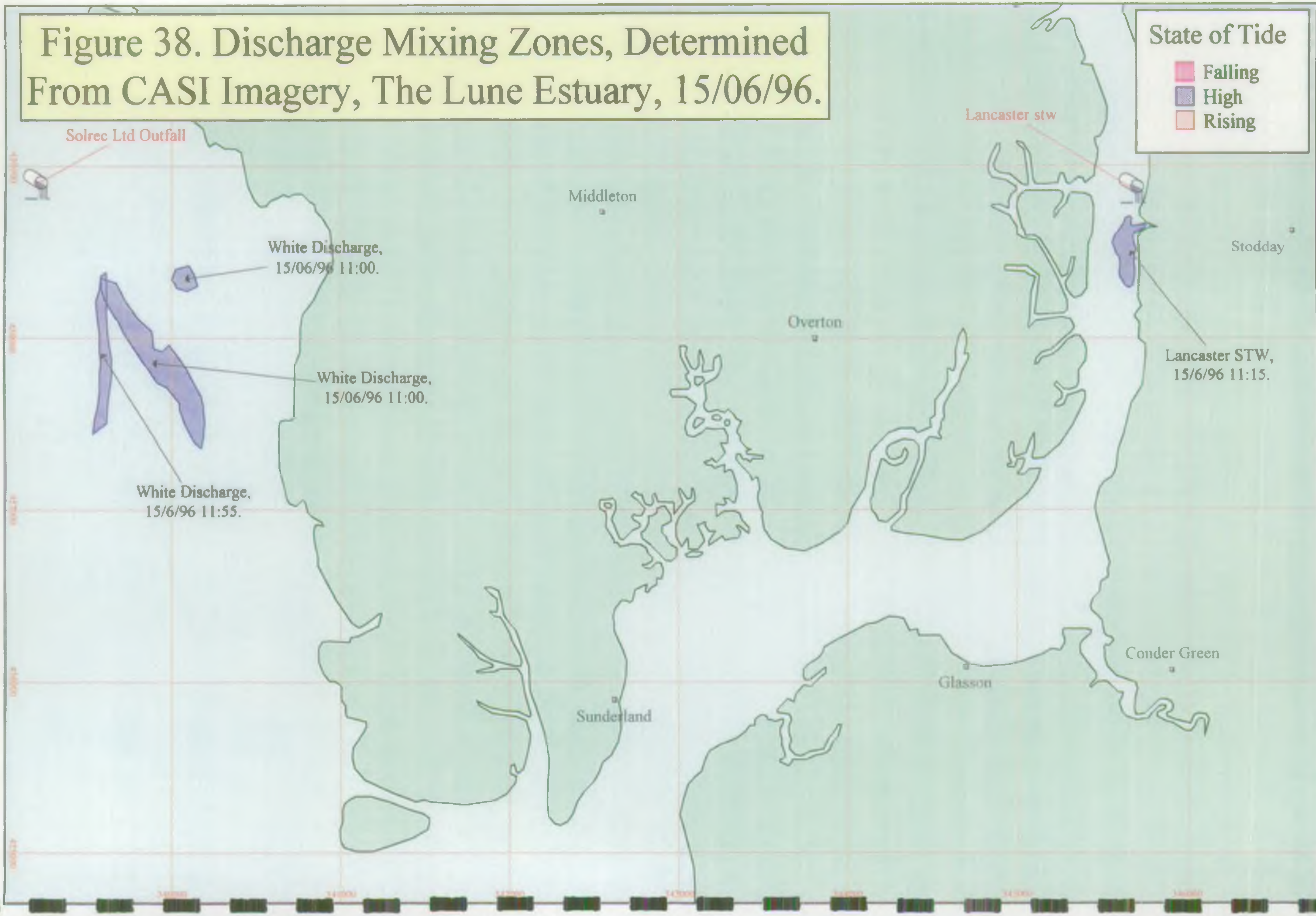


Figure 36

Figure 37.
Selected Discharges,
The Lune Estuary

Figure 38. Discharge Mixing Zones, Determined From CASI Imagery, The Lune Estuary, 15/06/96.



The Lune Estuary
19th October 1996, Low Water

A false colour composite of two CASI images

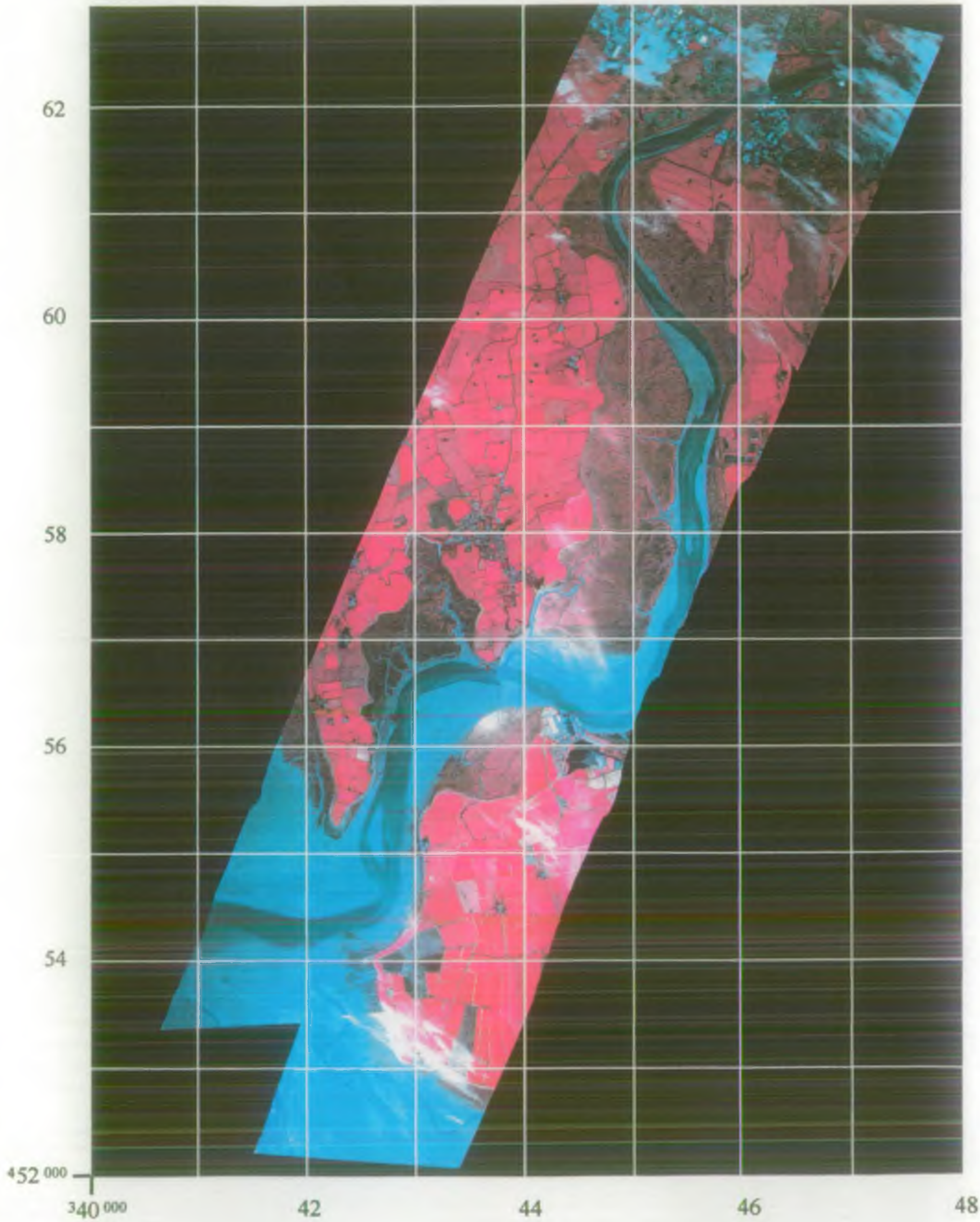


Figure 39

The Lune Estuary
19th October 1996, Low Water

An unsupervised classification of inter-tidal areas

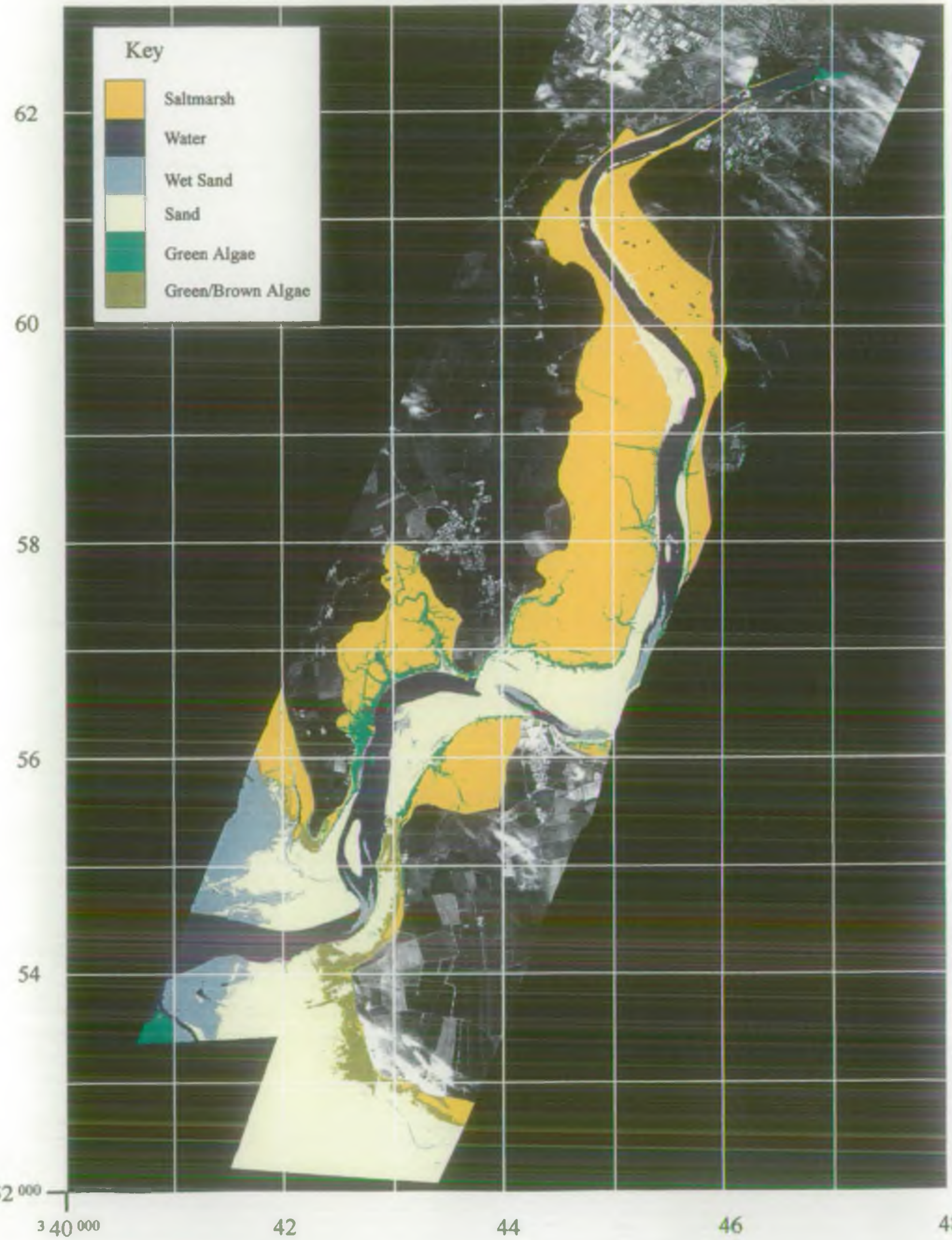


Figure 40

3.7 THE MERSEY ESTUARY

3.7.1 Background Description

3.7.1.1 The Mersey Estuary on the western coast of the UK drains one of the largest catchments in the UK. This catchment is heavily industrialised, with the area having been the birthplace of the British chemical industry. Since the closure of the port of Chester in the 18th Century, the Mersey has become an important trade route, which is reflected in its dense population.

3.7.1.2 The tidal limit of the Mersey is found at Howley Weir in Warrington, and the estuarine area under consideration is shown in figure 41. This figure also shows the locations of Sites of Special Scientific Interest (SSSI). Figure 42 shows a mosaic of three flightlines collected during 1995, which clearly illustrates the high suspended sediment loading of the estuary.

3.7.1.3 The Mersey has in the past been one of the most polluted estuaries in Europe. Dramatic improvements have been made in recent years, through implementation of the Mersey Estuary Pollution Alleviation Scheme. Further improvements are ongoing in order to achieve an appropriate balance between development needs and environmental protection (NRA, 1995*a*).

3.7.2 Discussion of major issues

3.7.2.1 Due to the tidal regime and physical characteristics of the Mersey, pollutants discharged to the upper and middle estuary may remain within the estuary for several weeks. The discharge of sewage effluent and organic waste has resulted in pronounced oxygen sags in past years, most pronounced on Summer Spring tides. Observation of discharge mixing zones could therefore provide information on the fate of pollutants (NRA, 1995*a*).

3.7.2.2 In order to overcome the problems of pollution, the large number of sewage and industrial outfalls have had more stringent discharge consents applied, with a decrease in the number and quantities of pollutants which may be discharged. These improvements have decreased the occurrence of oxygen sags, although they are still exacerbated by Spring tides.

3.7.2.3 Subsequent to the improvements in trade effluent discharges, sewage effluent discharges are being improved under the provisions of the Urban Waste Water Treatment Directive (91/271/EEC).

3.7.2.4 The improvement in the water quality of the estuary has been shown in the return of fish to the estuary. Additionally, the estuary is both nationally and internationally important for a number of bird species. The maintenance of inter-tidal mudflats and saltmarsh is key to retaining this status.

3.7.2.5 The Mersey Estuary is subject to changes in the positions of the deep water channels. This results in re-suspension of industrial pollutants which have been laid down in sediments. This is both detrimental to the water quality of the estuary and may subsequently result in the deposition of the pollutants in sensitive areas of the inter-tidal zone.

3.7.3 Discharge mixing zones

3.7.3.1 The high industrial development of the estuary is reflected in the number of consented discharges of sewage and industrial effluent to its waters. Figure 43 shows all consented trade and sewage effluent discharges to the Mersey. There are two major centres for industrial development, at Ellesmere Port and Runcorn

3.7.3.2 The estuary was surveyed on two occasions. On 15th June 1996 the estuary was overflown at high water. On 17th July 1996 the estuary was surveyed at three tidal states: on the rising tide, at high water and on the falling tide. On both occasions the data were of high quality, in terms of the cloud cover and sunglint effects.

3.7.3.3 Imagery from both occasions fails to reveal the presence of any point discharges and no mixing zones were noted within the estuary. This is unexpected when there are such a large number of consented discharges within the estuary.

3.7.3.4 The thermal imagery in June shows higher variability in temperature than that of July. This is due to the seasonal warming of the water masses which would have occurred between the two dates. In June the water would have been undergoing warming, having reached a stable temperature by July. The difference in temperature between discharging and receiving waters will therefore have decreased by July. Collection of thermal imagery in Spring or Winter months would show greater differentiation between discharging and receiving waters.

3.7.3.5 The Mersey Estuary has very high suspended solids loadings, which are shown in the CASI imagery as high reflectance. Discharged waters generally contain solids, and are more easily distinguishable against clear receiving waters. This may account for the lack of clear discharge mixing zones within the CASI imagery. Other estuaries with high suspended solids loading, such as the Humber and the Severn, show only discharges which are of clear water or have a very individual colour signal, such as the Tioxide UK Ltd. outfall on the Humber.

3.7.4 Saltmarsh and beaches

3.7.4.1 The presence of saltmarsh and beaches in estuarine regions acts as a protection against coastal flooding by dissipating tide and wave energy. Saltmarsh is an important habitat being highly diverse and supporting a wide range of flora and fauna.

3.7.4.2 The importance of saltmarsh in the Mersey Estuary is reflected in the designation of much of the estuary as a Site of Special Scientific Interest (SSSI). The main SSSI is in the inner estuary between Runcorn and Eastham. This is also a proposed RAMSAR site in recognition of its importance to migratory birds. Further SSSIs are found at Woolston in the upper estuary and at the estuary mouth (see figure 41).

3.7.4.3 Many attempts were made during 1996 to survey the Mersey Estuary at low water in order to map the inter-tidal zone. Meteorological constraints, however, meant that data collection was not possible. In order to demonstrate the inter-tidal area, data from 1995 has been processed. These images were not collected at low water, but did show the presence of the saltmarsh areas and some of the inter-tidal mudflats.

3.7.4.4 These images are displayed as a false colour composite in figure 44. This mosaic displays an infrared channel as red which allows the differentiation of vegetation. Figure 45 shows a digital classification of the land cover in the estuary. This classification relies on the variation in all spectral channels of the CASI, which allows a clear discrimination of vegetated and non-vegetated surfaces. The numerical results of this classification are shown in table 8. The figures quoted are for the area of the estuary covered by aerial surveillance. It is clear from the imagery that some areas were excluded, and therefore the figures can not be taken as fully representative.

Land cover classes	**Area (ha)**	**% Cover**
Sand	834	38
Mud	469	22
Saltmarsh	394	18
Sparse algae	181	9
Dense algae	177	8
Wet mud	111	5
Total	**2167**	**100**

Table 8: Inter-tidal land cover classification in a sub-section of the Mersey Estuary, 10th October 1995

3.7.4.5 Figure 46 shows enlargements of key areas of interest. The major area of saltmarsh is between Runcorn upstream and Ellesmere Port downstream which corresponds to the Inner Estuary SSSI. The saltmarsh has a well established nature, with drainage channels throughout and a natural saltmarsh vegetation progression. This consists of algae at the boundary of the marsh and the mud, with a progression to terrestrial vegetation on the landward side of the marsh. This marsh extends upstream in the second image as far as Ellesmere Port.

3.7.4.6 The other large area of marsh again corresponds with a SSSI, this time at Woolston (see figure 41 and figure 46). This marsh is more dense with less drainage channels.

3.7.4.7 These data were not collected at the lowest tide, and the entire inter-tidal zone may not therefore be visible. They do, however, provide an indication of the saltmarsh resource of this estuary. Changes in the position of deep water channels may result in re-suspension of industrial pollutants from saltmarsh environments. Monitoring of changes in the extent of saltmarsh would provide a measure of the potential re-suspension.

3.7.5 Inter-tidal vegetation

3.7.5.1 The presence of algae on the mudflats of the inter-tidal zone of an estuary may signify that the estuary is subject to eutrophication. Enhanced macro-algal growth may be caused by effluent discharges from sewage treatment works, thus requiring more stringent treatment to be applied to the sewage under the provisions of the Urban Waste Water Treatment Directive (91/271/EEC).

3.7.5.2 The digital classification shows the presence of varying densities of algal cover on the mudflats and sands of the Mersey Estuary. A large area of algae is seen upstream of the main marsh within the Inner Estuary SSSI. This may be linked to the discharge of sewage effluent from the Halewood sewage treatment works (see figure 43), which receives only primary treatment.

3.7.5.3 The most dense area of algae is located downstream at Ellesmere Port. This region which is again part of the Inner Estuary SSSI, is not located close to any sewage treatment works.

3.7.6 Summary of estuary

3.7.6.1 The aerial surveillance of the Mersey Estuary carried out during 1995 and 1996 has revealed information on the environmental quality of this estuary. This estuary is one of the most heavily industrialised of those surveyed, with approximately half of the shoreline showing industrial or urban development.

3.7.6.2 The digital classification, however, recorded the presence of extensive saltmarsh within the estuary, which provides a key haven for migratory birds. This indicates the complexity of the interaction between man and nature in this estuary. The discontinuity in the data means that this classification will not provide an ideal basis for future comparisons. Further data collection would be advantageous to provide an added contextual layer to studies of saltmarsh accretion of depletion in this estuary.

3.7.6.3 Recent studies predict an increase in sea level as a result of global warming (DoE, 1996). The north-westerly location of the Mersey means that this increase will be decreased by the effects of rising land. There will, however, be some flooding of the existing inter-tidal zone. The presence of hard coastal defences at the landward edge of some saltmarsh will effect the ability of the marsh to retreat landward. Existing hard defences may need improvement to protect the high asset value of the estuarine shoreline. Thus there are conflicting pressures which must be considered in the development of flood defences.

3.7.6.4 The presence of dense green algae was recorded on the mudflats of the Mersey Estuary, in particular close to Ellesmere Port. There is no evidence to prove a direct causal link between this algae and the discharges from sewage treatment works. The extent of the algal cover may mean that this area warrants further investigation.

3.7.6.5 The population of this region is not likely to be effected by increased tourism over the next 50 years. Studies predict that tourism will increase in the south of England as temperatures increase as a result of global warming (DoE, 1996).

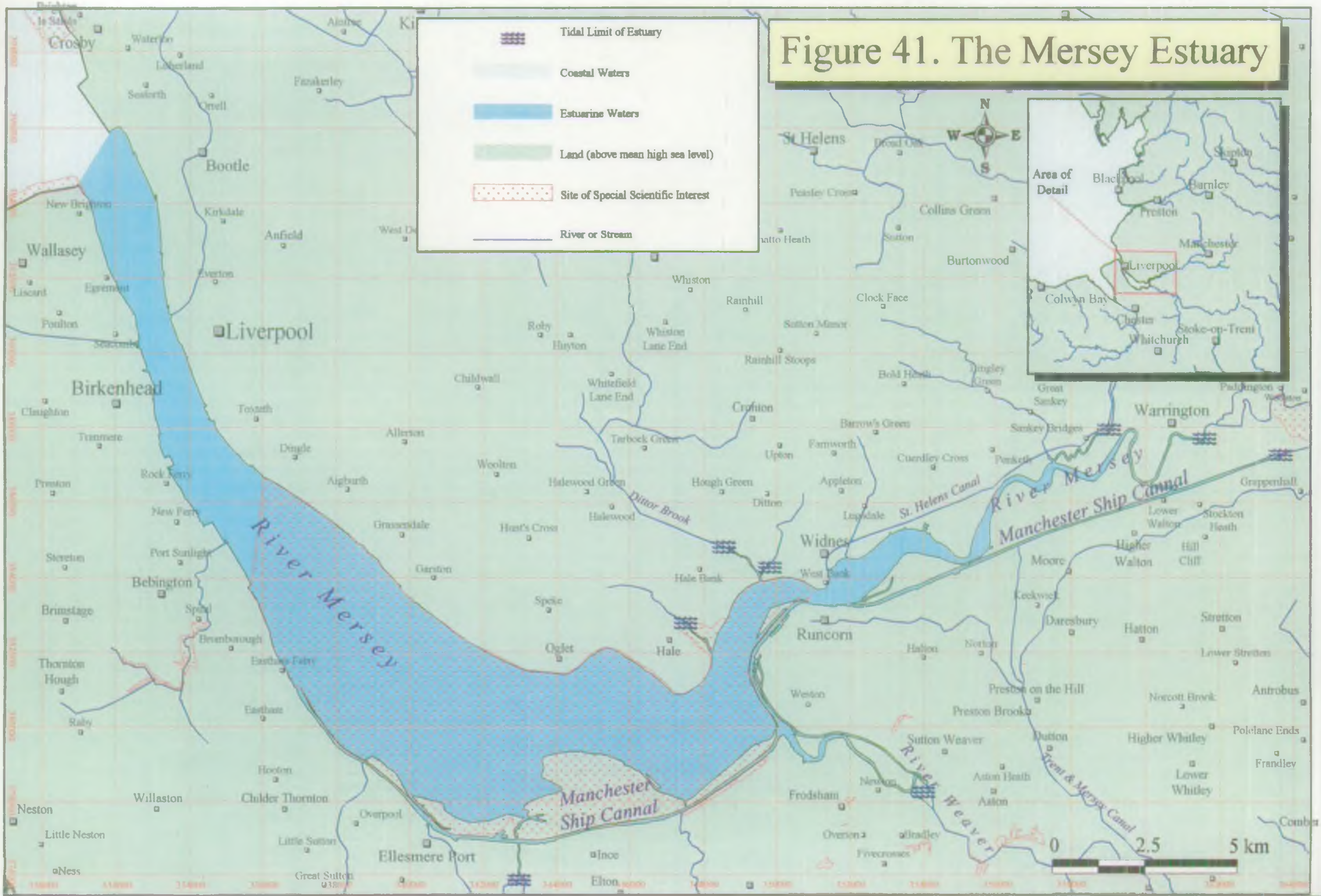


Figure 41. The Mersey Estuary
Tidal Limit of Estuary
Coastal Waters
Estuarine Waters
Land (above mean high sea level)
Site of Special Scientific Interest
River or Stream
River Mersey
Manchester Ship Canal
River Weaver
St. Helens Canal
Ditton Brook
Trent & Mersey Canal
Liverpool
Birkenhead
Wallasey
Bootle
Crosby
Warrington
Runcorn
Widnes
Ellesmere Port
St Helens
Area of Detail
0
2.5
5 km

The Mersey Estuary
10th October 1995
True colour composite of 3 CASI images

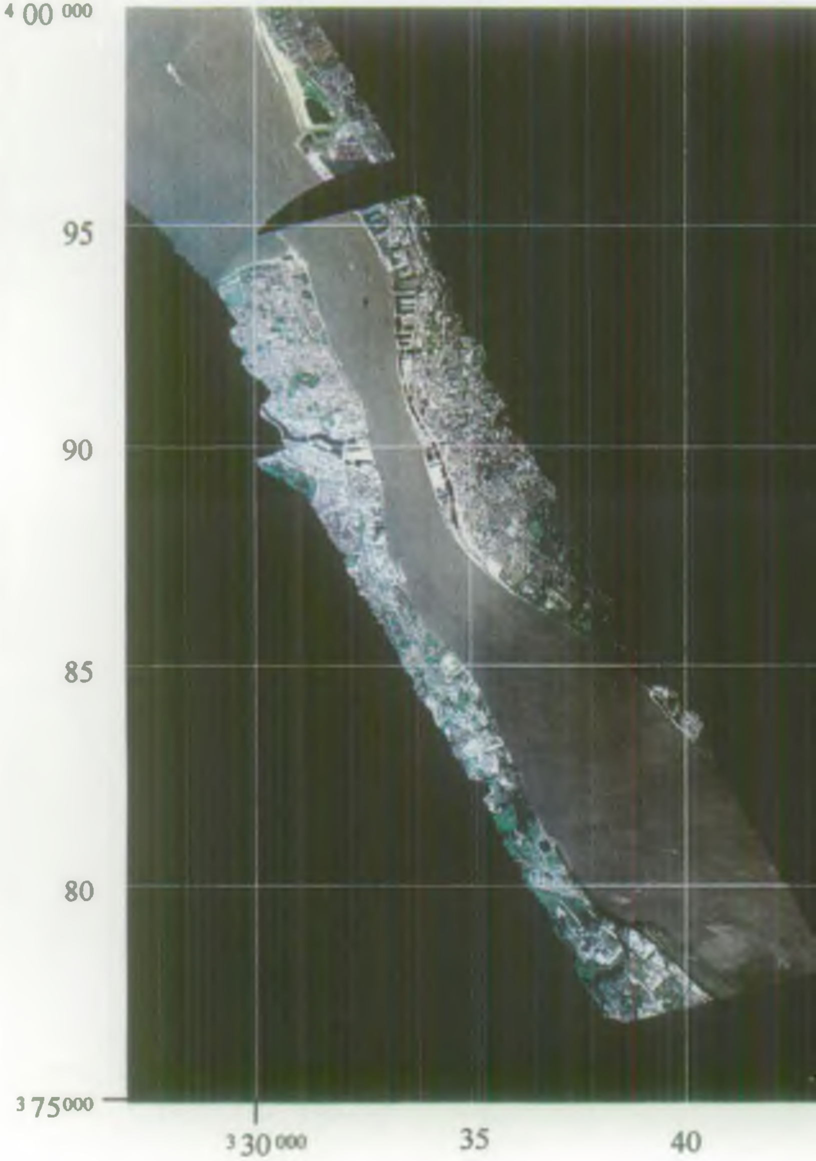
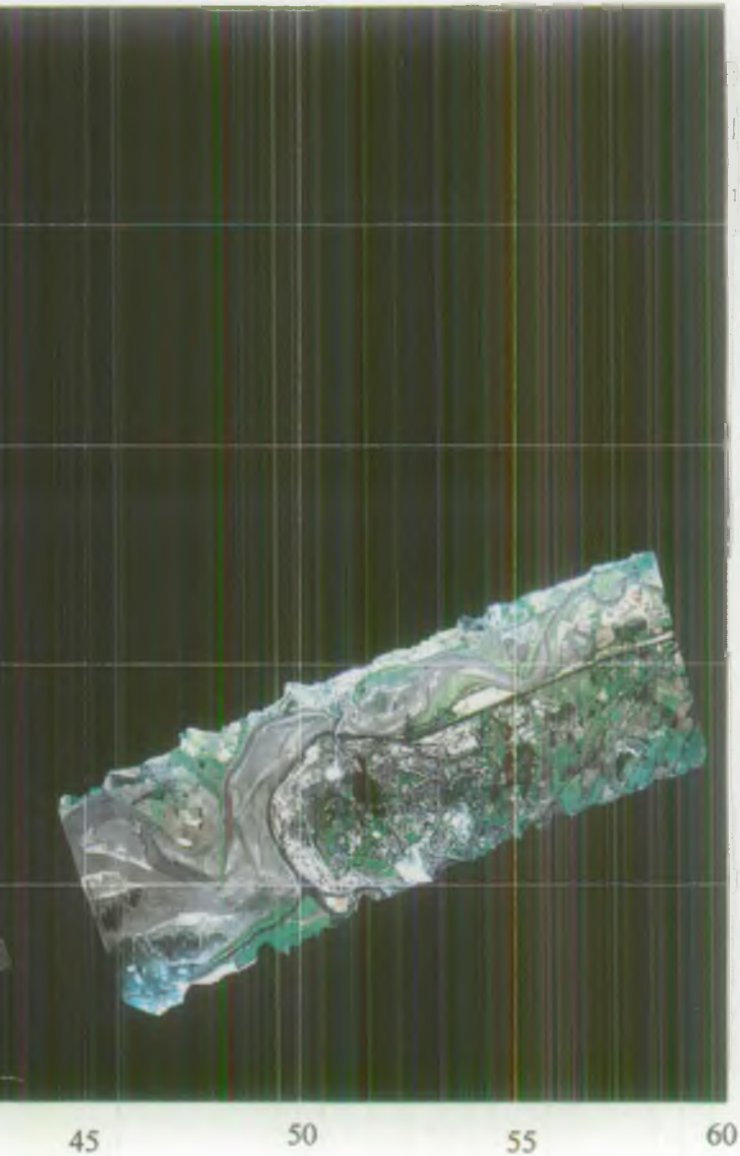


Figure 42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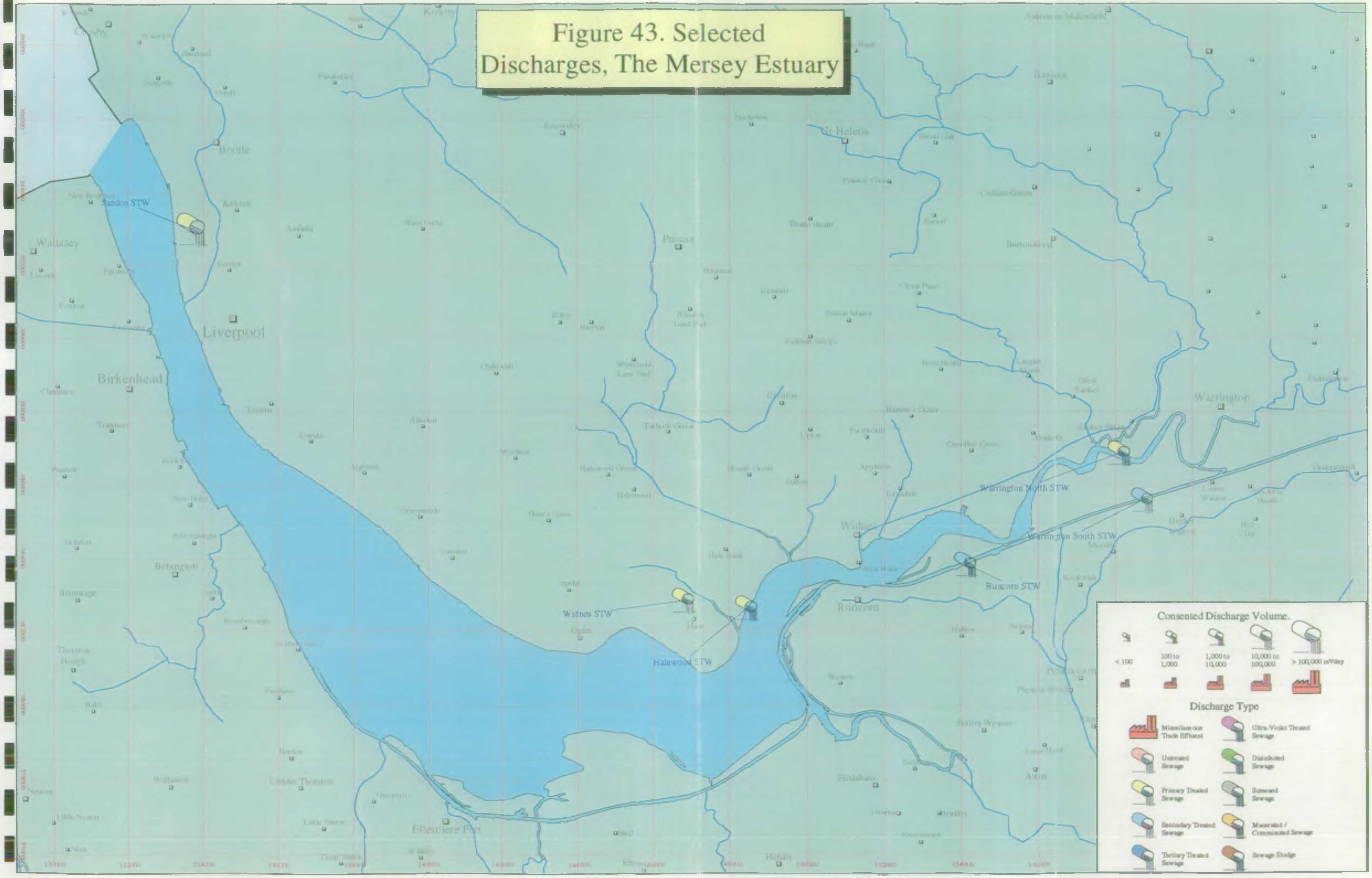


Figure 43. Selected Discharges, The Mersey Estuary

The Mersey Estuary
10th October 1995

False colour composite of 3 CASI images

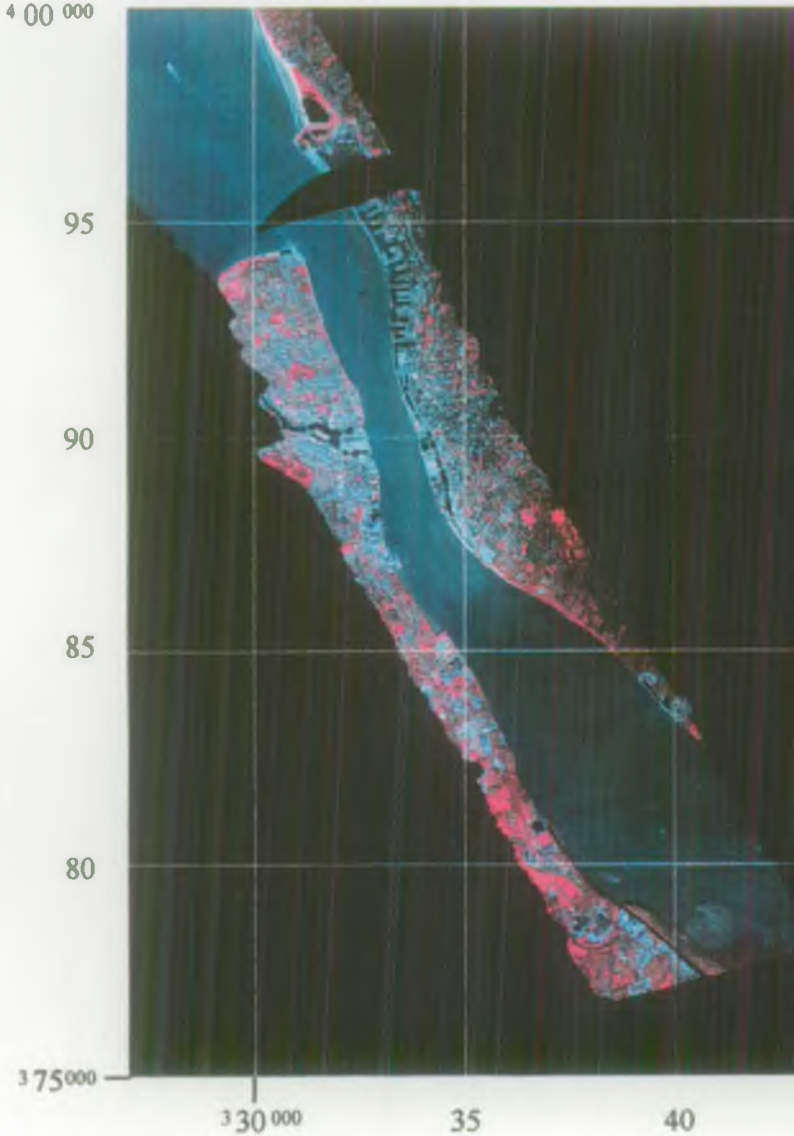


Figure 44


45
50
55
60

The Mersey estuary
10th October 1995

Unsupervised classification of inter-tidal areas

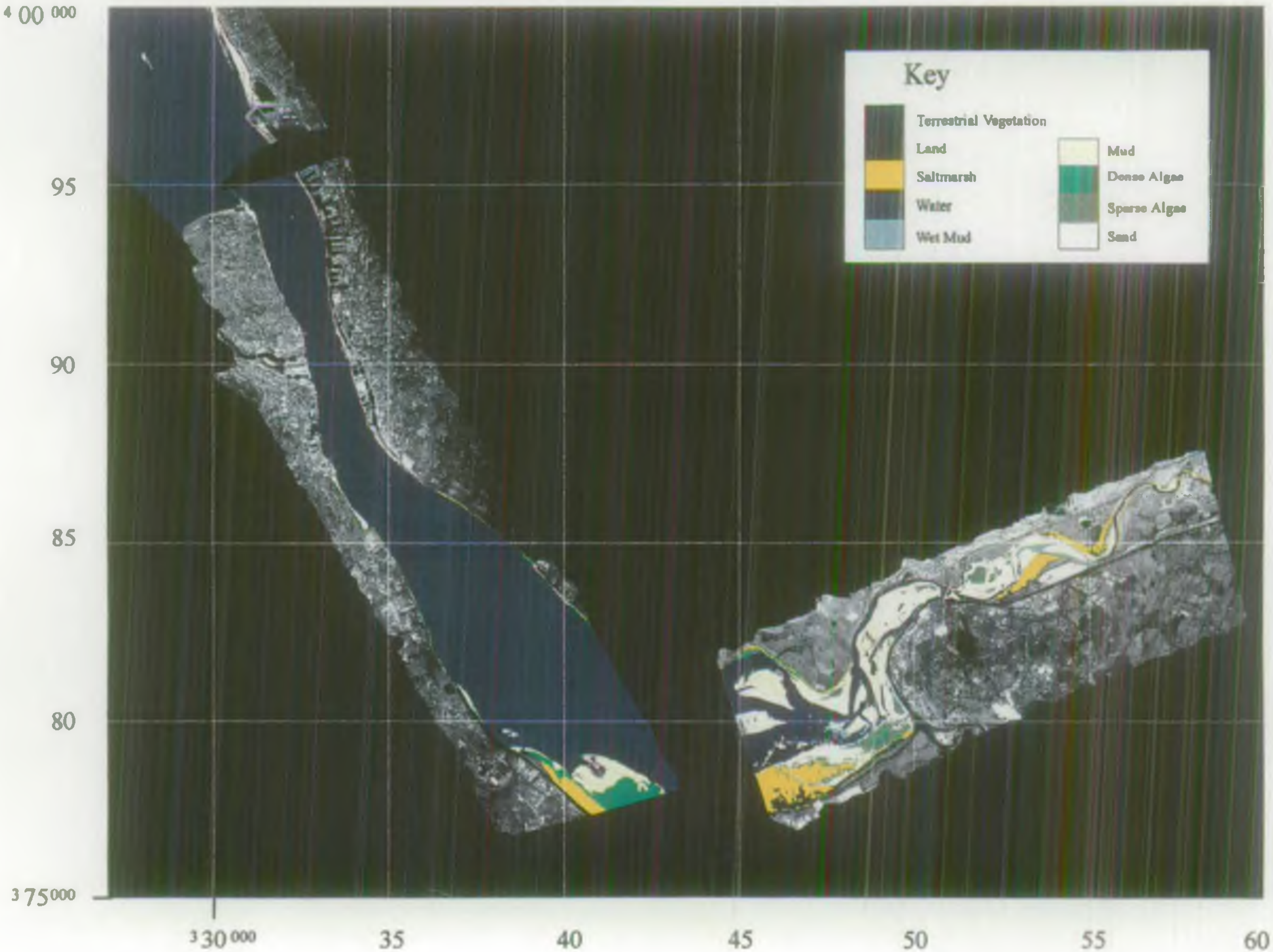
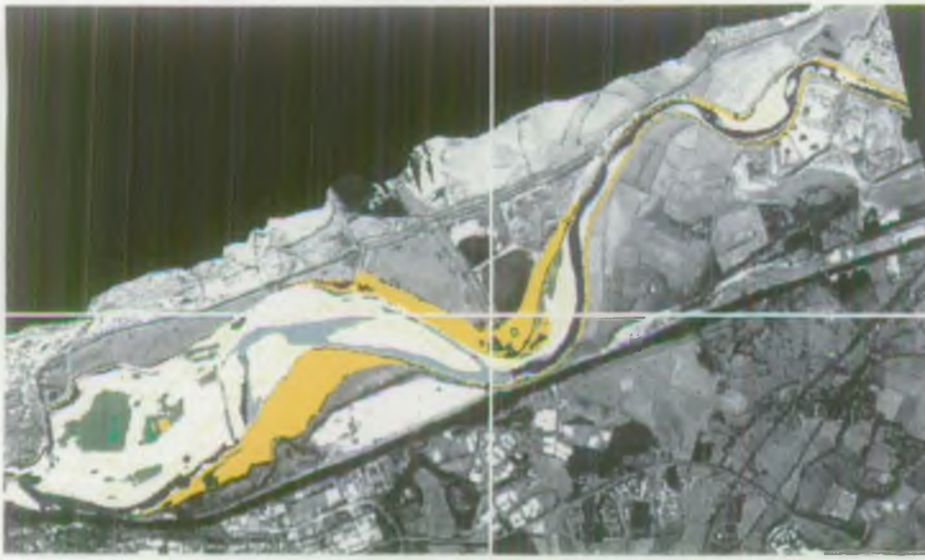
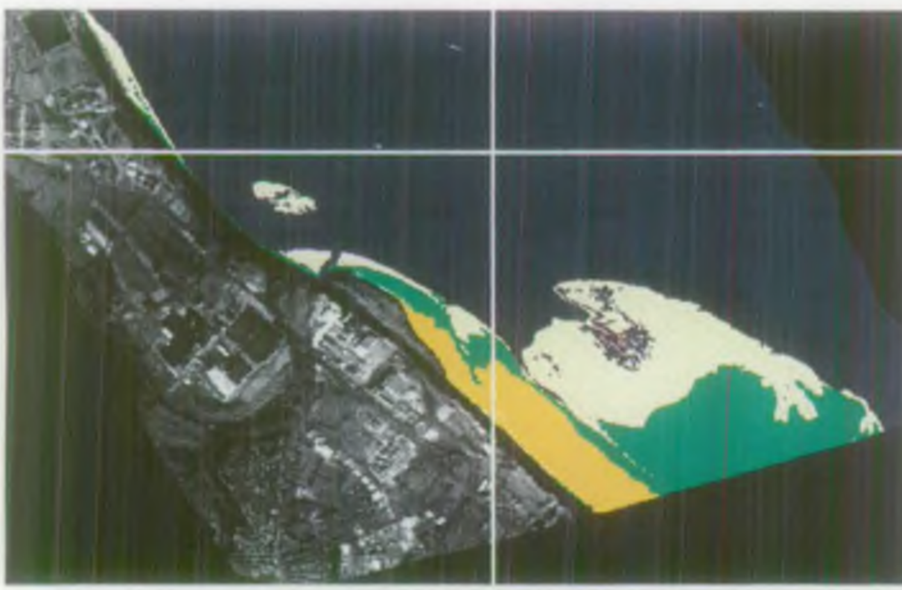


Figure 45



Woolston

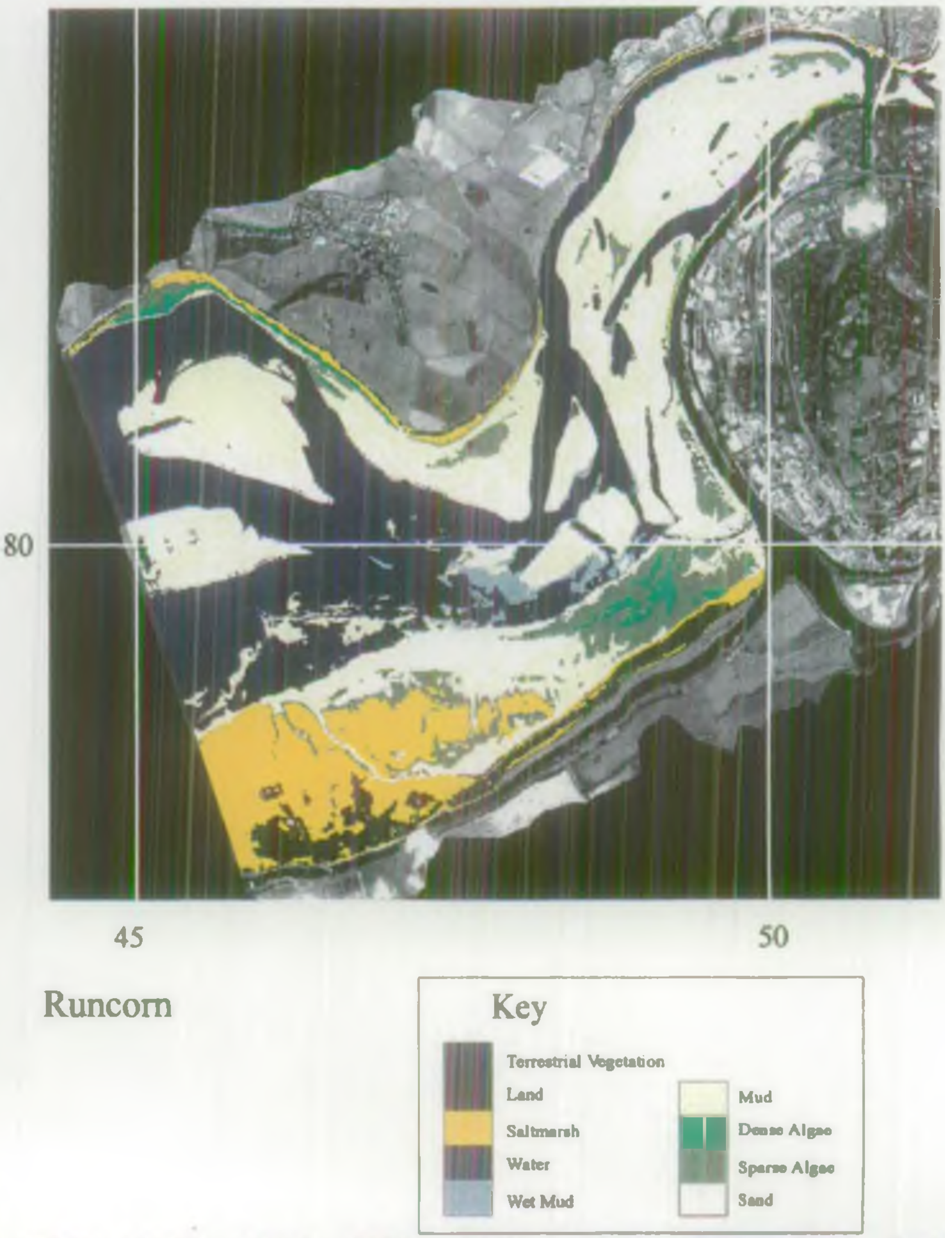


Ellesmere Port

Figure 46

The Mersey estuary
10th October 1995

Unsupervised classification of regions of interest



3.8 MILFORD HAVEN

3.8.1 Background Description

3.8.1.1 Milford Haven is a macro-tidal ria, or drowned river valley, located on the south coast of Wales. The estuary drains the waters of the Eastern and Western Cleddau, which together form the Daugleddau. Downstream this meets with the Carew and Pembroke rivers to form the east-west orientated Milford Haven. The estuarine area is illustrated in Figure 47 which shows the tidal limit on each of the rivers. The figure also marks the locations of Sites of Special Scientific Interest (SSSI).

3.8.1.2 The area has the largest oil refining capacity in Europe, with three major refineries. The passage of oil tankers through this region has resulted in typically about small 20 to 30 oil spills per annum (NRA, 1995*b)*. In addition 1996 saw a major incident in this area involving the Sea Empress oil tanker.

3.8.1.3 Figure 48 shows a mosaic of four CASI images of Milford Haven taken close to low water on 4th August 1996. The imagery shows a narrow inter-tidal zone in the main part of the Haven, with extensive mudflats in the upper reaches of the Eastern and Western Cleddau and the River Carew.

3.8.2 Discussion of major issues

3.8.2.1 Milford Haven is an area of many conflicting pressures from for example, tourism and industry. The Pembrokeshire Coast National Park, of which Milford Haven is part, attracts over 1 million visitors per annum, increasing the population two-fold during the peak of the tourist season. Such land based tourism places pressure on the systems for disposal of sewage to the Haven, and these visitors also make use of the waters of the Haven for a variety of water sports.

3.8.2.2 The general water quality of the estuary is very good, or Class A, when compared against the National Water Council (NWC) Estuary Water Classification Scheme. Localised areas of lower quality are associated with local inputs.

3.8.2.3 Historically, there had been poor aesthetic quality in parts of the Haven, caused by sewage solids and debris and oil remnants, which have also effected floating cage fish farms. This has been addressed by improvements to the treatment at crude sewage treatment works, with one major improvement scheme completed and a further underway.

3.8.2.4 A range of water quality problems may affect the fish farms and shell fisheries in the Haven, including the presence of tri-butyl tin from vessel anti-fouling painting, chemical spillages as well as sewage effluent. In addition, dredging and spoil dumping operations may impact on the sub-littoral flora and fauna in the Haven.

3.8.3 Discharge mixing zones

3.8.3.1 Three oil companies have constructed refineries within Milford Haven, these being Gulf, Elf and Texaco, with this complex having the largest refining capacity in Europe. These refineries discharge treated process water through consented discharges, which are monitored regularly. The other major industrial development is the Pembroke power station, which has consent for the discharge of cooling waters.

3.8.3.2 Figure 49 shows the positions of selected discharges within Milford Haven. Recent upgrades have been applied to the sewage treatment works within the Haven under the provisions of the Urban Waste Water Treatment Directive (91/271/EEC). The two largest sewage effluent discharges are from Neyland sewage treatment works (settled sewage) and Pembroke Dock sewage treatment works (treated sewage).

3.8.3.3 Aerial surveillance was carried out in Milford Haven on 15th July 1996 and 23rd September 1996. The data collected in July are of high quality, but do not show any discharge mixing zones. Thermal differentiation of discharges in July has been shown to be difficult in other estuaries surveyed, due to the warm ambient temperature of estuaries at this time of year. The suspended solids loading of Milford Haven is not high in comparison to some of the other estuaries studied. The difficulty in distinguishing effluent plumes in the imagery is therefore probably due to the application of secondary treatment to many of the discharges, which means that the discharged waters also have low turbidity.

3.8.3.4 The data collected on the 23rd September 1996 show two clearly delineated discharge mixing zones. The positions and extents of these at different tidal states are shown in figure 50.

3.8.3.5 The Texaco Oil Refinery discharge, marked in figure 50, was evident as a thermal plume at 09:00 GMT. The tidal state at this time was slack low water which accounts for the shape of the mixing zone. The warmer water is collecting around the pier structure, in a near circular shape. This discharge is also detected in the CASI imagery collected two hours later at 11:05 GMT. In this case the discharge is characterised by a streak of higher reflectance material which is deflected to the east by the tidal stream. There is no corresponding thermal signal at this time, suggesting that the stronger tidal currents are diffusing the heat more effectively.

3.8.3.6 Thermal influences from this plume are unlikely to have a detrimental effect on the surrounding environment, because of the size and direction of the mixing zones recorded. Data collected throughout the remainder of this day failed to show any significant warming of the region, with waters entering from tributaries and streams having a temperature warmer than that of both the discharge and the ambient temperature of the Haven.

3.8.3.7 The second discharge, from Gulf Oil Refinery, is recorded in thermal imagery at two tidal states. At 07:35 GMT there is a small but distinct thermal signal close to the position of the outfall, with a temperature of 2°C above ambient (see figure 50). Imagery collected 85 minutes later shows that this thermal feature has dispersed to the larger mixing zone shown in figure 50. Tidal flow at this time is slight, with imagery colleted close to slack low water. The mixing zone suggests that there is a slight residual upstream flow at this time. By the time of the next overpass at 11:00 GMT, there is no thermal signature at this site. This suggests that a warmer discharge has been made prior to the collection of the first image, which disperses over the course of the following three hours.

3.8.4 Saltmarsh and beaches

3.8.4.1 Saltmarsh and beaches provide an important defence against coastal flooding by dissipating the tide and wave energy and by providing a physical barrier preventing the passage of water. Saltmarsh is also a diverse habitat, supporting a rich collection of flora and fauna, which in turn provide an important resource for over-wintering of migratory birds.

3.8.4.2 Figure 51 shows a false colour composite image of Milford Haven. In this image, vegetation is represented in red because of its enhanced infrared reflectance. Figure 52 shows a digital classification of the land cover types in the inter-tidal zone of Milford Haven. This has been produced using CASI data collected at low water on 4th August 1996. The classification relies on the variation in the reflectance of different land cover types, with vegetation recording a high infrared reflectance in comparison with that recorded by bare land cover and water. The classification results are shown in table 9.

Land cover classes	Area (ha)	% Cover
Mud	696	36
Wet mud	411	21
Saltmarsh	388	20
Sparse green algae	221	11
Brown algae	151	8
Dense green algae	71	4
Sand	7	0
Total	**1945**	**100**

Table 9: Inter-tidal land cover classification for Milford Haven, 4th August 1996

3.8.4.3 Saltmarsh is shown in the classification as the yellow class, with mud and sand being shown as pale yellow and white respectively. The main areas of saltmarsh are seen in the Pembroke River and the Carew River, with some marsh seen in the Gann Estuary. Saltmarsh is also seen along the banks of the Western and Eastern Cleddau.

3.8.4.4 Figure 53 shows enlargements of the main areas of inter-tidal zone. The largest saltmarsh is in the Pembroke River. This marsh has a typical profile with a region of mud at the seaward edge, which protects the marsh from tidal action. Drainage channels allow the penetration of water throughout the marsh.

3.8.4.5 In the upper reaches of the Cleddau rivers, the marshes form a fringe to the wide expanse of inter-tidal mudflats. The Carew and Cresswell rivers show an intermediate marsh community, with areas of mudflats being the dominant land cover type in reaches of the rivers.

3.8.4.6 The final area of marsh is found in the Gann Estuary. This is a coastal grazing marsh which has recently been recolonised by saltmarsh species (Gee, 1995*d*). This accounts for the presence of small areas of terrestrial vegetation, shown by the classification, within the marsh.

3.8.5 Inter-tidal vegetation

3.8.5.1 Digital classification of land cover in the inter-tidal zone allows the investigation of macro-algae growing on inter-tidal mudflats. The growth of macro-algae on mudflats and beaches can be enhanced in areas of eutrophication. Identification of algal cover therefore provides one basis upon which to assess those estuaries which are potentially Sensitive Areas under the provisions of the Urban Waste Water Treatment Directive (91/271/EEC).

3.8.5.2 The classification of Milford Haven shows large areas of algae on the mudflats (figure 53). The most dense area of green algae is found close to Pembroke Dock to the north of the entrance of the Pembroke River. This site is downstream of the discharge from Pembroke Dock sewage treatment works but it is unlikely that this discharge is influencing the algal growth as secondary treatment is applied.

3.8.5.3 In the upper reaches of the Western Cleddau there is dense green algal cover on the fringes of the saltmarsh. Large areas of sparse cover are seen at the confluence of the Eastern and Western Cleddau.

3.8.5.4 Brown algae are seen at the edge of the main channel between the confluence of the Eastern and Western Cleddau and the mouth of Milford Haven. These algae are growing on the narrow rock region at the shoreline.

3.8.5.5 Brown algae are also seen within the saltmarsh in the Pembroke River. On the mudflats at the toe of this marsh there are green algae, although the cover is mainly sparse, with some dense patches. Sewage effluent discharges into the Pembroke River upstream of this site may be enhancing the algal growth, but ground based studies of the species composition would be required to assess whether this is the case.

3.8.5.6 Sparse algal cover is seen in the Gann Estuary, between the area of wet muds and the saltmarsh. There is one small sewage effluent discharge at this point. The algal growth does not appear to be being enhanced by this discharge.

3.8.5.7 The majority of algal cover is close to the confluence of tributaries and the Haven. It is possible that the increased organic loading of the tributaries, caused by diverse inputs, may be enhancing the growth of algae at these points.

3.8.6 Summary of estuary

3.8.6.1 The aerial surveillance data of Milford Haven collected throughout 1996 has revealed information on the environmental quality of this estuary. The majority of urban and industrial development is in the lower reaches of the estuary, with the upper reaches showing mixed farmland.

3.8.6.2 The data collected close to high water revealed a number of small discharge mixing zones, mainly from the Texaco and Gulf oil terminals (section 3.8.3). These were of warm water, although significant warming was not shown more than 200 m from the discharge source. The estuary has a large number of inputs from adjoining rivers and creeks, which cause high variability in the thermal signal. This means that discharge mixing zones are difficult to distinguish at certain times. Collection of data in winter months may be more useful in the delineation of discharge mixing zones.

3.8.6.3 The saltmarsh of Milford Haven is a key ecological resource, having SSSI status. The spatial extent of the saltmarsh has been accurately mapped in the digital classification, and was measured as 388 ha, some 20% of the land cover of the inter-tidal zone. The digital classification may be integrated into a Geographical Information System (GIS) which would allow spatial changes to be assessed between this survey and future surveys.

3.8.6.4 Recent studies predict an increase in sea level of approximately 37 cm due to global warming (DoE, 1996). This will result in flooding of the present inter-tidal zone, with corresponding loss of saltmarsh. Much of the saltmarsh is in rural regions of the estuary, and the practice of managed retreat should be considered to allow maintenance of this important resource.

3.8.6.5 The digital classification shows a number of regions in Milford Haven to have dense growth of green algae close to sewage effluent discharges. This growth may be enhanced by the presence of many discharges of untreated or primary treated sewage to the estuary. The classification will aid staff in assessing the sensitivity of the region to eutrophication.

3.8.6.6 Global warming will also result in raised temperatures in the south of the UK, with a corresponding increase in tourism (DoE, 1996). South Wales is currently a popular tourist resort, and it is anticipated that this will increase. This may place extra pressures on the sewage disposal systems of the Milford Haven waterway, potentially increasing eutrophication in the estuary.

3.8.6.7 The algal growth may additionally have been affected by the Sea Empress oil spill in February. Regional studies are being carried out to assess whether the algal communities, both in the inter-tidal zone and within the water column, have been affected by the incident. The classification may be used as a basis against which to compare data collected in future years.

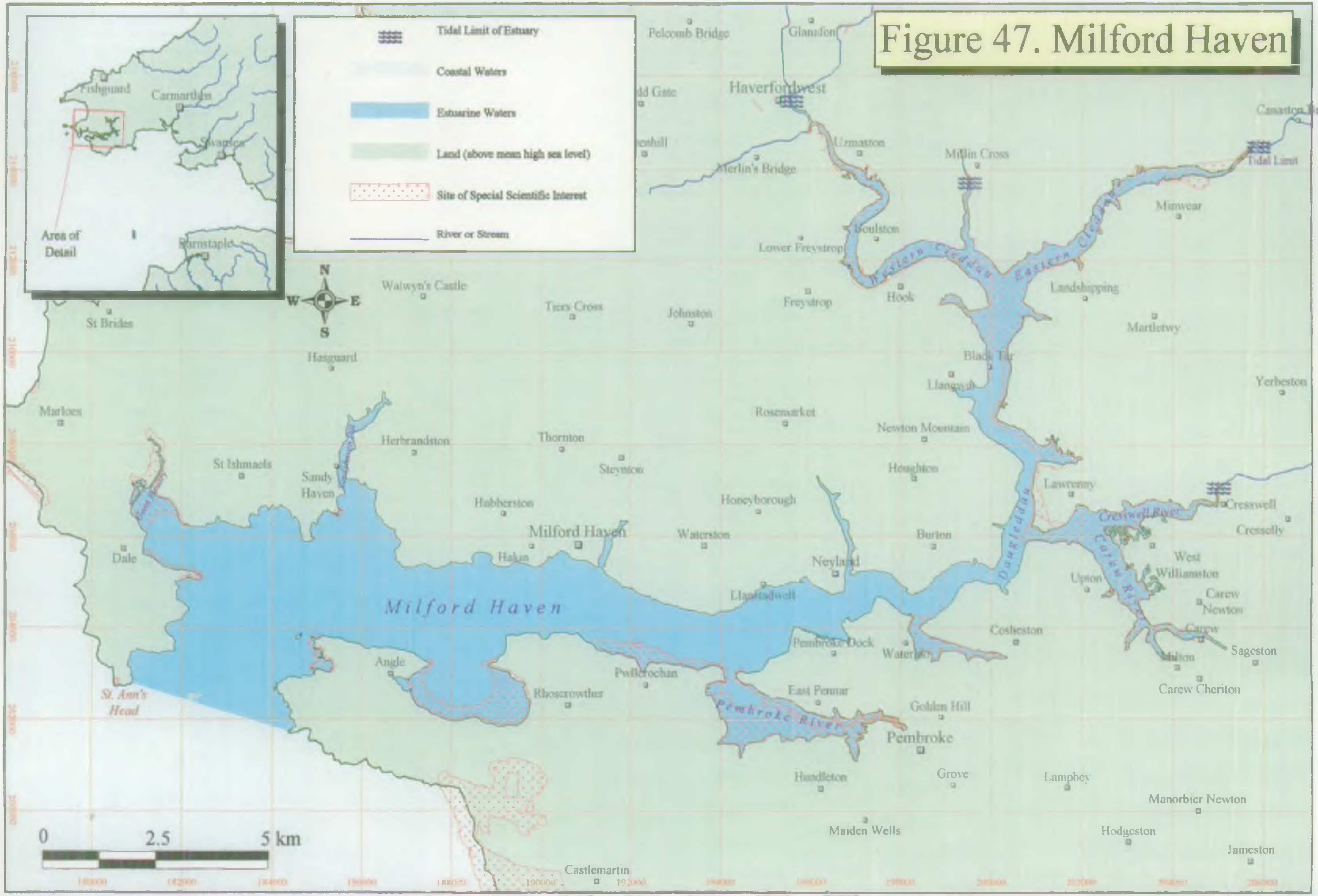


Figure 47. Milford Haven
Tidal Limit of Estuary
Coastal Waters
Estuarine Waters
Land (above mean high sea level)
Site of Special Scientific Interest
River or Stream
Area of Detail
Fishguard
Carmarthen
Swansea
Barnstaple
N
S
E
W
Pelcomb Bridge
Glanrhyd
Haverfordwest
Uzmaston
Merlin's Bridge
Millin Cross
Canaston Br
Tidal Limit
Minwear
Boulston
Lower Freystrop
Western Cleddau
Eastern Cleddau
Hook
Freystrop
Landshipping
Martletwy
Walwyn's Castle
Tiers Cross
Johnston
St Brides
Hasguard
Black Tar
Llangwm
Yerbeston
Marloes
Rosemarket
Newton Mountain
Herbrandston
Thornton
St Ishmaels
Sandy Haven
Steynton
Houghton
Lawrenny
Hubberston
Honeyborough
Cresswell
Cresswell River
Cresselly
Dale
Milford Haven
Waterston
Burton
Daugleddau
Hakin
Neyland
West Williamston
Upton
Carew River
Carew Newton
Llanstadwell
Cosheston
Carew
Sageston
Pembroke Dock
Waterloo
Milton
Carew Cheriton
Angle
Pwllcrochan
East Pennar
St. Ann's Head
Rhoscrowther
Golden Hill
Pembroke River
Pembroke
Hundleton
Grove
Lamphey
Manorbier Newton
Maiden Wells
Hodgeston
Jameston
Castlemartin
0
2.5
5 km

Milford Haven
4th August 1996, Low Water

A true colour composite of four CASI images

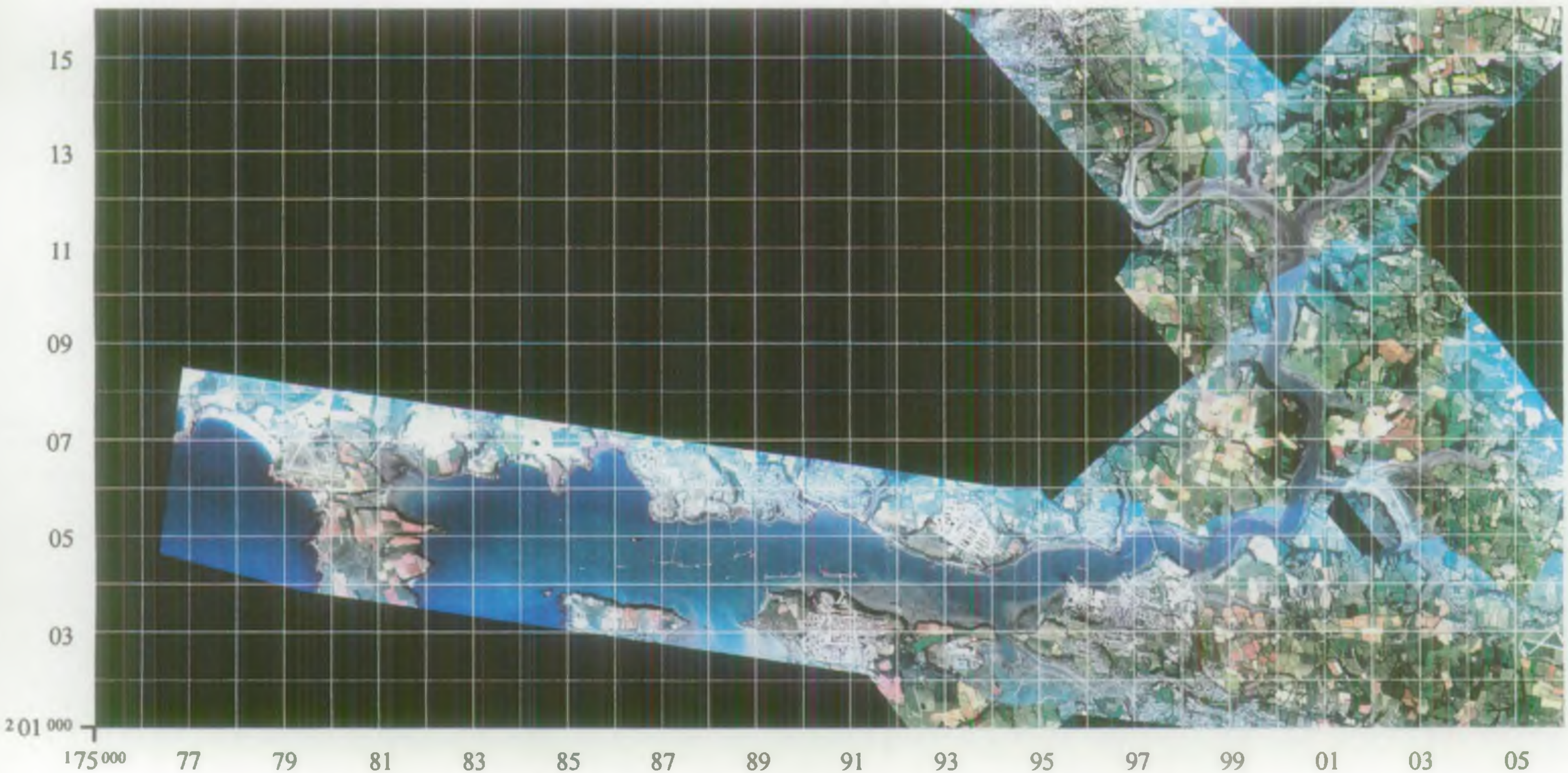
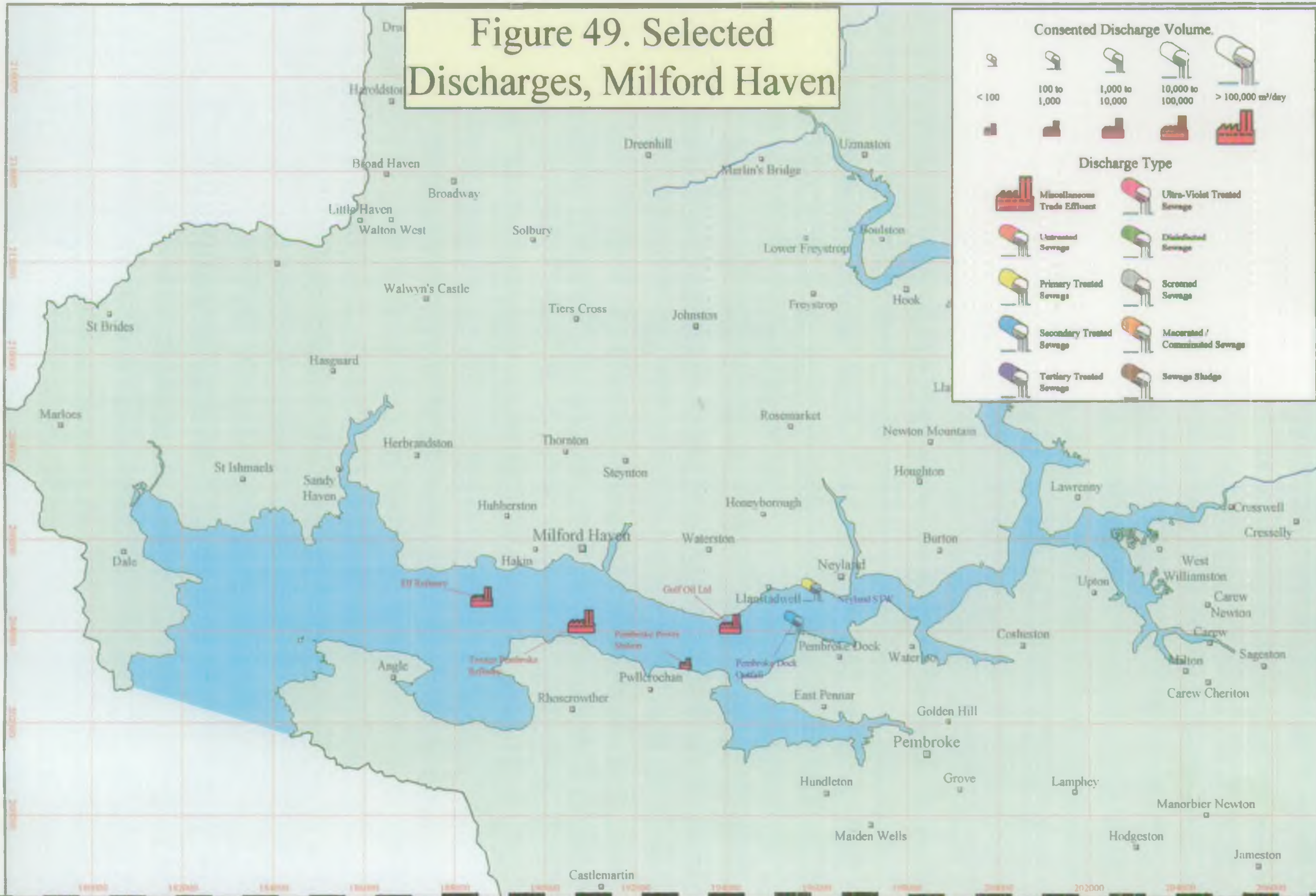


Figure 48

Figure 49. Selected Discharges, Milford Haven



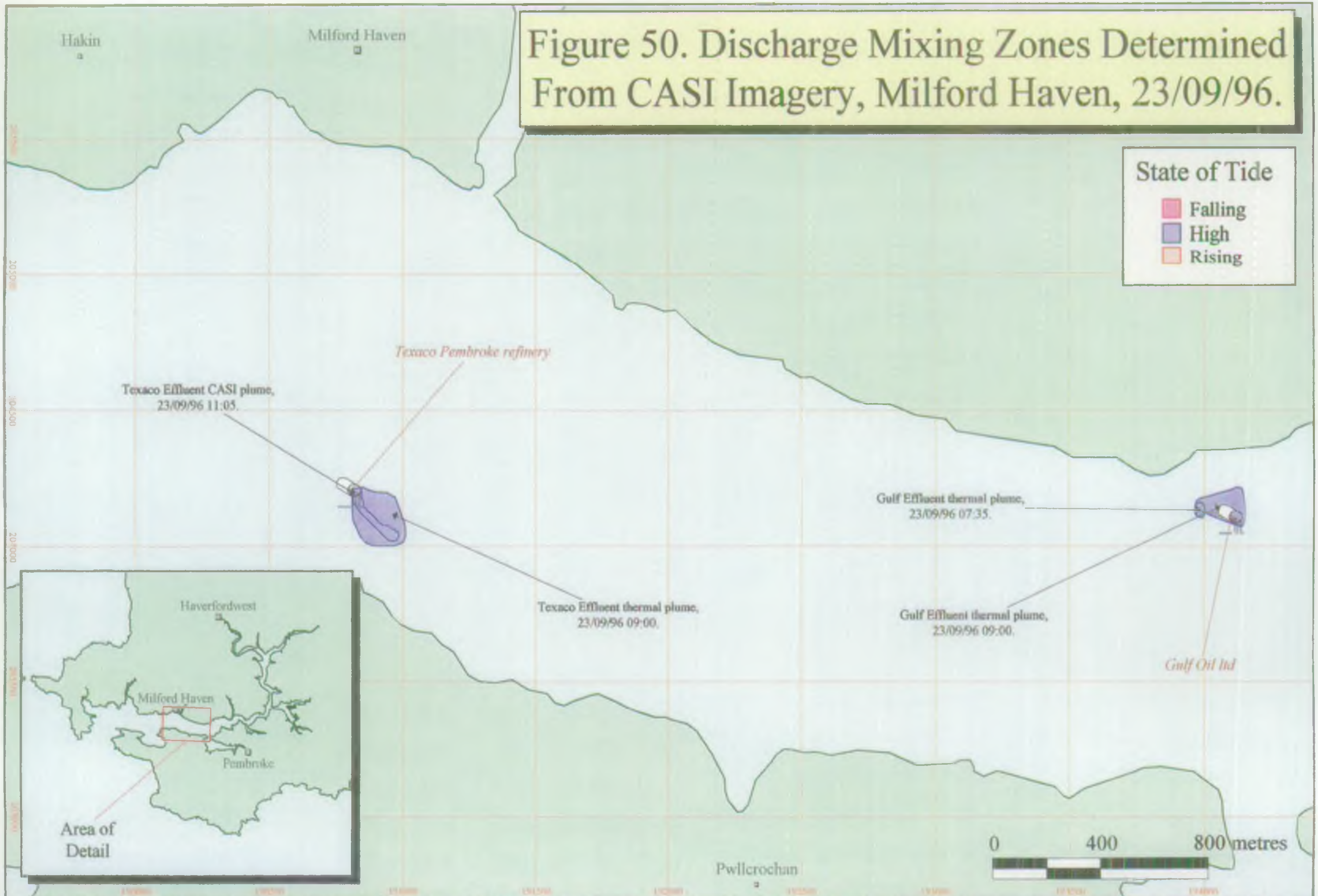


Figure 50. Discharge Mixing Zones Determined From CASI Imagery, Milford Haven, 23/09/96.

Milford Haven
4th August 1996, Low Water

A false colour composite of four CASI images

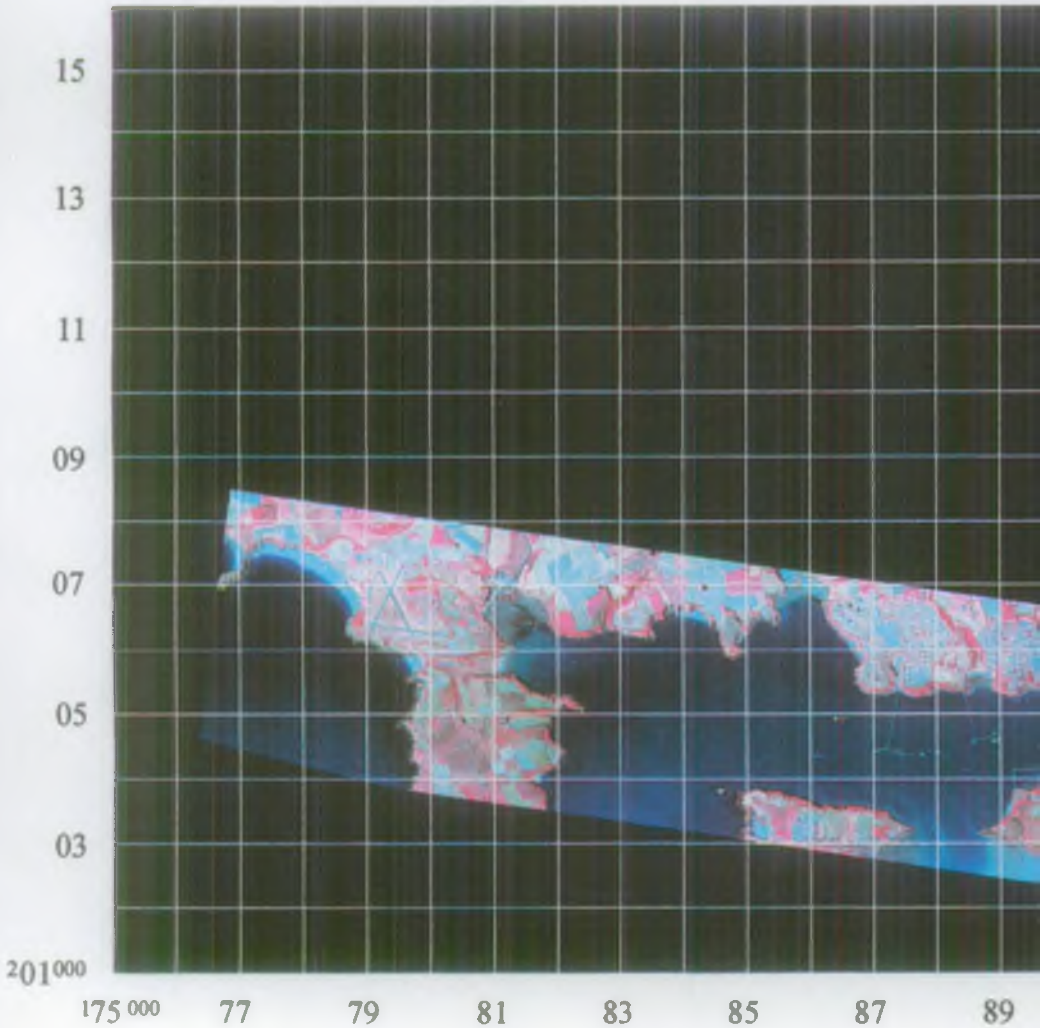
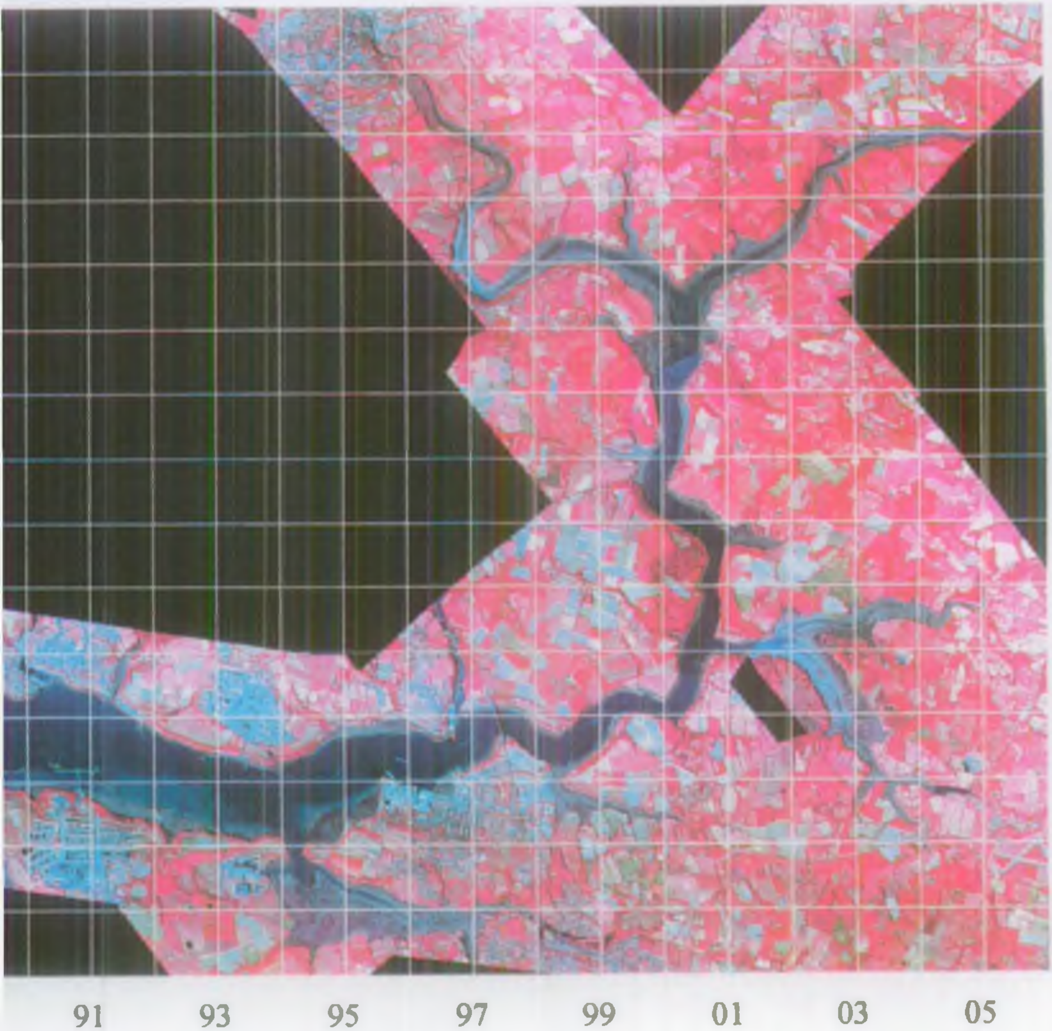


Figure 51



91
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Milford Haven
4th August 1996, Low Water

Unsupervised classification of inter-tidal areas

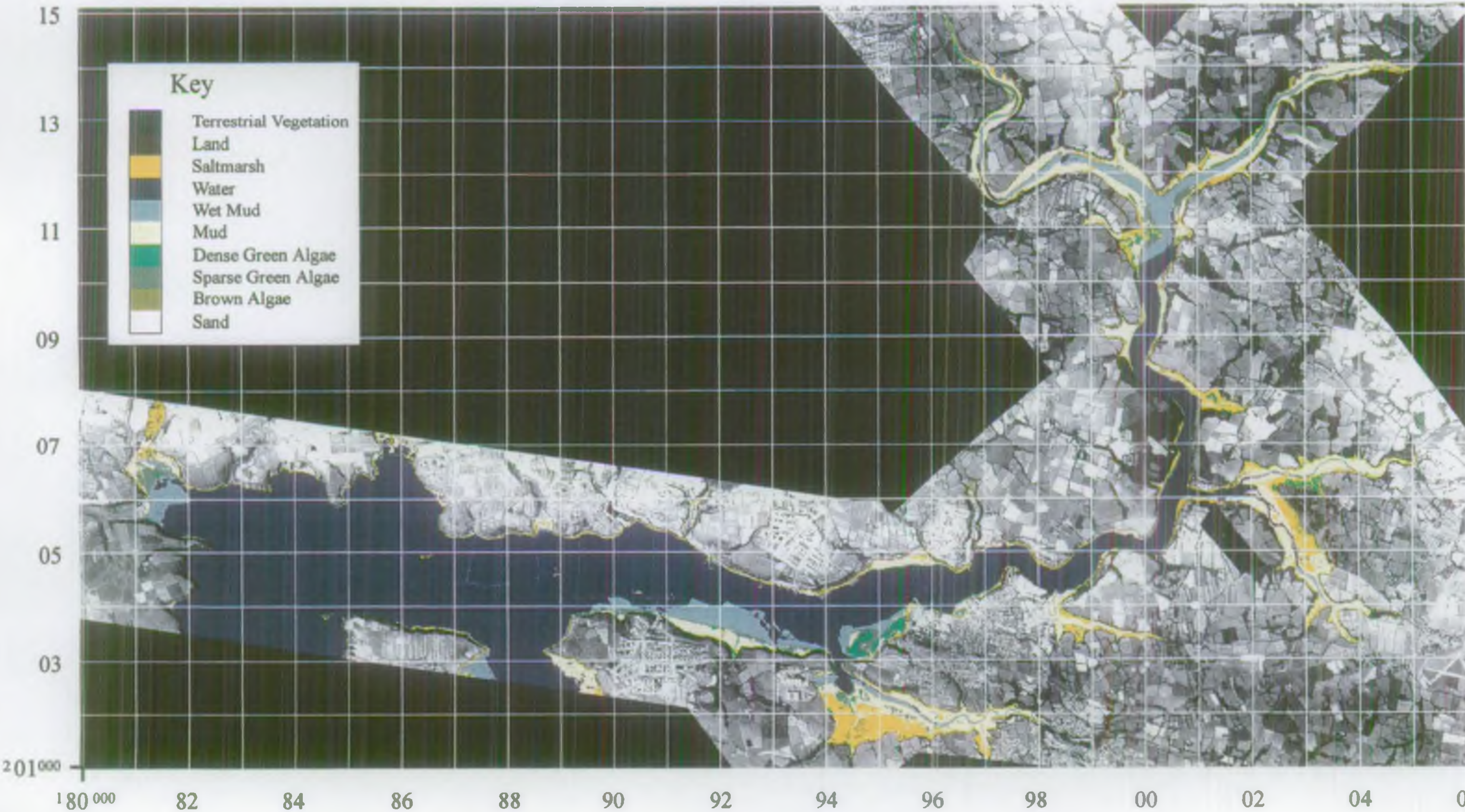


Figure 52

Milford Haven
4th August 1996, Low Water

Unsupervised classification - regions of interest

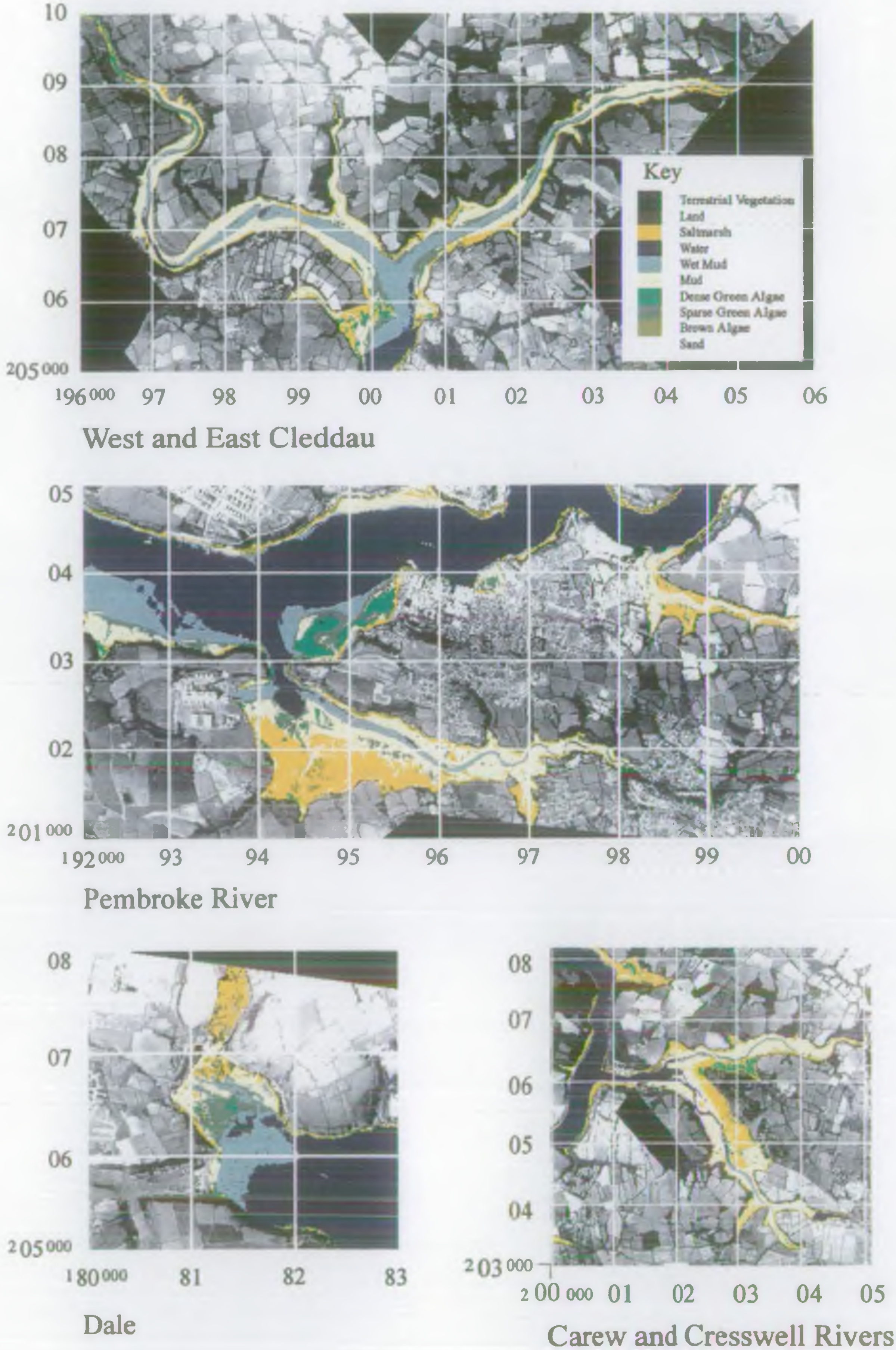


Figure 53

3.9 POOLE HARBOUR

3.9.1 Background Description

3.9.1.1 Poole Harbour is one of the largest and shallowest natural harbours in the world, with an area of 3800 ha at high water spring tides. Inter-tidal mudflats, sandflats and marshes are a key resource, accounting for some 80% of this area at low water. The estuarine area under consideration in shown in figure 54. This figure also shows the Sites of Special Scientific Interest (SSSI) within Poole Harbour. Much of the southerly shore has this designation.

3.9.1.2 Figure 55 illustrates a mosaic of CASI images flown close to low water in August 1996, which shows the extent of the inter-tidal zone. Saltmarshes are seen, particularly to the west of the harbour, with inter-tidal mudflats in other parts of the harbour.

3.9.1.3 The area has low industrial development, with the majority of industry within the catchment being linked with agriculture, forestry and fisheries. The major centre for both urban and industrial development is the north shore of the harbour, around the town of Poole.

3.9.2 Discussion of major issues

3.9.2.1 Poole Harbour is of exceptional ecological value and is protected by many conservation designations, for example as a Site of Special Scientific Interest (SSSI) and as a proposed RAMSAR site, under the Convention on Wetlands of International Importance. The ecological value is centred around the inter-tidal zone, with important saltmarshes, mudflats and sandflats. Additionally, the diversity of shoreline is marked, ranging from reed and marsh to sand and shingle.

3.9.2.2 Under the provisions of the Urban Waste Water Treatment Directive (91/271/EEC), Poole Harbour is being studied to establish whether the area is eutrophic and should be defined as a Sensitive Area. There is one direct qualifying discharge, from Poole sewage treatment works located within Holes Bay, and two further indirect discharges, which may have an influence on eutrophication in the region (NRA, 1995*c*).

3.9.2.3 In order to identify the sensitivity of the region, studies are concentrating on the growth of macro-algae on mudflats, particularly within Holes Bay. Techniques include a combination of ground truth surveys and aerial remote sensing. Surveys have been carried out in both 1995 and 1996, the results of which will be compared in section 3.9.5.

3.9.2.4 A number of EC Directives are applicable within Poole Harbour. There have been no failures to meet the standards required by the EC Dangerous Substances

Directive in recent years. There have been some cases of non-compliance with the EC Shellfish Water Directive, which are currently under internal investigation.

3.9.3 Discharge mixing zones

3.9.3.1 Figure 56 shows the positions of selected consented trade and sewage effluent discharges in Poole Harbour. Trade effluent discharges within the harbour are generally small having consented volumes of less than 10,000 m^3/day. The majority of these are close to Poole on the north shore. Those on the south shore are associated with oil extraction.

3.9.3.2 The largest sewage discharge into Poole Harbour is from Poole sewage treatment works. Recent amendments to this consent have altered this to a biologically treated sewage effluent discharge, as this discharge, into a tributary of Holes Bay, is prompting the study of Poole Harbour as a potentially Sensitive Area under the Urban Waste Water Treatment Directive (91/271/EEC).

3.9.3.3 Poole Harbour was surveyed at high water on 16th June 1996, in a series of three flightlines. Both the CASI and thermal image data were of good quality, in terms of the cloud cover and glint within the images. However, none of the consented discharges were visible in the imagery.

3.9.3.4 It is probable that the aerial surveillance data failed to show these discharges because of the small consented volumes of each of the discharges. Additionally, data were only collected at Poole on one tidal state due to meteorological constraints. Releases of effluent may have been made on the falling tide to aid in dispersion.

3.9.3.5 Although data collected during June from other estuaries showed the presence of clear discharge mixing zones in the thermal data, a combination a factors may have resulted in early seasonal warming of this harbour. Firstly, the harbour is located on the south coast of England, and experiences warmer temperatures than those estuaries to the north. Secondly, the enclosed nature of the harbour and the shallow water within will have allowed warming by insolation to be more effective. It is possible therefore that further data collection, earlier in the year, may have revealed the presence of the discharges.

3.9.3.6 The high suspended solids loading of Poole Harbour and the shallow water depth will enhance the signal received at the CASI sensor. This will make the differentiation of mixing zones in the CASI imagery more difficult as discharged effluent will generally be high is suspended solids.

3.9.4 Saltmarsh and beaches

3.9.4.1 Saltmarsh and beaches constitute an important inter-tidal resource by acting as a barrier to coastal flooding, both by dissipating the wave and tidal energy and by providing a physical barrier. Additionally, the marshes provide a diverse habitat for many species, and provide a haven for migratory birds.

3.9.4.2 Poole Harbour is a highly important saltmarsh resource. It is both a proposed Special Protection Area under the EC Birds Directive and a proposed RAMSAR site in recognition of its international wetland importance.

3.9.4.3 A digital classification of the CASI imagery was carried out to delineate the extent of the saltmarsh and beaches within Poole Harbour. The imagery was collected at low water spring tides and illustrates the full extent of the inter-tidal zone. The results of this classification are shown in figure 59, with the statistics summarised in table 10. Table 10 also includes statistics from a similar survey carried out in 1995. The two sets of imagery were collected at slightly different tidal states in 1995 and 1996, resulting in the different inter-tidal area. Additionally, a null class has been added to the 1996 data to allow for the gaps in the aerial data (see figure 59). The digital classification for 1995 is shown in figure 58.

Land Cover Class	Area (ha) 1995	% Cover 1995	Area (ha) 1996	% Cover 1996
Mud	2032	75	1215	49
Saltmarsh	540	20	649	26
Submerged green algae	0	0	146	6
Dense green algae	88	3	141	6
Medium green algae	0	0	24	1
Sparse green algae	8	0.5	14	0.5
Sand	37	1.5	12	0.5
Null	0	0	259	11
Total	**2705**	**100**	**2460**	**100**

Table 10: Inter-tidal land cover classification in Poole Harbour in 1995 and 1996

3.9.4.4 The main areas of saltmarsh are located to the west of the harbour and within Holes Bay and Lytchett Bay. In each region, the saltmarsh is mainly concentrated on the western shore, for example around Wareham Channel and Wych Channel.

There are small areas of saltmarsh to the south of the harbour, although in this region the terrestrial vegetation extends almost to the edge of the mudflats

3.9.4.5 To the north of the harbour, around the conurbation of Poole, the shoreline is artificial, although there are small areas of inter-tidal mudflats.

3.9.4.6 The 1995 data shows the same areas of saltmarsh vegetation, implying that the saltmarshes are stable. Mudflats around Poole town are not visible in the 1995 classification because of the change in water level between the two sets of imagery.

3.9.4.7 Enlargements of the main areas of saltmarsh are shown in figures 60 and 61 for both 1995 and 1996. The saltmarsh in Holes Bay is well established with a network of drainage channels. Channels are less evident in the saltmarsh around Round Island, although this may be due to the pixel resolution of the CASI, which may be too coarse to detect narrow drainage channels.

3.9.4.8 The Wareham Channel region showed a large area of saltmarsh vegetation. In 1995, this area was classified as partially terrestrial vegetation. This signifies that the area is probably well established.

3.9.5 Inter-tidal vegetation

3.9.5.1 The importance of the inter-tidal region in Poole Harbour has been stated above. There is concern that there may be an increase in certain species of inter-tidal vegetation in the region due to discharges from sewage treatment works within the harbour, in particular within Holes Bay. This would result in Poole Harbour being declared a Sensitive Area under the provisions of the Urban Waste Water Treatment Directive. A detailed study of the inter-tidal vegetation using a combination of ground truth surveys and the digital classification of multispectral imagery has been carried out in 1995 and 1996.

3.9.5.2 The digital classifications for 1995 and 1996 (figures 58 and 59) identify the presence of substantial quantities of macro-algae on the mudflats of Poole Harbour, shown as the dark green class, in addition to areas of more sparse algae.

3.9.5.3 Dense algae is seen to the west of the harbour on the marshes surrounding Wareham Channel. This is shown in more detail in figures 60 and 61. The algae is concentrated within the water channels of the mudflats. Ground truth studies have not identified the algae due to tidal constraints, although information from local experts supports the existence of algae in this area. Two sewage effluent outfalls discharge to this area (see figure 56), which may be enhancing the algal growth in this region.

3.9.5.4 In Lytchett Bay, the 1996 data show the presence of sparse algae to the north of the bay where no algae was identified in 1995. There is no ground truth data from this region to identify the type of algal cover.

3.9.5.5 Figure 60 and 61 show enlargements of the classification for the Holes Bay region in both 1995 and 1996. This region has been identified as potentially eutrophic due to the effects of the sewage outfall to the bay (see figure 56). The classification shows that the areas of saltmarsh are constant between the two images, but the algal cover has changed between the times of the two surveys.

3.9.5.6 The algal cover to the east of the central marsh is greater in 1996 than in 1995, and some dense algae is also found to the west of this marsh. Similarly, there is more dense algal cover in the channels within the western saltmarsh. Ground truth surveys identified this algae as mainly *Ulva* with some *Enteromorpha*. These surveys also identified rock armouring by *Enteromorpha* along the eastern shore.

3.9.5.7 At the south of the bay there is a further small private discharge. Algal cover was recorded here in the 1996 data. Observation of the false colour composite image of the area shows this to be extensive, although the classification may underestimate the cover due to image quality. Ground truth data showed this to be *Ulva* with some *Enteromorpha*. During the 1995 aerial survey this area was submerged and therefore no algae was identified.

3.9.5.8 Figure 60 and 61 show enlargements of the Round Island region of Poole Harbour, which shows increased algal growth in 1996 compared with 1995. Ground truth data shows that this algae was again mainly *Enteromorpha* and *Ulva*. The 1996 data also shows the presence of submerged algae on the mudflats in regions which were obscured by deeper water in 1995. Ground truth data from both years confirmed the presence of this submerged algae.

3.9.5.9 To the north of the harbour there is extensive artificial shoreline associated with Poole town. The 1996 classification shows submerged algal growth on the narrow mudflats adjacent to this. Additionally, there are small patches of dense algal growth within the Blue Lagoon. These were noted in ground truth studies in 1995, but the area was submerged when the aerial survey was carried out.

3.9.5.10 Although direct comparison of the percentage coverage by algae between the two years is made difficult by the differing inter-tidal areas, in is clear that the coverage by algae has increased between 1995 and 1996 in many of the areas surveyed. There is no direct evidence to link this with sewage treatment works, although the high coverage close to Poole sewage treatment works would suggest a link. Changes to the discharge consent of this works implemented in September 1996 may result in a decrease in algal cover in future years.

3.9.6 Summary of estuary

3.9.6.1 The aerial surveillance data of Poole Harbour collected at both high and low water reveals information on the environmental quality of this ecologically important estuary. The land use of the estuary shoreline is predominantly rural, with much of the southern shoreline having protected SSSI status.

3.9.6.2 The consented discharges to this harbour did not record mixing zones with either a thermal or colour signal that could be detected from the aerial techniques. This may be due to the small consented volumes, although further data collection would be required to verify this.

3.9.6.3 The important saltmarsh resource of Poole Harbour has been mapped using digital classification techniques in both 1995 and 1996. This has shown there to be little change in the position and extent of the marshes. This information may provide a baseline for comparison with future data in order to continually monitor these marshes. More detailed classifications of the species composition of the marshes could be carried out if required, with the aid of ground truth studies.

3.6.6.4 The digital classification has also revealed the presence of algal cover on inter-tidal mudflats. Some regions of Poole Harbour have shown increases in algal cover between 1995 and 1996. This may be linked to the discharge of sewage effluent within the harbour. Integration of this data with the detailed ground truth studies, collected by Regional staff will allow a decision to be made on the sensitivity of this harbour to eutrophication.

3.6.6.5 Recent studies predict an increase in sea level due to global warming of 37 cm on average across the United Kingdom (DoE,1996). The southerly position of Poole Harbour will further exacerbate this. The results of sea level rise will be increased flooding of the existing inter-tidal zone. It is not possible to make any broad conclusions on the effects of this on the sensitive saltmarsh areas within Poole Harbour, because of the complex nature of the estuary.

3.6.6.6 A further result of global warming will be an increase in the temperature of southern England. It is anticipated that this will increase tourism in this region (DoE, 1996). This may put extra pressures on the beach infra-structure of the harbour, as well as affecting the water quality by increasing inputs of sewage effluent.

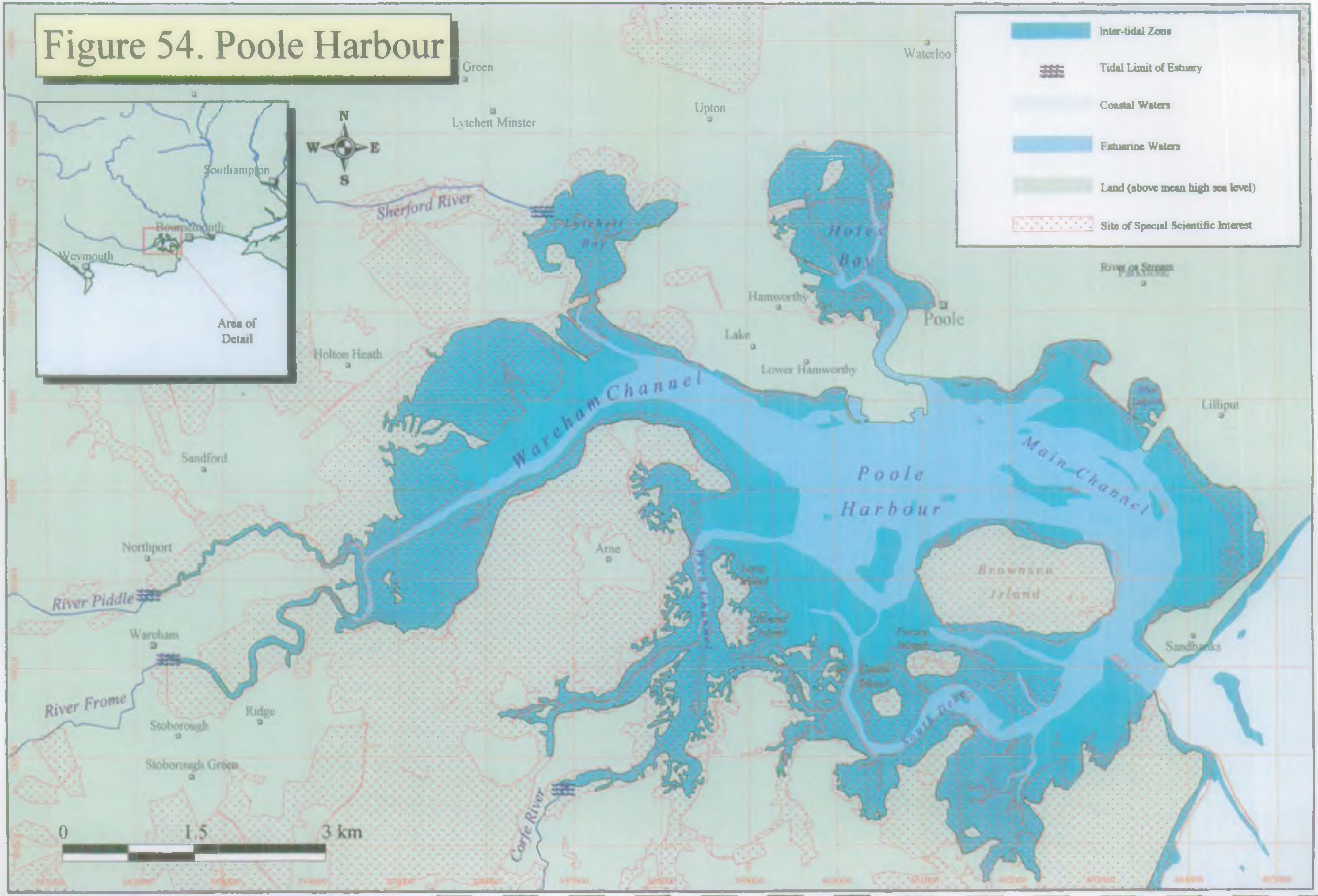


Figure 54. Poole Harbour
Inter-tidal Zone
Tidal Limit of Estuary
Coastal Waters
Estuarine Waters
Land (above mean high sea level)
Site of Special Scientific Interest
River or Stream
Southampton
Bournemouth
Weymouth
Area of Detail
N
S
W
E
Green
Lytchett Minster
Upton
Waterloo
Sherford River
Holes Bay
Hamworthy
Poole
Lake
Lower Hamworthy
Holton Heath
Wareham Channel
Poole Harbour
Main Channel
Lilliput
Sandford
Northport
Arne
River Piddle
Wareham
River Frome
Ridge
Stoborough
Stoborough Green
Brownsea Island
Sandbanks
Corfe River
0
1.5
3 km

Poole Harbour
3rd August 1996
Low Water

True colour composite of nine CASI images

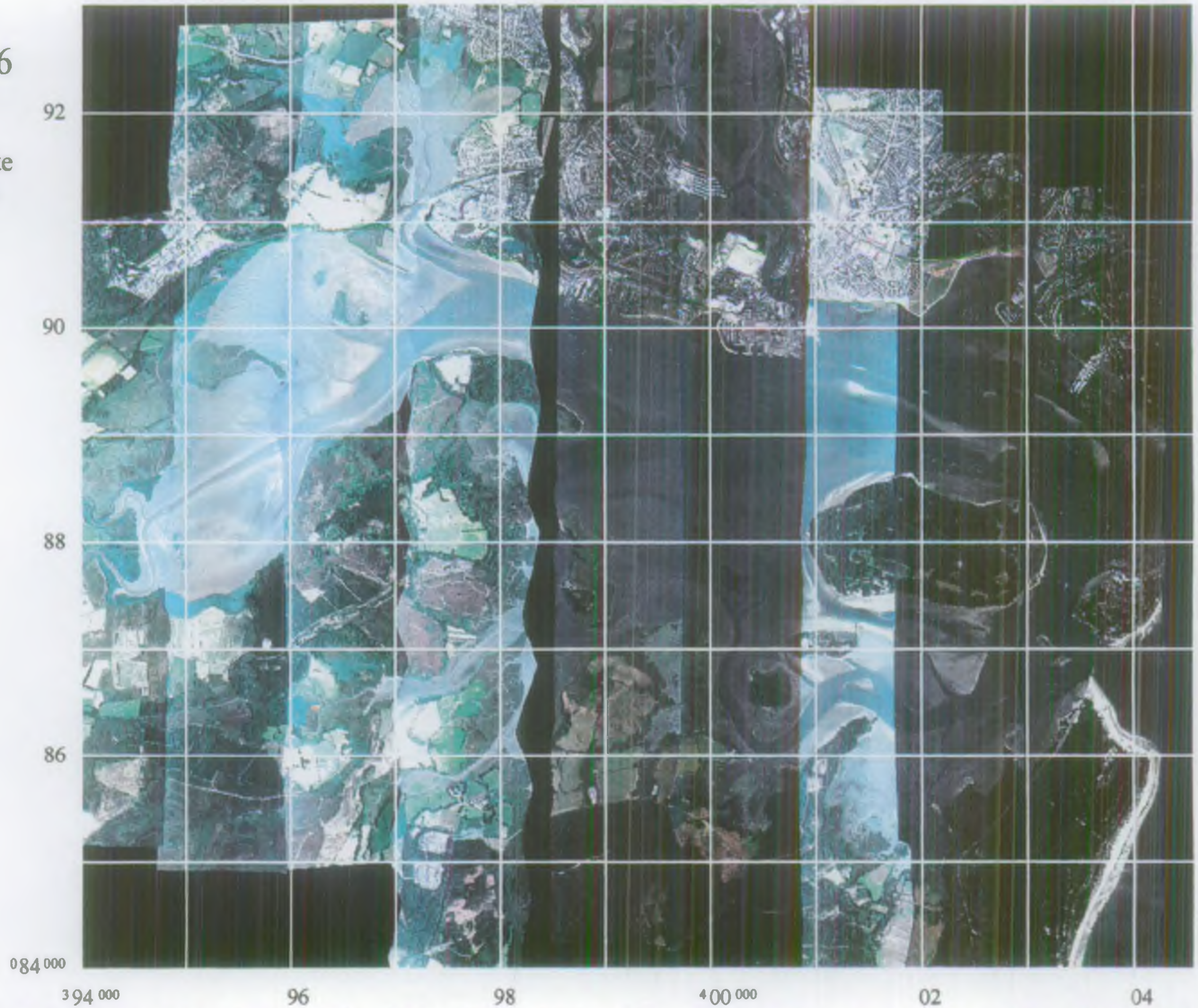


Figure 55

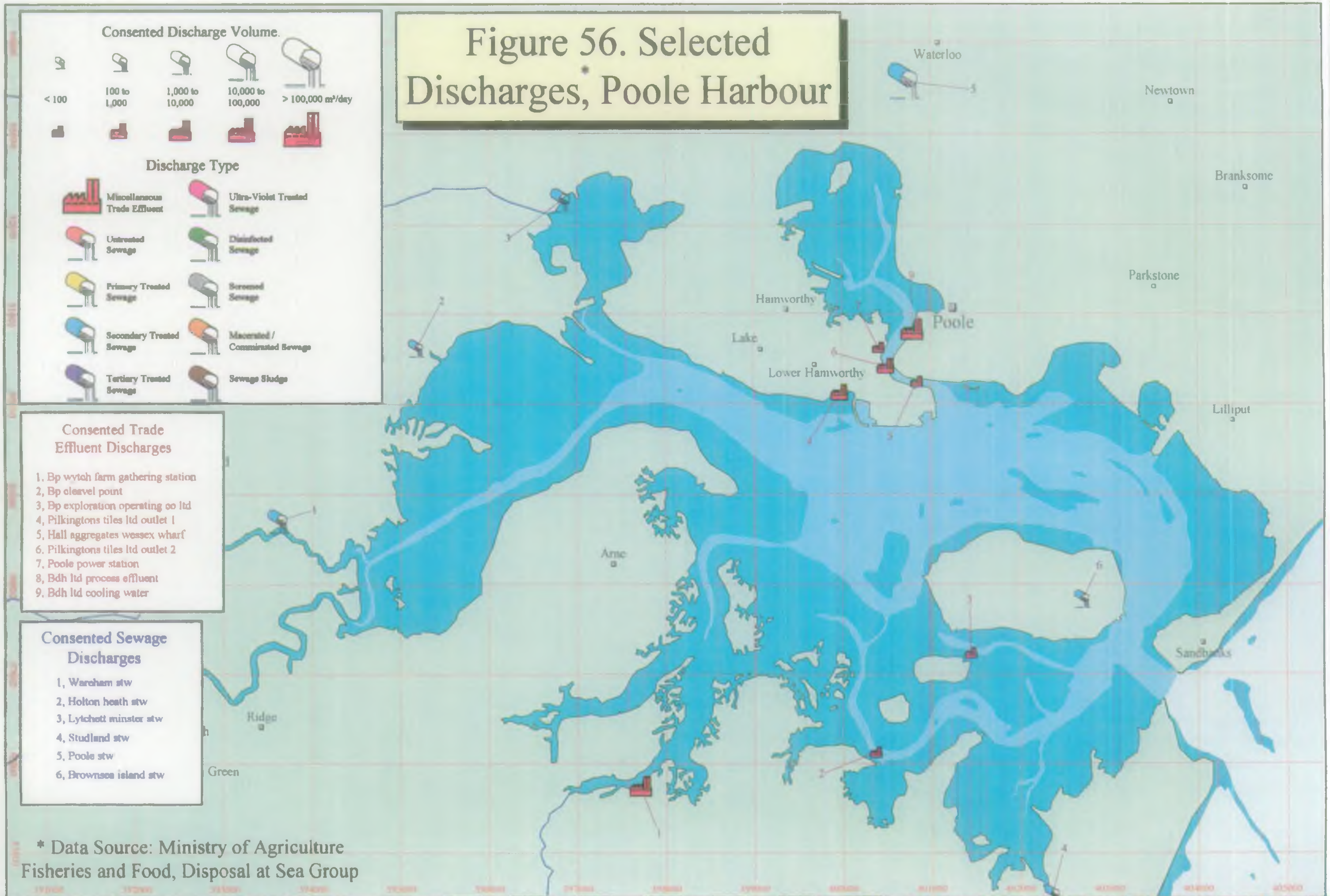


Figure 56. Selected Discharges, Poole Harbour

Poole Harbour
3rd August 1996
Low Water

False colour composite of nine CASI images

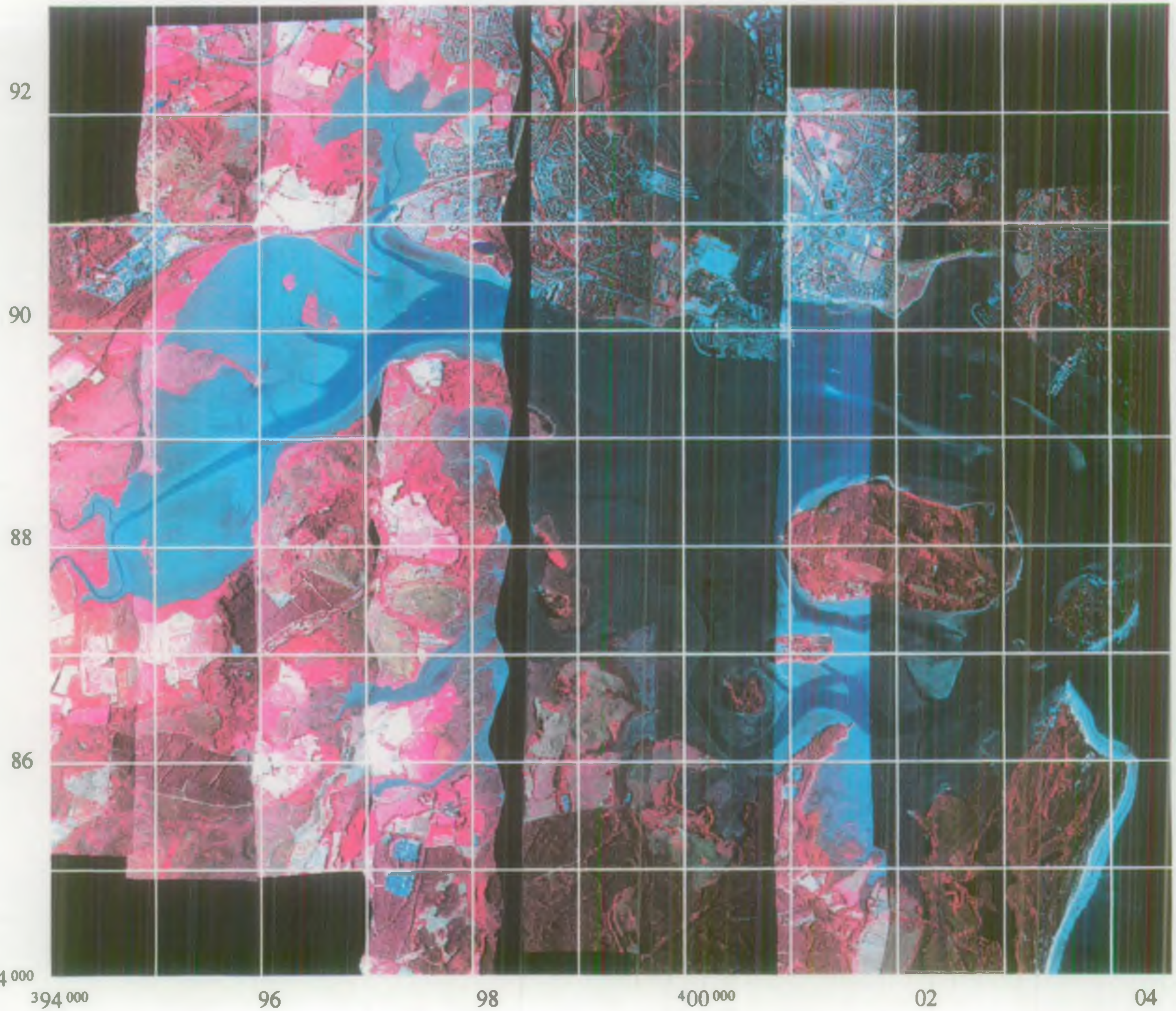
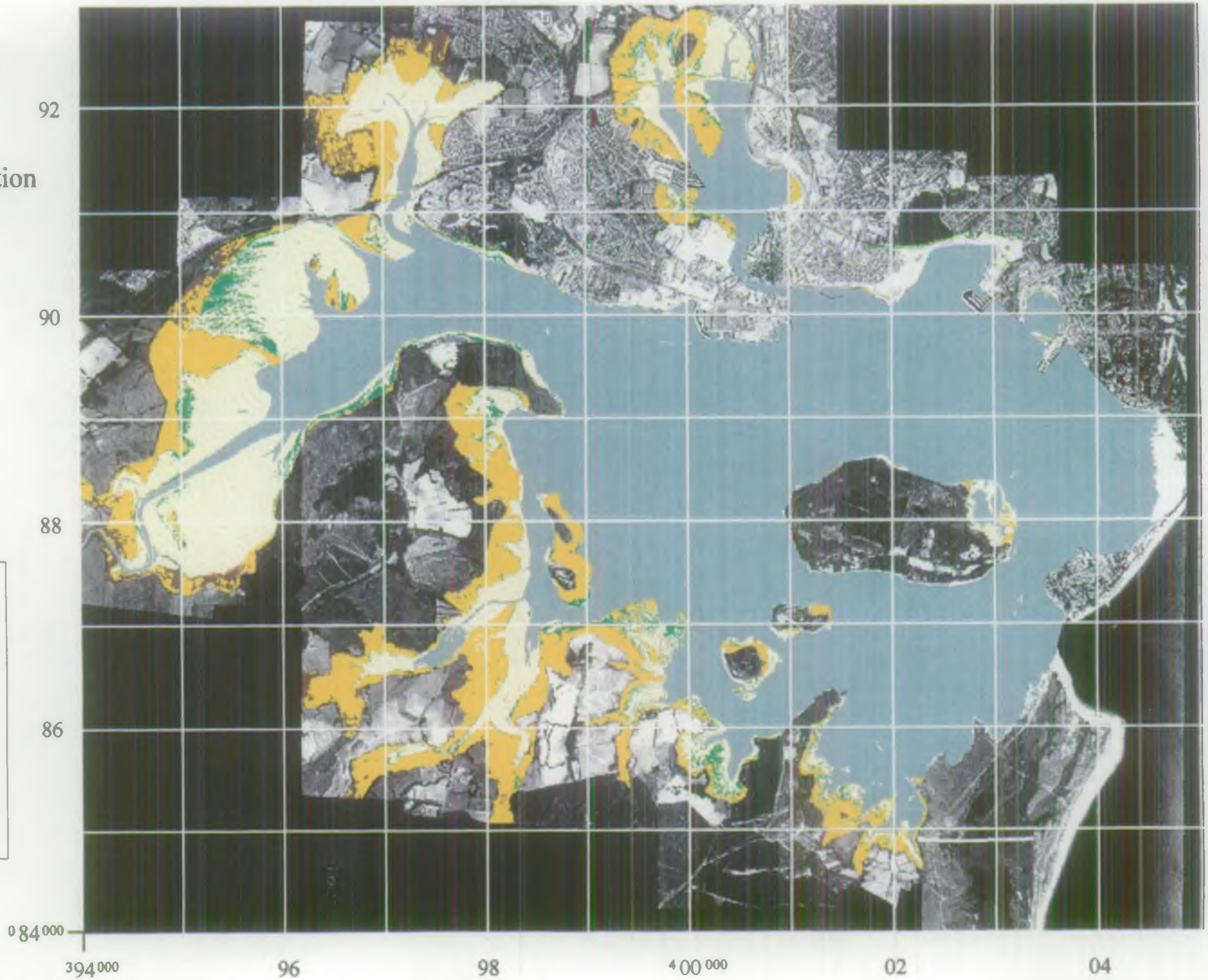


Figure 57

Poole Harbour
14th August 1995
Low Water

Unsupervised classification of inter-tidal areas



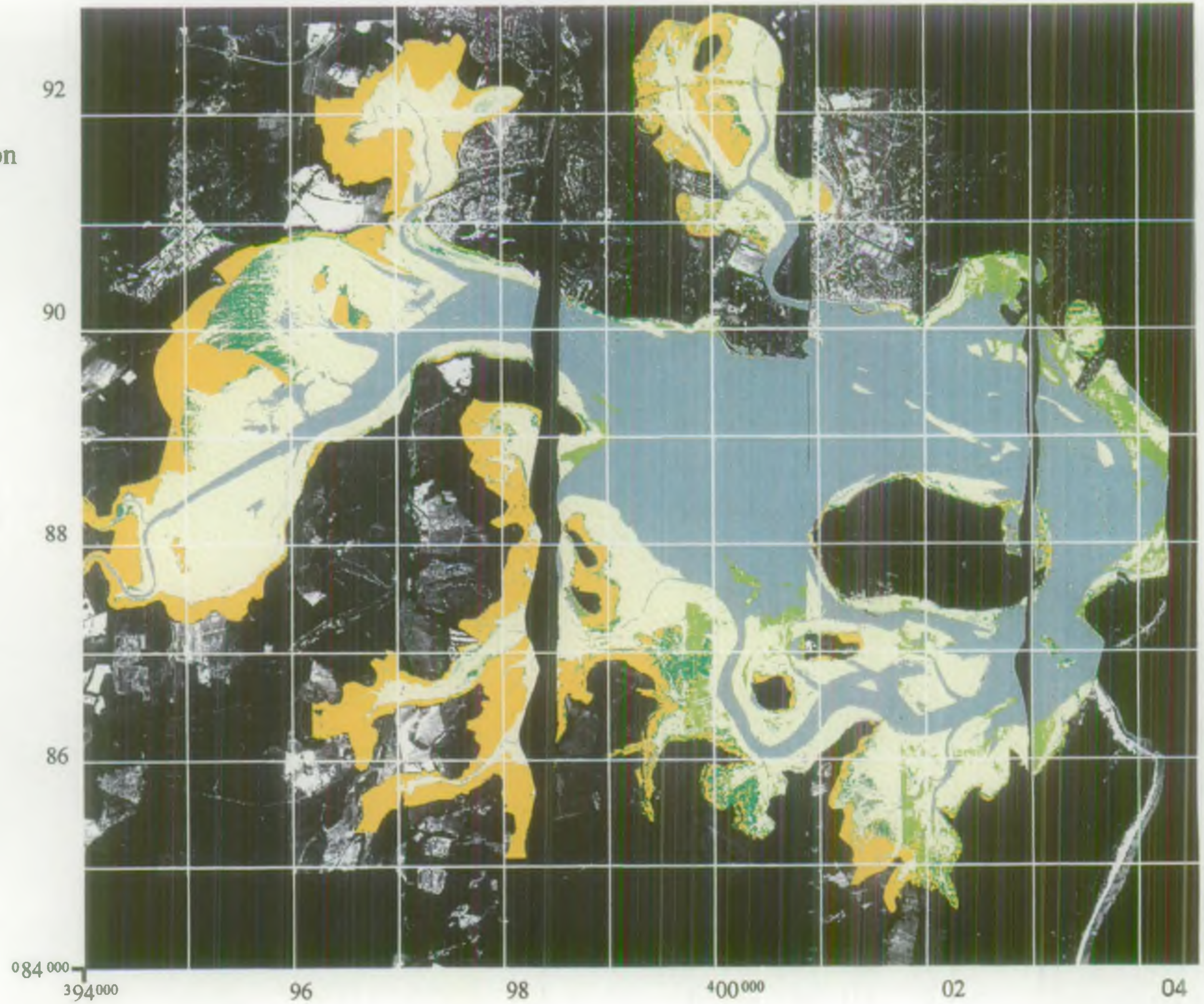
Key

- Terrestrial Vegetation
- Saltmarsh
- Shallow Water
- Mud
- Dense Algae
- Sparse Algae
- Sand & Water Glint

Figure 58

Poole Harbour
3rd August 1996
Low Water

Unsupervised classification of inter-tidal areas



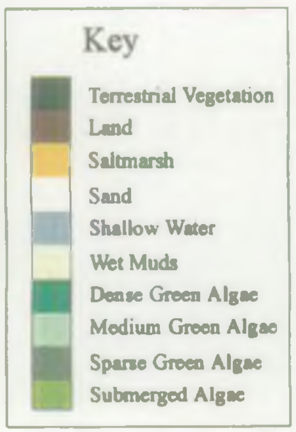
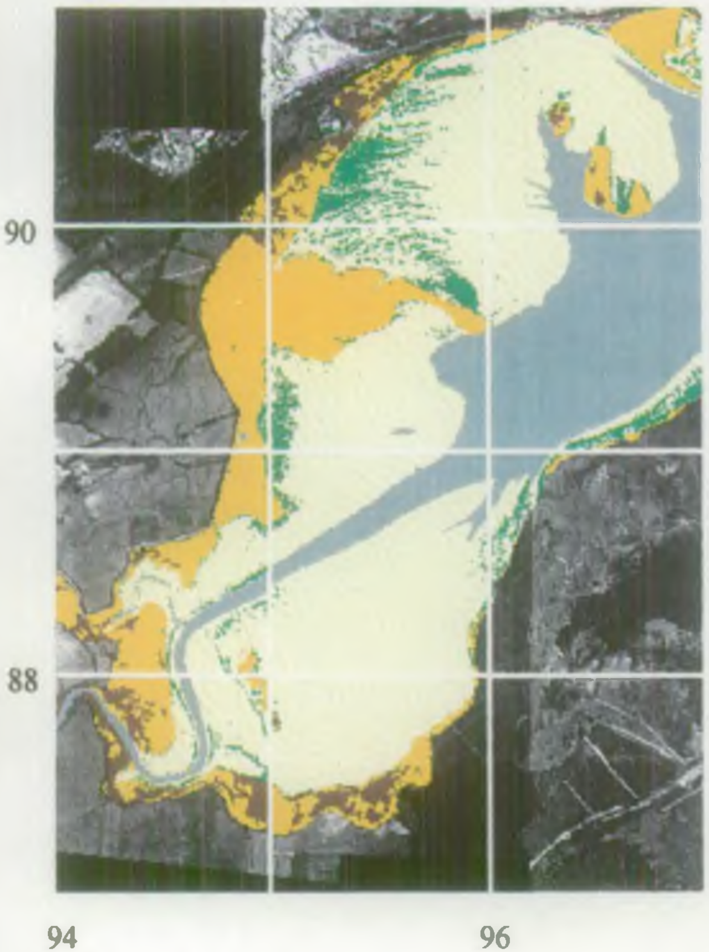


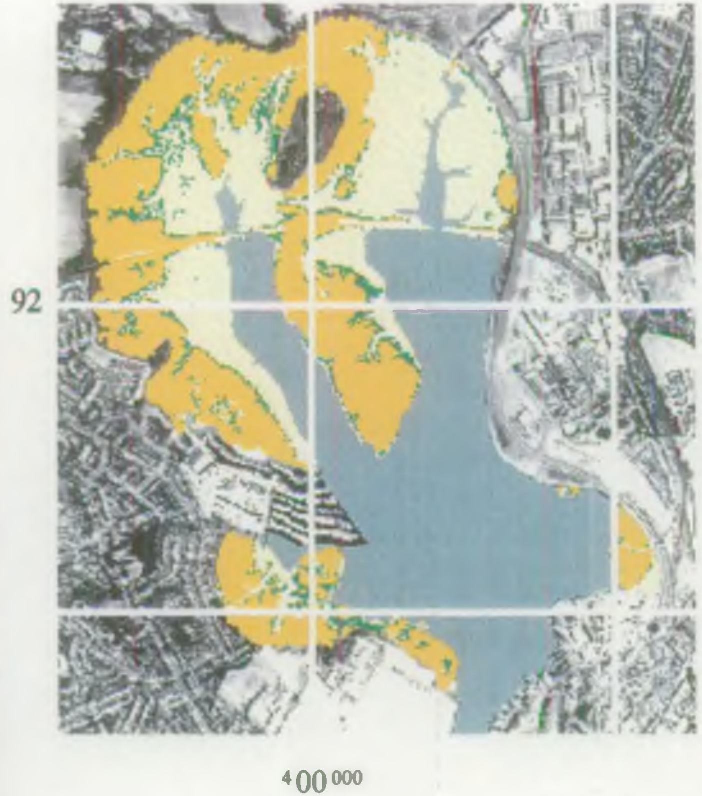
Figure 59

Poole Harbour
14th August 1995
Low Water

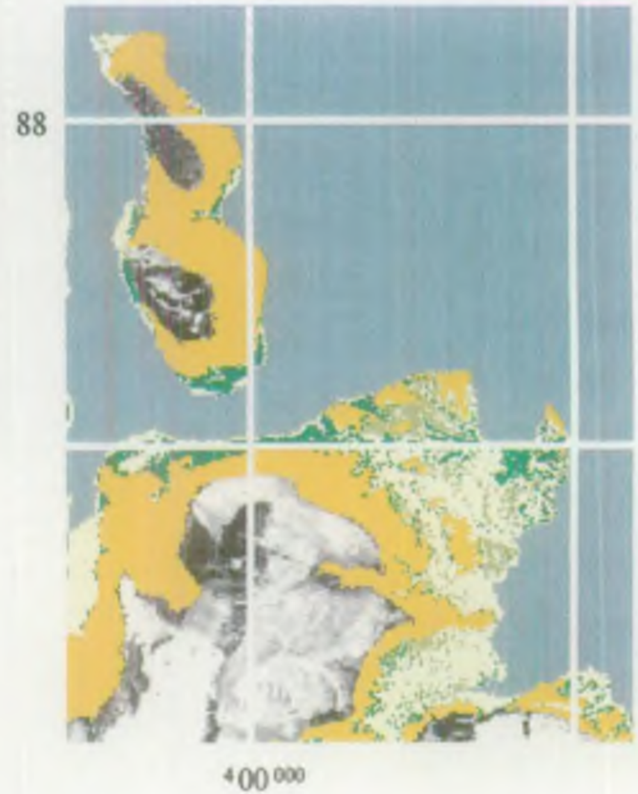
Unsupervised classification - regions of interest



Wareham Channel



Holes Bay



Round Island & Long Island

Key

- Terrestrial Vegetation
- Saltmarsh
- Shallow Water
- Mud
- Dense Algae
- Sparse Algae
- Sand & Water Glint

Figure 60

Poole Harbour
3rd August 1996
Low Water

Unsupervised classification - regions of interest

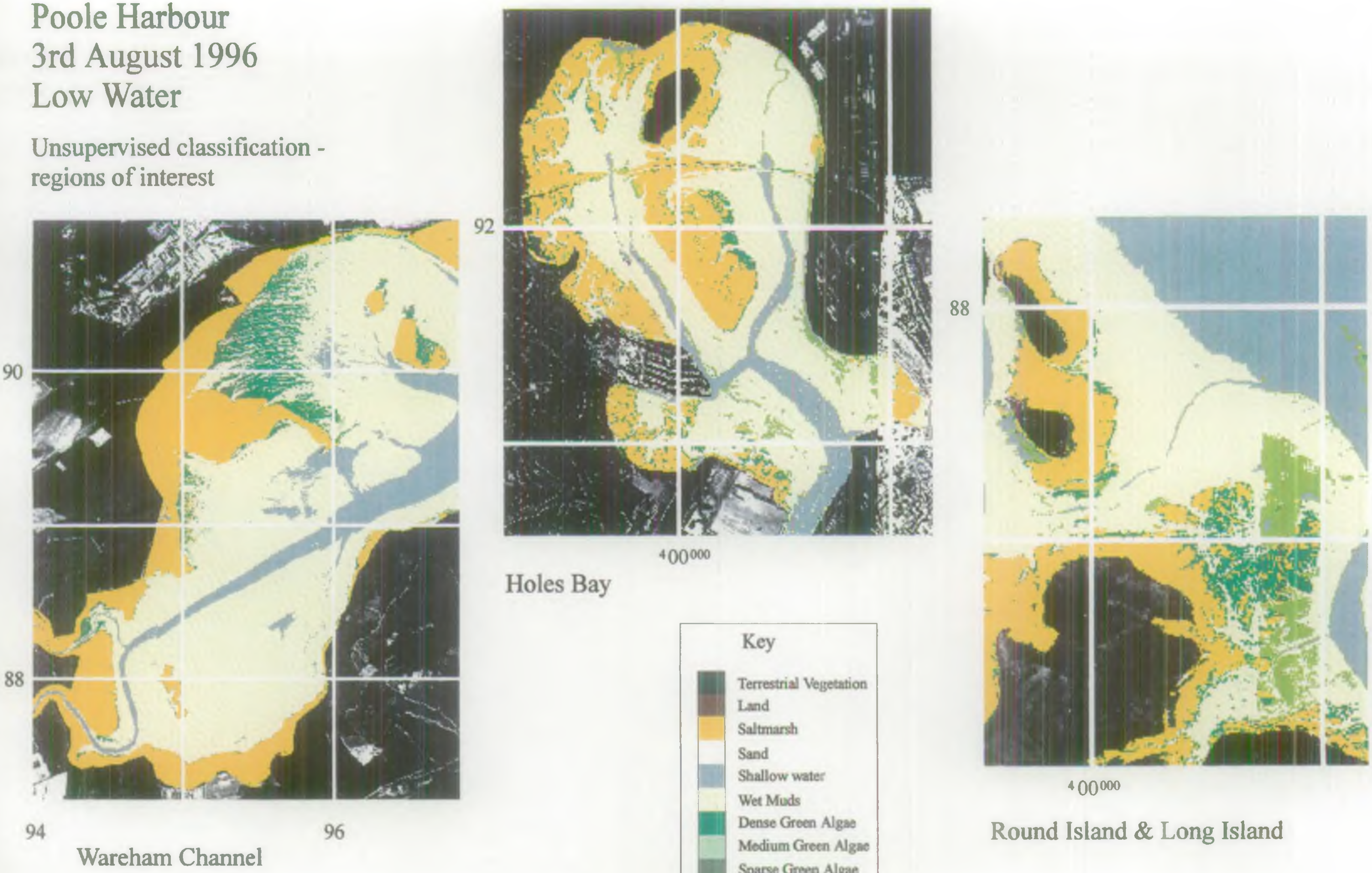


Figure 61

3.10 THE SEVERN ESTUARY AND AVONMOUTH

3.10.1 Background Description

3.10.1.1 The Severn Estuary has the largest volume of flow of any estuarine source in the UK. The tidal waters extend from Gloucester to a line joining Hinkley Point on the North Somerset coast and Lavernock Point on the Welsh coast. The area is illustrated in figure 63. This figure shows the locations of Sites of Special Scientific Interest (SSSI) within the estuary.

3.10.1.2 Figures 64 and 65 show two mosaics of CASI images collected at low water on 15th September 1996 showing the Lower and Upper Severn Estuary respectively. These show the high suspended solids loading of this estuary, and the presence of a large number of sandbars and mudflats along its length.

3.10.1.3 The estuary is a highly industrialised region, with most industry located around Avonmouth on the North Somerset coast and the towns of Cardiff and Newport on the Welsh coast. The upper reaches of the estuary are a mixture of rural development and small scale industry, particularly from paper and timber mills.

3.10.2 Discussion of major issues

3.10.2.1 Potential pollution effects of past and present industrial development are of key interest to the three Environment Agency Regions responsible for the estuary, these being Welsh, South West and Midlands.

3.10.2.2 There are a number of water quality surveys carried out in the Severn Estuary, to examine the water quality in order make comparisons with defined water quality standards, for example the EC Dangerous Substances Directive. These are carried out both by vessel and helicopter. The helicopter survey is used to enable collection of samples at similar tidal state throughout this highly dynamic estuary. Failures to meet the Environmental Quality Standards defined in the directives have been recorded for a number of determinands in recent years. The Environment Agency is actively searching for the cause of these failures.

3.10.2.3 The Severn Estuary is divided into eleven reaches for National Water Council classification purposes. The 1995 classification recorded 3 reaches as Good, with eight being Fair. These have not changed since 1990, except for two of the upper reaches which have improved from Poor to Fair following improvements to Gloucester sewage treatment works (Environment Agency, 1997*a*).

3.10.2.4 Historically very low dissolved oxygen levels have been recorded in the upper estuary, especially associated with the Severn Bore. These have been alleviated through improvements to the Gloucester sewage treatment works.

3.10.2.5 The definition of the extent of the Severn Estuary has recently been the subject of a judicial review. Under the Water Resources Act 1991 the River Severn off Avonmouth was identified as an estuary. However, because the estuary is a highly dispersive environment due to its large tidal range, the Department of the Environment recommended that this area be considered as a coastal environment under the provisions of the Urban Waste Water Treatment Directive (91/271/EEC). The judicial review overturned this decision.

3.10.3 Discharge mixing zones

3.10.3.1 Aerial surveillance of the Severn Estuary and Avonmouth was carried out on the 18th July 1996 at three tidal states: on the rising tide, at High Water and on the falling tide. There were a total of six flightlines flown, encompassing the estuary from the tidal limit at Gloucester to the boundary with the Bristol Channel.

3.10.3.2 Figure 65 shows the positions of selected consented sewage and trade effluent discharges in the Severn Estuary.

3.10.3.3 Three of sewage effluent discharges have consented volumes in excess of 100,000 m^3/day. One of these, from Western Valley trunk sewer outfall in Wales is of untreated sewage. The Avonmouth sewage treatment works presently discharges primary treated sewage, although this treatment will be increased following the judicial review discussed in section 3.10.2.4.

3.10.3.4 The thermal data show high variability in surface temperature within the estuary. The variations are large scale, linked to changes in suspended solids loading and water depth, with no point discharges visible in the data.

3.10.3.7 Upstream of the St Regis Paper Company, at Lydney, there is a further paper mill discharge, from J.R. Crompton paper mill. This discharge is clearly shown on the imagery collected on the falling tide, having a red spectral signature. The discharge extends downstream for approximately 0.5 km, before the effect becomes integrated in the spectral response of the sediment. There is no thermal signal from this outfall. Concerns have been raised regarding the effects of this outfall on fishing grounds to the south. This imagery does not show any immediate transport of effluent to this point, but further investigations would be required to determine this fully.

3.10.3.8 The imagery collected on the falling tide shows the presence of a discharge mixing zone from the Portbury Dock, with a spectral signature indicating that this is of lower suspended solids concentration than the receiving waters. The presence of this less turbid water would suggest that it is an input of riverine water, as apposed to an effluent discharge.

3.10.3.9 There is a distinct mixing zone located to the north of Avonmouth, at Holes Mouth, which is visible in CASI data collected at all three tidal states. This discharge is from Avonmouth sewage treatment works, which is the largest consented sewage effluent discharge on the English shore of the Severn Estuary. This discharge consists of primary treated sewage and assorted trade effluent. On the rising tide the mixing zone extends upstream, with some offshore flow. The other images, collected at one hour after and three hours after high water, the mixing zone extends downstream, with flow alongshore.

3.10.3.10 The Avonmouth sewage discharge has been detected in CASI imagery from previous years gathered as part of the National Coastal Baseline Survey.

3.10.3.11 Two small discharge mixing zones were detected in the CASI imagery at High Water, one associated with Chepstow sewage treatment works at Hunger Pill and one to the south of the second Severn crossing. Both mixing zones indicate downstream flow, consistent with the collection of data one hour after high water.

3.10.3.12 There are a large number of consented effluent discharges within the Severn Estuary which have not been recorded by the aerial imagery as either a variable surface temperature or a change in water colour. There are a number of possible explanations for this. The high suspended sediment loading of the Severn Estuary will make the differentiation of effluent mixing zones more difficult, as effluent discharges typically have higher solids loading. There is also high tidal mixing in this region which will result in efficient dispersion of the effluent on a local scale. However the long flushing time of the estuary means that the effluent will not be removed from the estuary for a number of tidal cycles, which may result in build up of pollutants.

3.10.3.13 The data were recorded on 18th July 1996, which will have an effect on the ability of the thermal system to detect mixing zones, because the temperature difference between the discharging and the receiving waters will be low. This is due to seasonal warming of the estuarine waters.

3.10.4 Saltmarsh and beaches

3.10.4.1 The presence of saltmarsh and beaches in an estuary acts as a defence against flooding by dissipating tide and wave energy and by providing a physical barrier against the passage of water. Saltmarsh is also a diverse habitat supporting a wide variety of flora and fauna, which in turn provides a haven for migratory birds.

3.10.4.2 Figures 67 and 68 show mosaics of false colour composite images of the Upper and Lower Seven estuary respectively. These mosaics are not of high quality due to the collection of data under imperfect weather conditions. The presence of vegetation is shown by a red colouration in the imagery. Vegetation on some of the inter-tidal mudflats within the main channel is immediately apparent.

3.10.4.3 The CASI data have also been used to produce a digital classification of the inter-tidal zone of the estuary. This technique relies on the variation of all spectral channels of the CASI but is particularly suitable for the differentiation of vegetated from non-vegetated surfaces. The apparently higher quality of these images in comparison to the false and true colour composites shows the ability of the classification technique to account for variability in ambient light conditions.

3.10.4.4 The classification of the Upper and Lower Severn are shown in figure 69 and 70 respectively. The numerical results of this classification are shown in tables 11 and table 12 respectively.

Land cover classes	Area (ha)	% Cover
Mud and sand	3237	68
Sparse green algae	418	9
Sparse brown algae	379	8
Saltmarsh	319	7
Dense brown algae	231	5
Dense green algae	142	3
Total	**4727**	**100**

Table 11: Inter-tidal land cover classification for the Lower Severn Estuary, 15th September 1996

Land cover classes	Area (ha)	% Cover
Mud and sand	1317	92
Dense algae	90	6
Sparse algae	24	2
Total	**1431**	**100**

Table 12: Inter-tidal land cover classification for the Upper Severn Estuary, 15th September 1996

3.10.4.5 The classification results show that there is no saltmarsh within the Upper Severn Estuary, with marsh occurring in the Lower Severn only between Sharpness and Portishead. This marsh is in the form of a coastal fringe, with an area of mud at the toe. In many places this mud in covered by algae.

3.10.4.6 The Upper Severn Estuary shows the presence of extensive inter-tidal mudflats and sandflats. In both the upper and lower sections of the estuary mudflats and sand are the major land cover class recorded by the remote sensing system.

3.10.5 Inter-tidal vegetation

3.10.5.1 An increase in algal cover on inter-tidal mudflats may be indicative of eutrophic conditions. This has been suggested by the Department of the Environment as an indicator to be used in the determination of Sensitive Areas for further sewage effluent treatment under the provisions of the Urban Waste Water Treatment Directive (91/271/EEC).

3.10.5.2 The presence of algae is shown by the digital classification. In the Upper Severn there are two key areas of dense algal cover, which are shown in more detail in figure 72. The first area, on Pimlico Sands, shows extensive dense algal cover.

3.10.5.3 The second area on the sandflats of The Noose is located close to the Frampton sewage treatment works. It is therefore possible that discharges from this works are enhancing the growth of algae at this site, although there may be other causes for enhanced growth. The presence of macro-algae must be considered with other factors in determining the trophic status of an estuary.

3.10.5.4 In the Lower Severn Estuary there is more extensive algal cover, with both green and brown species recorded. Figure 71 shows the area of the two River Severn road crossings. The rocks beneath the Second Severn Crossing are covered by brown algae which is dense in parts. The shorelines of this area are colonised by the less established green algae.

3.10.5.5 The area around the tidal reservoir at Oldbury is shown in more detail in figure 71. Brown algae is again found on the rocks surrounding this reservoir. Sparse green algae is seen on the shoreline to the north and south. The concentrations of green algae do not suggest the presence of eutrophic conditions.

3.10.5.6 There is a narrow band of dense green algae to the north and south of the river entrance at Avonmouth. This may potentially be enhanced by the discharge of primary treated sewage from Avonmouth sewage treatment works. An alternative cause for this enhanced algal growth is the input of high nutrient waters from the River Avon and its agricultural catchment.

3.10.6 Summary of estuary

3.10.6.1 The data collected through aerial surveillance of the Severn Estuary during 1996 has revealed information on the environmental quality of this highly important estuary.

3.10.6.2 The data collected at three tidal states in July 1996 showed the presence of a number of discharge mixing zones within both the CASI and the thermal data. However, the warm temperature of the estuarine water during July and the high suspended solids loading of this estuary mean that not all the consented discharges were evident in the imagery.

3.10.6.3 The imagery has revealed useful information on the shape of the mixing zones which will aid in future consenting procedures. The highly complex nature of these discharges clearly illustrates that the strong tidal streams in this estuary do not result in effective flushing at all tidal states.

3.10.6.4 The digital classification shows that saltmarsh is not an important resource in this estuary, with the dominant inter-tidal land cover being mudflats. These mudflats, particularly in the middle estuary, are an important ecological resource, providing a feeding ground for migratory birds.

3.10.6.5 Recent studies have predicted an increase in sea level due to global warming of 37 cm across the UK by the year 2050 (DoE, 1996). This will result in flooding of the present inter-tidal zone, with resulting loss of the inter-tidal mudflats. Additionally, the fringe of saltmarsh in the lower reaches will most likely be removed as there is no potential for landward retreat of the marsh.

3.10.6.6 Areas of dense algal growth were evident within the Severn Estuary. In the Upper Severn, there are two areas of dense green algae, with dense brown algae being more evident in the lower Severn, particularly around the Second Severn Crossing. The high turbidity of the Severn Estuary, however, has meant that the area is not considered to be sensitive to eutrophication.

3.10.6.7 The digital classification produced from the CASI imagery may be integrated into a Geographical Information System to allow comparison with future data. This will allow assessments of change in the inter-tidal zone to be made, for example after changes are made to the treatment applied to Avonmouth sewage treatment works. Similarly, assessments of long-term change due to sea level rise may be mapped.

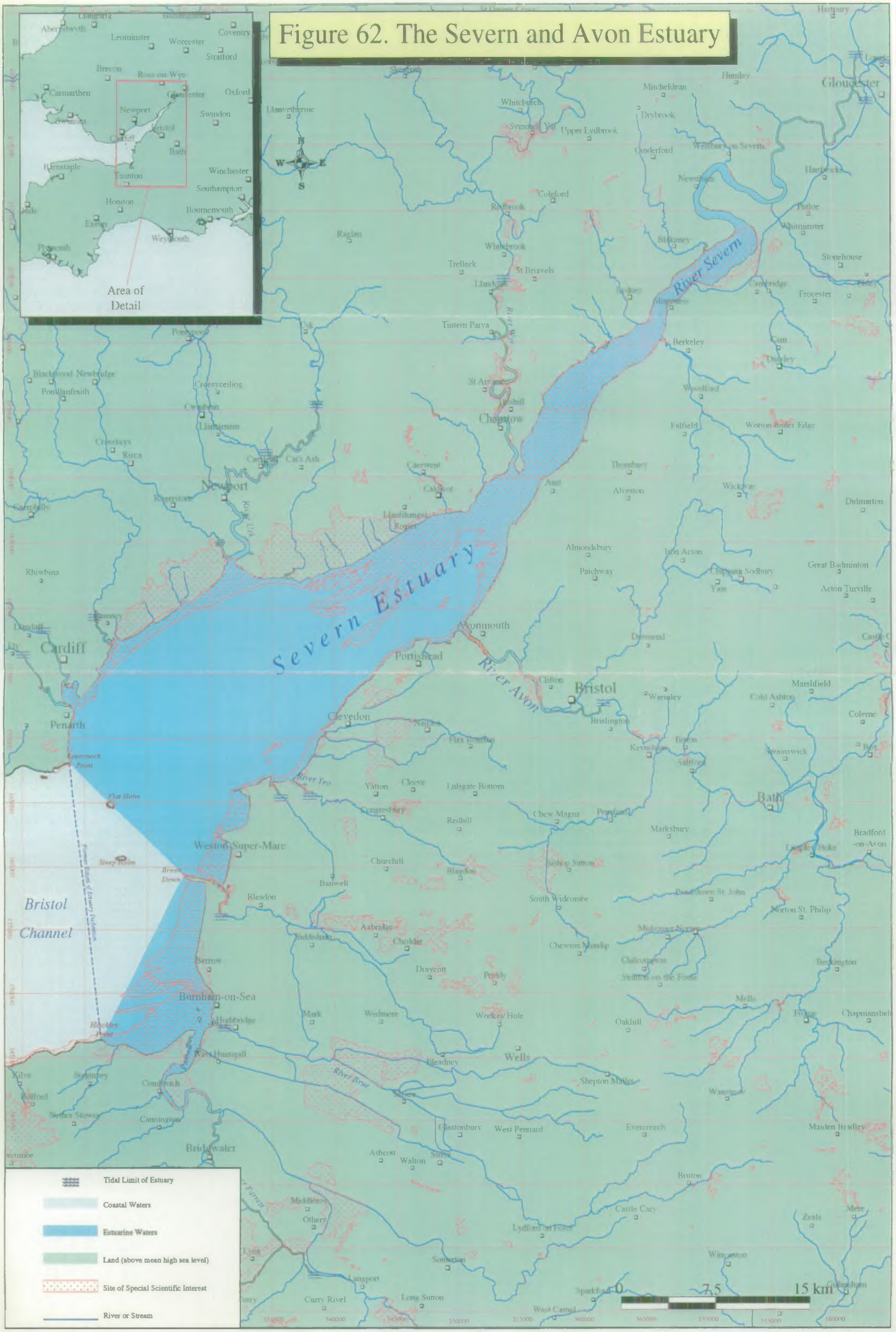
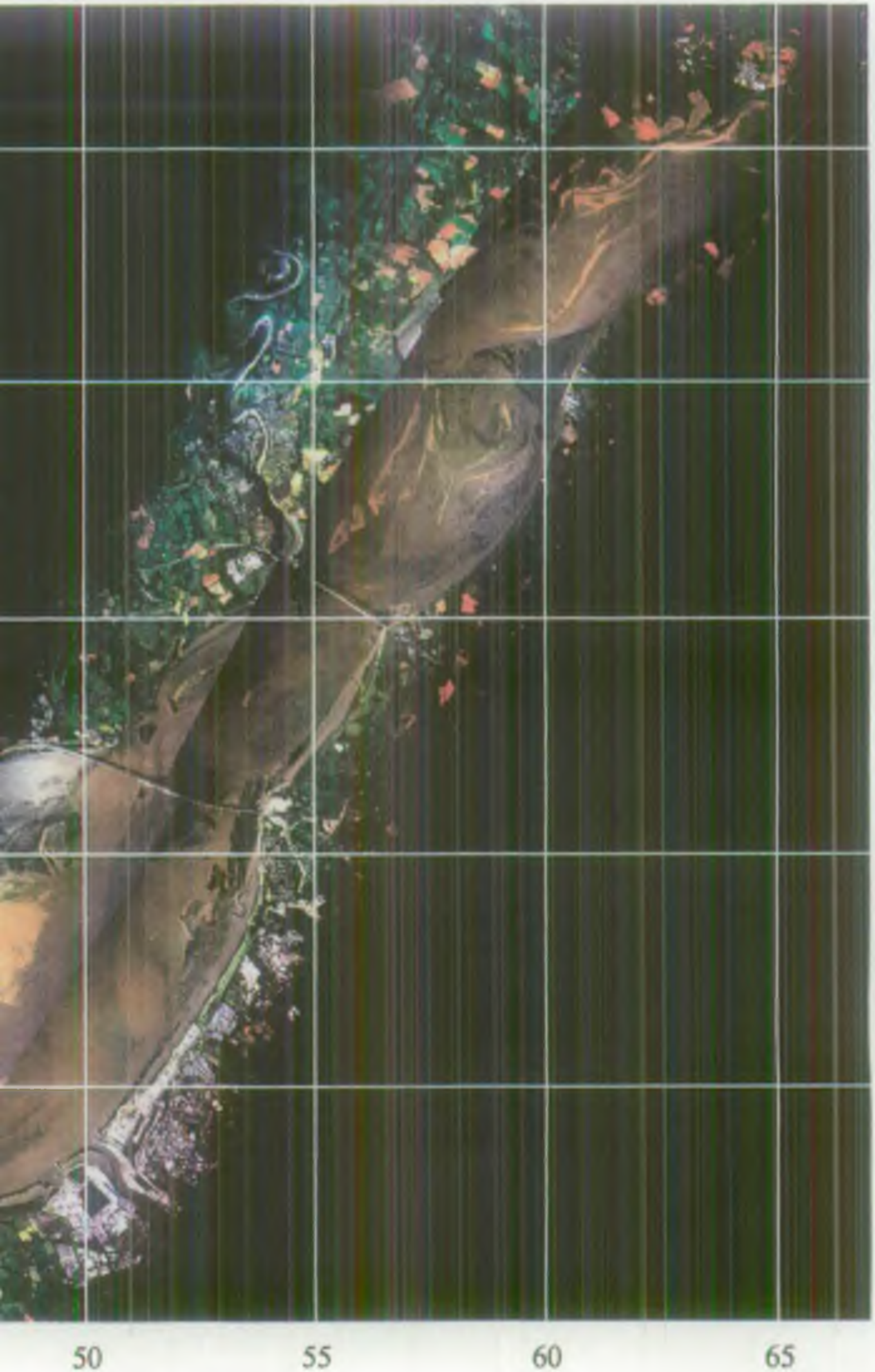


Figure 62. The Severn and Avon Estuary

Lower Severn Estuary
15th September 1996
Low Water

True colour composite of
two CASI images

Figure 63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Upper Severn Estuary
15th September 1996
Low Water

True colour composite
of four CASI images

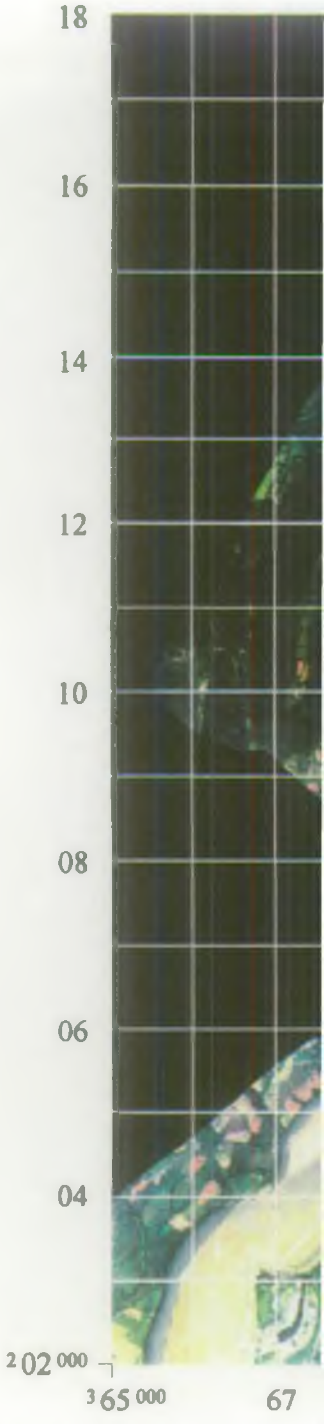
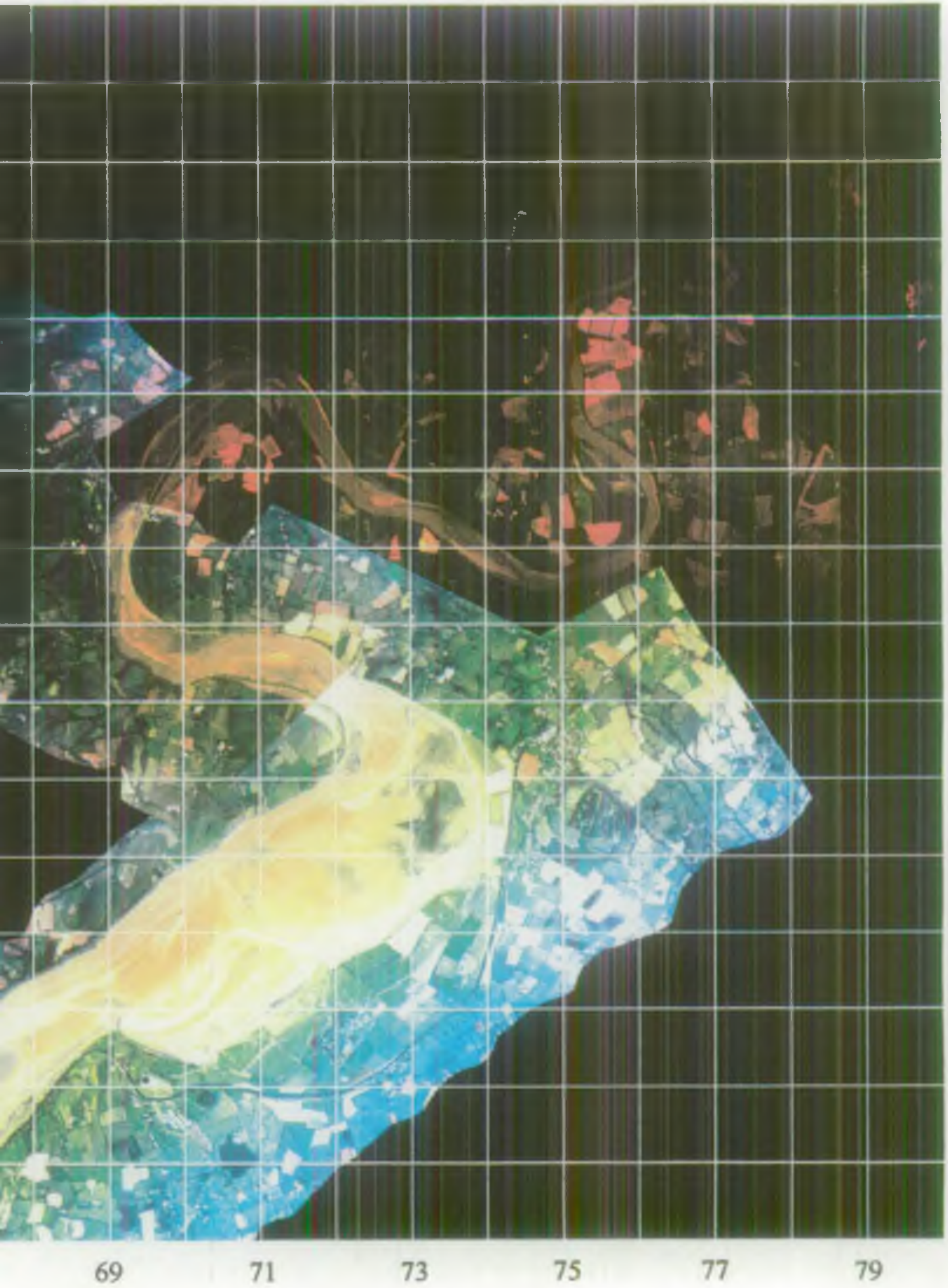


Figure 64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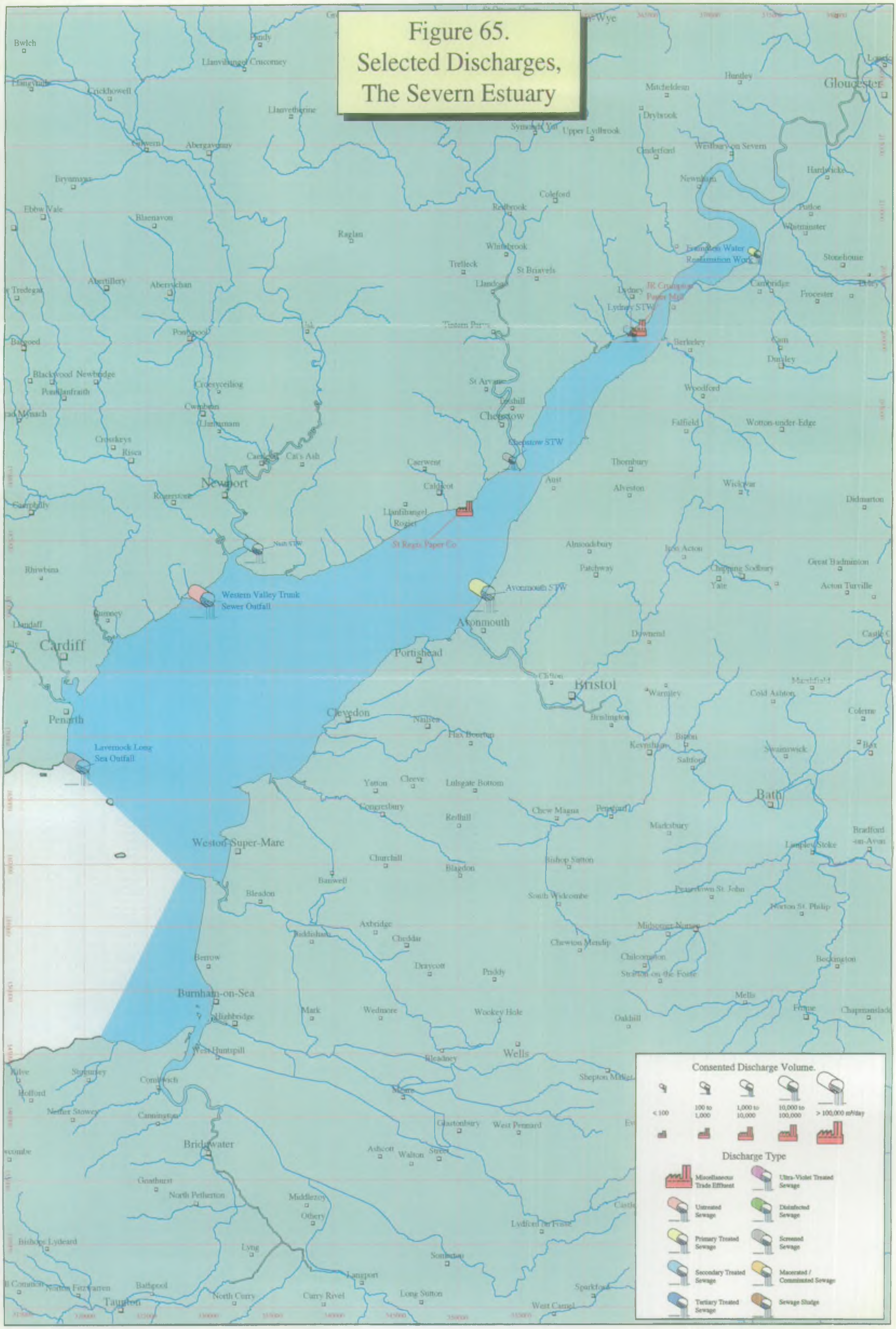


Figure 65.
Selected Discharges,
The Severn Estuary
Frampton Water Reclamation Work
JR Crompton Paper Mill
Lydney STW
Chepstow STW
St Regis Paper Co.
Nash STW
Avonmouth STW
Western Valley Trunk Sewer Outfall
Lavernock Long Sea Outfall
Gloucester
Newport
Cardiff
Bristol
Bath
Chepstow
Avonmouth
Portishead
Clevedon
Penarth
Weston-Super-Mare
Burnham-on-Sea
Bridgwater
Wells
Taunton
Consented Discharge Volume.
< 100
100 to 1,000
1,000 to 10,000
10,000 to 100,000
> 100,000 m³/day
Discharge Type
Miscellaneous Trade Effluent
Ultra-Violet Treated Sewage
Untreated Sewage
Disinfected Sewage
Primary Treated Sewage
Screened Sewage
Secondary Treated Sewage
Macerated / Comminuted Sewage
Tertiary Treated Sewage
Sewage Sludge

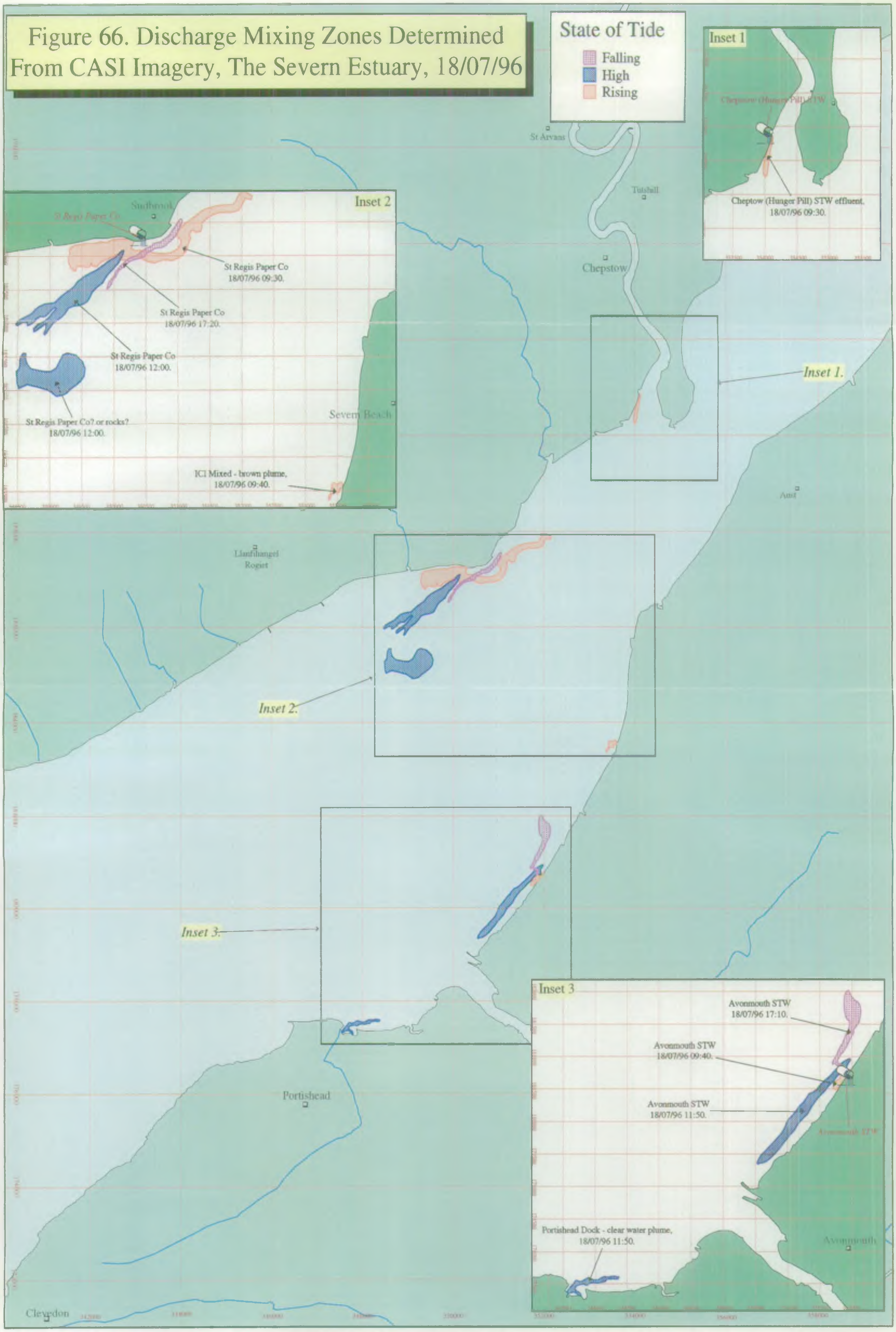
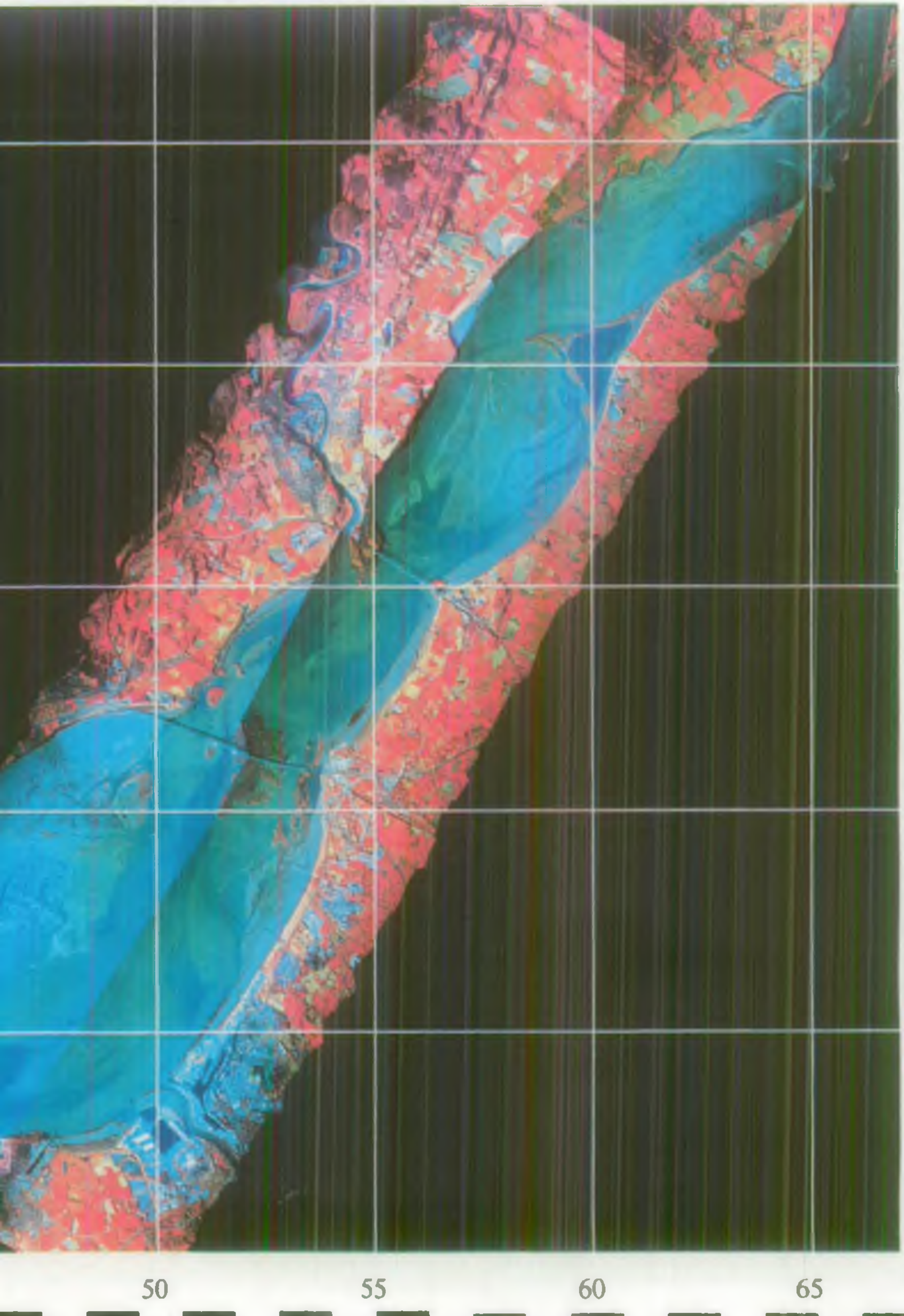


Figure 66. Discharge Mixing Zones Determined From CASI Imagery, The Severn Estuary, 18/07/96

Lower Severn Estuary
15th September 1996
Low Water

False colour composite
of two CASI images

Figure 67



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Upper Severn Estuary
15th September 1996
Low Water

False colour composite
of four CASI images

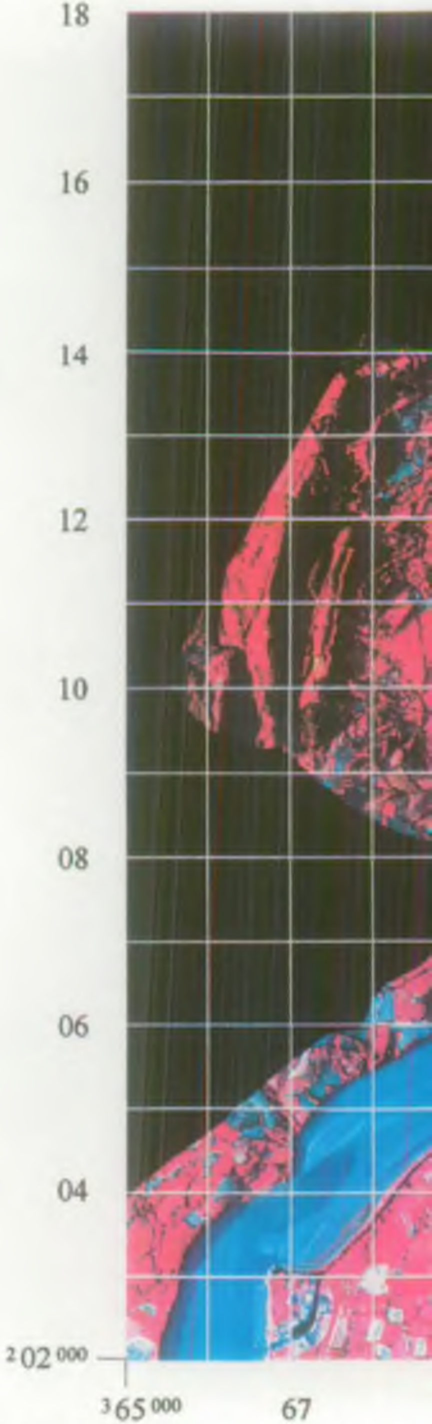
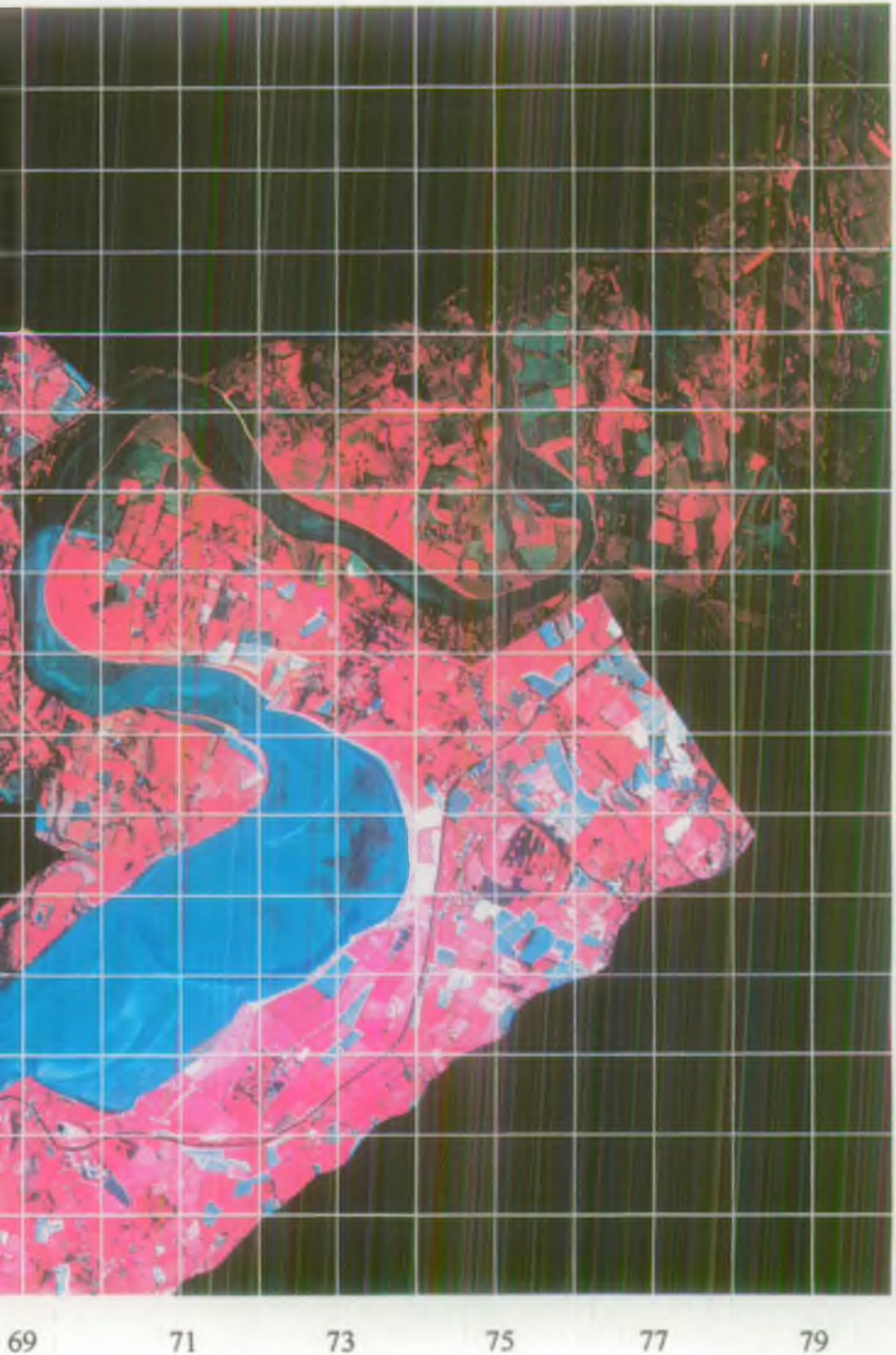


Figure 68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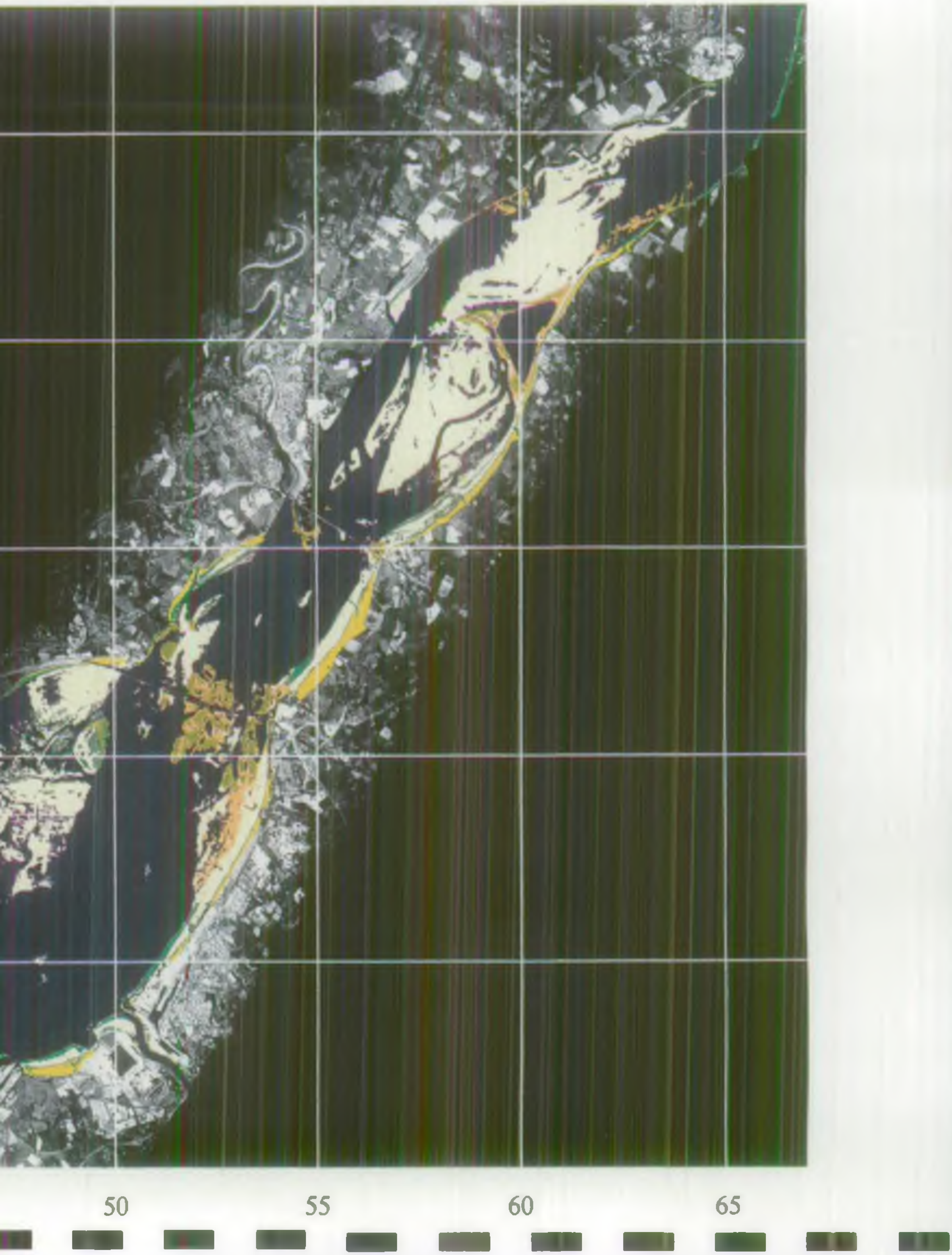
Lower Severn Estuary
15th September 1996
Low Water

Unsupervised classification of inter-tidal areas

Key

- Land
- Saltmarsh
- Water
- Mud & Sand
- Dense Green Algae
- Sparse Green Algae
- Dense Brown Algae
- Sparse Brown Algae

Figure 69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Upper Severn Estuary
15th September 1996
Low Water

Unsupervised classification of inter-tidal areas

Key

- Terrestrial Vegetation
- Land
- Saltmarsh
- Water
- Mud & Sand
- Dense Green Algae
- Sparse Green Algae

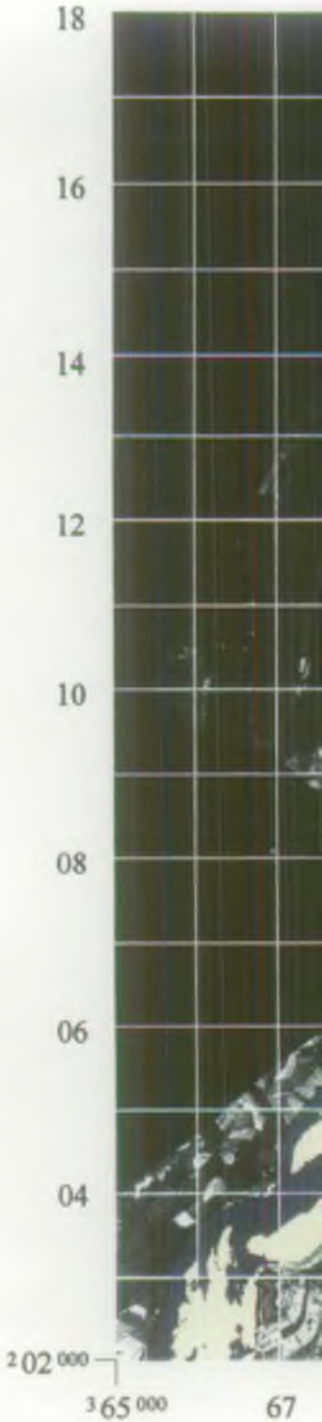
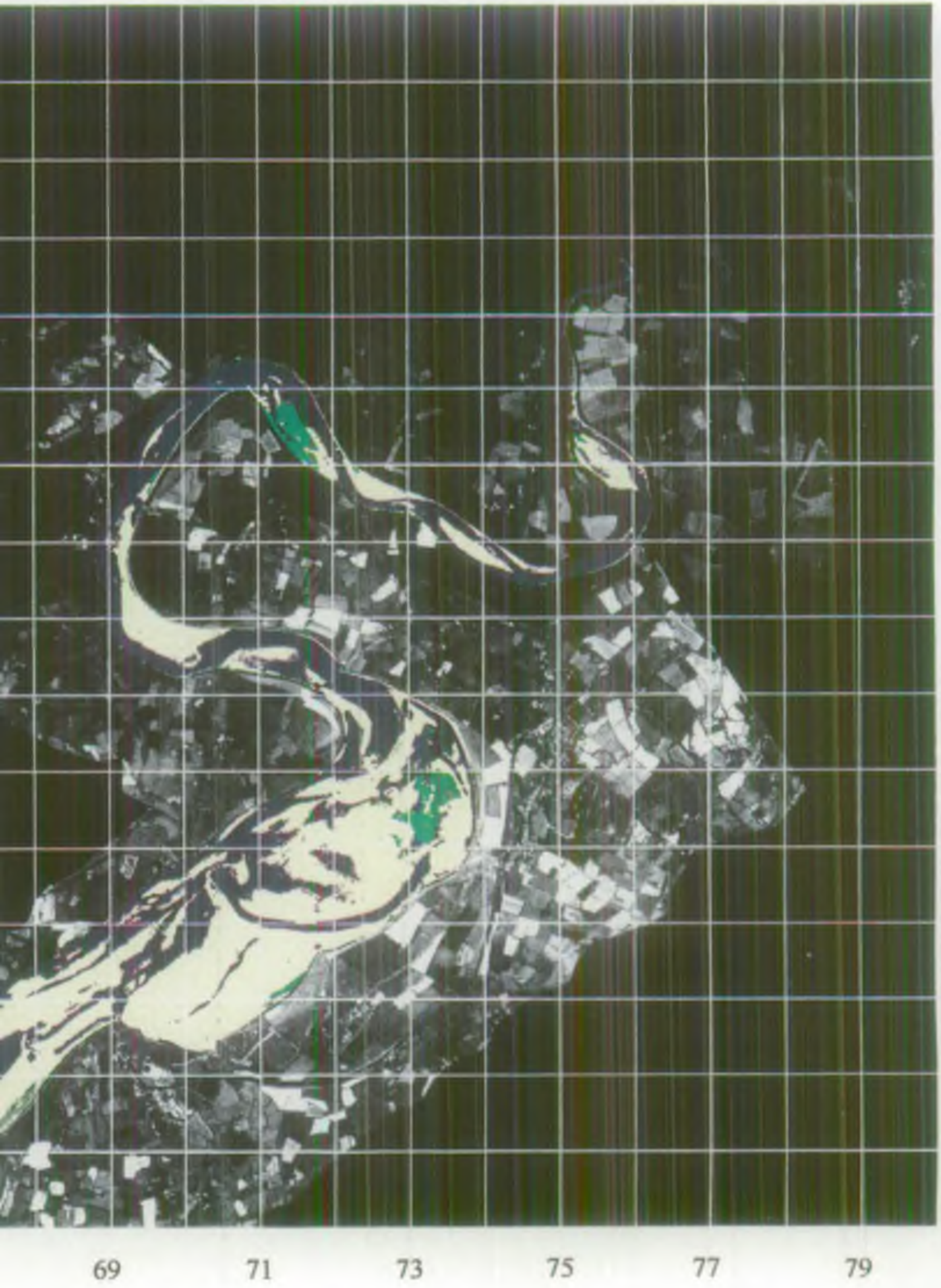


Figure 70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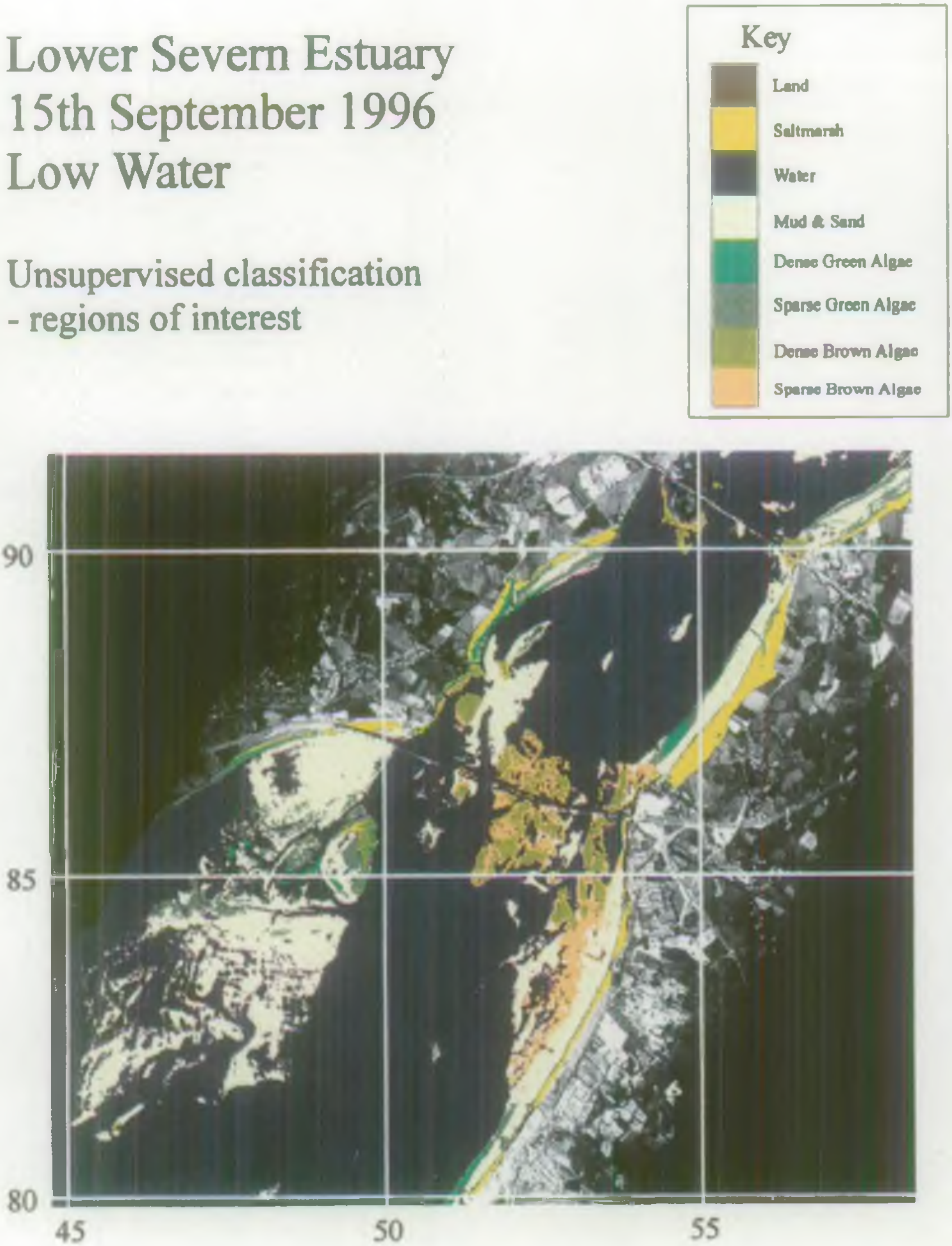
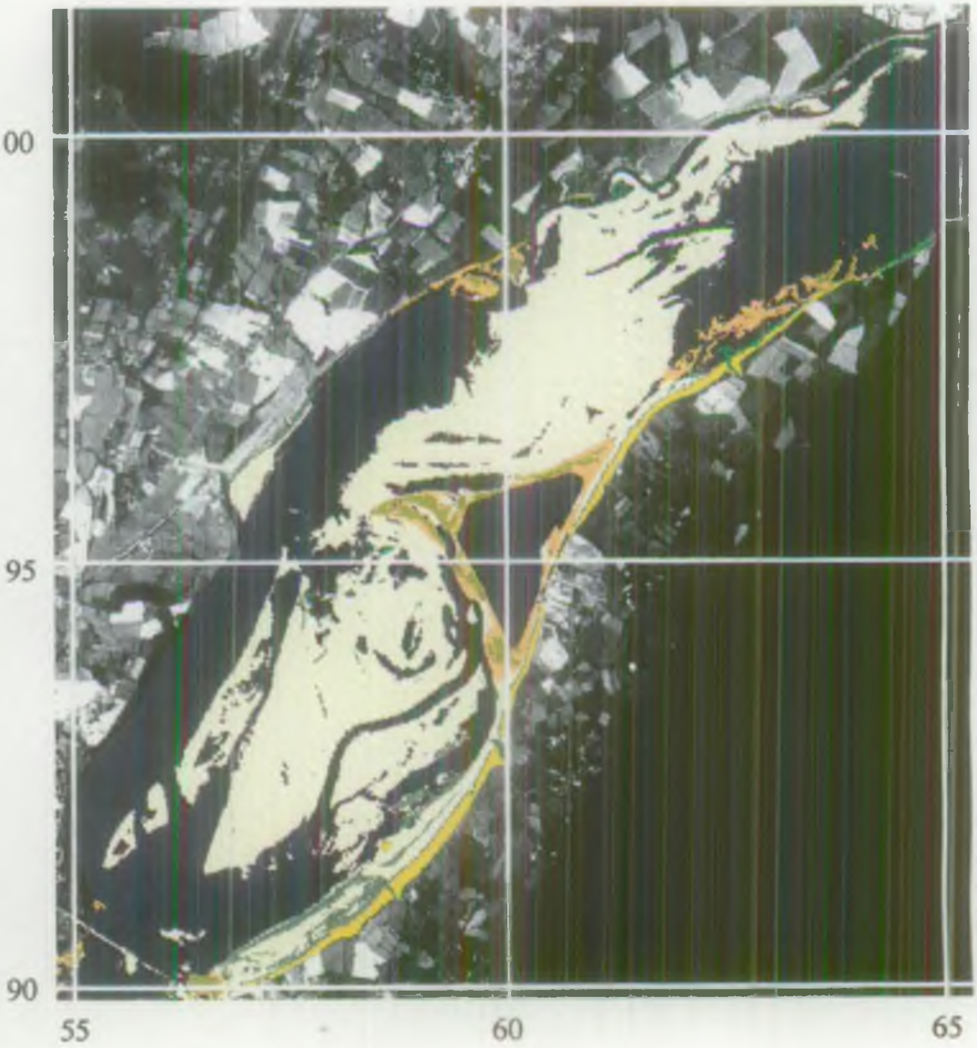
Lower Severn Estuary
15th September 1996
Low Water

Unsupervised classification
- regions of interest

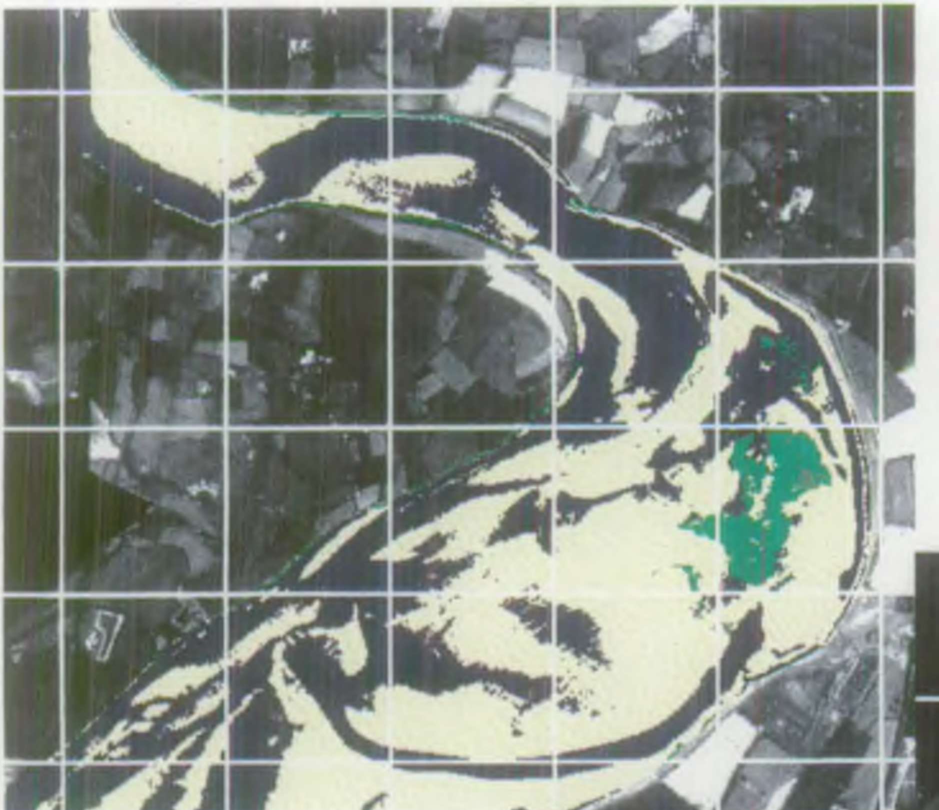


Second Severn crossing area

Figure 71



Oldbury area



The Noose

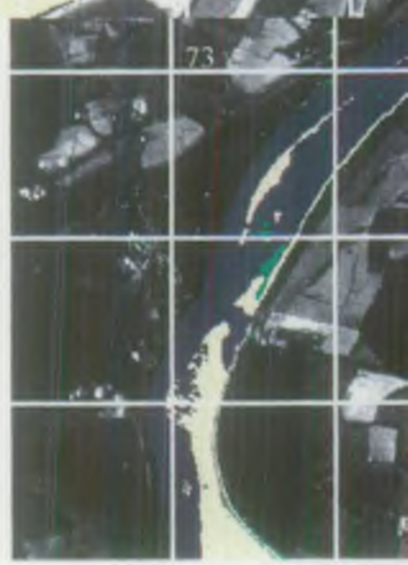
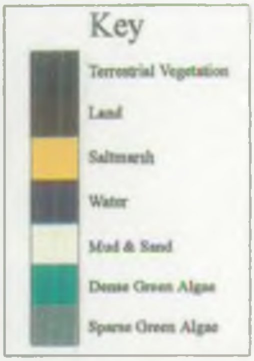


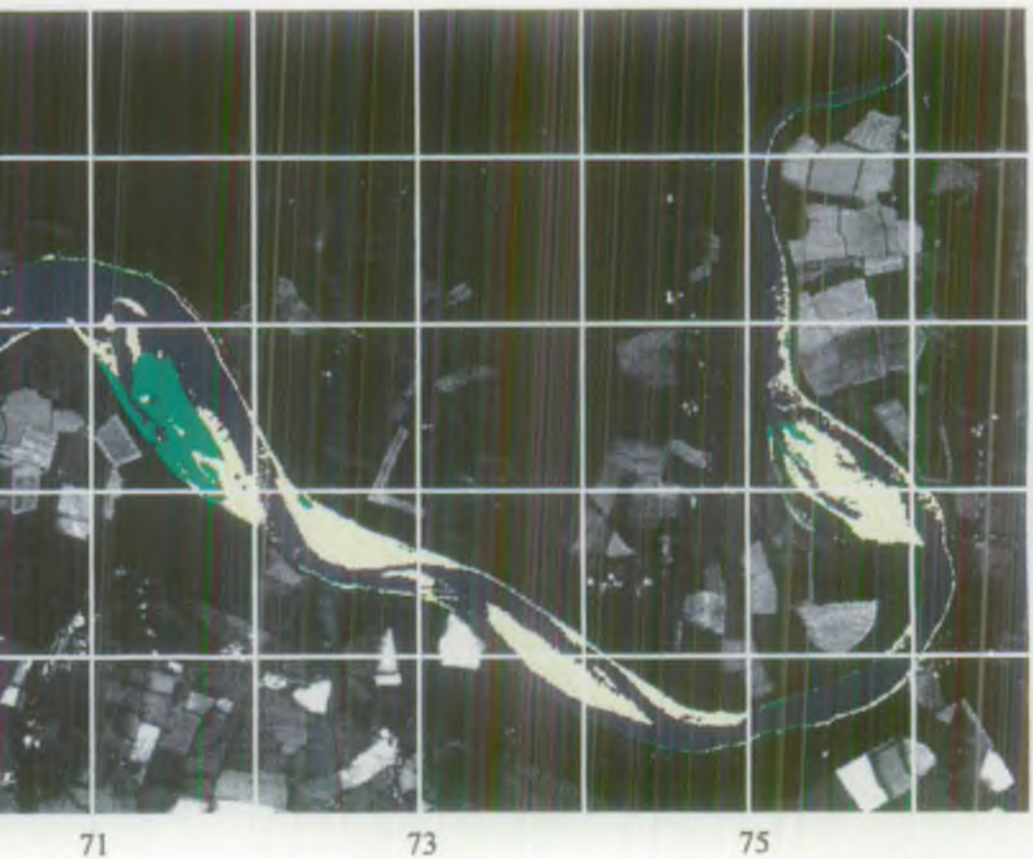
Figure 72

Pimlico Sands

Upper Severn Estuary
15th September 1996
Low Water



Unsupervised classification
- regions of interest



3.11 SOUTHAMPTON WATER

3.11.1 Background Description

3.11.1.1 Southampton Water, located on the southern shore of England, is a shallow linear body of water approximately 10 km in length and 2 km wide. The central channel is currently dredged to 10 m depth with extensive inter-tidal mudflats and saltmarsh, particularly on the western shore.

3.11.1.2 The area is a key maritime resource on the south coast of England, having been used for commercial shipping for centuries. The major population and industrial centre is the port of Southampton, at the confluence of the rivers Itchen and Test. The other major tributary of Southampton Water is the River Hamble. The estuarine region under consideration is shown in figure 73, which also shows the location of Sites of Special Scientific Interest (SSSI) within the estuary.

3.11.1.3 Figure 74 shows a true colour mosaic of CASI imagery collected at low water on 4th August 1996. The image shows the presence of major saltmarsh communities on the western side of the estuary, with mainly muds on the eastern side. Additionally, the imagery clearly shows the presence of the deep water channel in the centre of the estuary, which has a markedly lower radiance, shown darker in the image.

3.11.2 Discussion of major issues

3.11.2.1 Southampton Water is subjected to a number of diverse uses, being both an important area for sporting and recreational activities and an intense industrial and urban development. The sheltered waters of The Solent and Southampton Water have led to the development of the port of Southampton, and more recently the growth of industry mainly linked with power generation, chemicals and petrochemicals. The major industrial complex is located close to Fawley on the western shore.

3.11.2.2 English Nature has expressed concern regarding the potential problems regarding the maintenance of saltmarsh communities on the western shore of Southampton Water. This saltmarsh is recognised as an important resource and has SSSI status (see figure 73). Associated British Ports are dredging the channel a further 8 m in depth to allow larger capacity shipping to enter the port of Southampton, which may affect the saltmarsh communities. In order to assess any possible effects on these, the area is being surveyed using a combination of ground surveys and aerial surveillance.

3.11.2.3 Historically, the presence of blooms of the red phytoplankton *Mesodinium rubrum* within Southampton Water has resulted in periods of lower oxygen levels, in addition to exceptionally high concentrations of chlorophyll-*a*. These blooms have not been recorded in recent years, although no direct causes have been identified to account for this.

3.11.2.4 The water quality of Southampton Water was intensively studied as part of the assessment of the estuarine status of The Solent (NRA, 1993). This study concluded that The Solent should continue to be classified as an estuary, with corresponding treatment of sewage effluent. More recent water quality surveys have shown the estuary to be hyper-nutrified in winter months, with particularly high nitrate levels, mainly from riverine sources. However, no algal blooms have resulted in Spring and Summer. This has led to the conclusion that the estuary is not subject to eutrophication (Lowthian, *pers. comm.*).

3.11.2.5 Historically there have been high concentrations of dissolved metals on the western shore of Southampton Water close to Fawley. Improvements have been made to the quality of the discharges meaning that the water quality has improved although high concentrations remain in sediments and saltmarsh.

3.11.3 Discharge mixing zones

3.11.3.1 Figure 75 shows the positions of selected consented sewage and trade effluent discharges to Southampton Water. There are a large number of sewage effluent discharges, with the largest located at Woolston and Portswood in the River Itchen and Millbrook and Slowhill Copse in the River Test, serving the population of Southampton.

3.11.3.2 Three of the trade effluent discharges contain toxic and persistent substances, these being form the chemical complex to the north of Fawley. The Esso terminal has the largest consented volumes within this region.

3.11.3.3 Imagery was collected from Southampton Water at high water on 13th June 1996. Both the CASI and the thermal imagery show a clear delineation between the waters of The Solent and Southampton Water. Southampton Water has a higher water temperature, with temperatures 2°C to 3°C higher than those of the Solent (see figure 76), and a generally higher reflectance, signifying a higher suspended solids loading. The River Itchen has temperatures approximately 7°C warmer than the main body of Southampton Water, with a similar surface temperature in the Hamble. The River Test narrows rapidly with extensive reed beds. This area has markedly higher temperatures, up to 10°C above those found in the main estuary.

3.11.3.4 The thermal images of the area have been calibrated for temperature in degrees Celsius, and a mosaic has been made of the four images for Southampton Water (figure 76). The ambient temperature was set at that of the Solent.

3.11.3.5 The imagery shows high thermal variability within Southampton Water, with a full temperature range in excess of 12°C. However, the majority of the effluent outfalls discussed above are not shown within the thermal imagery, signifying that the effluent is at a similar temperature to that of the receiving waters.

3.11.3.6 The imagery reveals two key inflows of water that are warmer than ambient temperature on the western shore of Southampton Water. The first outflow, marked A on figure 76, is associated with a number of consented discharges. These discharges are from various chemical firms, which may contribute in varying degrees to the warming seen. The discharge has no signal in the CASI image, which signifies that the discharge has a similar colour to that of the receiving water. This suggests that the discharge is not high in suspended solids, and does not have a distinct colour associated with the chemical processing which has been carried out on it.

3.11.3.11 The mixing zone of these combined discharges is deflected to the south by the tidal stream, with data having been collected 2 hours past high water at Southampton. The plume disperses approximately 750 m downstream of the outfall, with effects being felt a maximum of 200 m offshore.

3.11.3.11 Further downstream the imagery shows a large plume of warmer water from Cadland Creek (marked B on figure 76). This plume has a surface temperature at the centre 11°C to 12°C above ambient. The plume is strongly deflected by the tidal stream, with a steep temperature gradient on the northern side, having a change in temperature of 7°C over approximately 10 m. The plume disperses to the south with the effects being experienced at least 3 km downstream, where the temperature of the plume is 5°C above ambient.

3.11.3.9 The outfall marked B is from the Esso Oil Refinery and is process cooling water. CASI data collected on this occasion shows no signal from this discharge. However, data collected at low water in July shows a distinct dark colouration to the water.

3.11.4 Saltmarsh and beaches

3.11.4.1 The presence of saltmarsh and beaches within an estuarine environment acts as a physical barrier against the passage of water to the shoreline, and dissipates wave and tide energy, thus protecting hard flood defences. Additionally, saltmarsh is a biologically diverse habitat, which is used as an important resource by over-wintering migratory birds. In Southampton Water this importance is reflected in the definition of much of the area as a SSSI (see figure 74).

3.11.4.2 Figure 77 shows a false colour mosaic of Southampton Water constructed from four CASI images flown close to low water on 4th August 1996. In this composite, an infrared channel has been displayed to show variations in vegetation cover. Highly vegetated areas appear red on the image, with bare surfaces having a darker signal. This mosaic clearly shows the presence of saltmarsh in Southampton Water.

3.11.4.3 A digital classification of the area has been produced which uses the variation in all spectral channels to distinguish between different land cover types. This has resulted in the classification map shown in figure 78. Summary results of this classification are shown in table 13.

Land cover classes	Area (ha)	% Cover
Mud	558	33
Sparse green algae	384	23
Saltmarsh	254	15
Dense brown algae	143	9
Wet mud	127	8
Dense green algae	104	6
Sand	53	3
Sparse brown algae	49	3
Total	**1671**	**100**

Table 13: Inter-tidal land cover classification for Southampton Water, 4th August 1996

3.11.4.4 There is a clear distinction between the two shores of Southampton Water. On the western side there are many saltmarshes, whereas the eastern shoreline is dominated by muds, many covered with algae (see section 3.11.5). Figures 79 and 80 show enlargements of the key areas of interest within Southampton Water.

3.11.4.5 The main saltmarsh is seen to the north of Cadland Creek. This saltmarsh shows a typical structure, with algae covered muds at the toe between the marsh and the water channel. There is a distinct pattern of drainage channels which allows distribution of seawater throughout the marsh, maintaining marsh development. This marsh is bordered by a narrow band of shells, between the marsh and the edge of the mud, which is picked out in the classification as land (Langman, *pers comm.*).

3.11.4.6 In Eling Marsh (figure 79), there is a large area classified as land vegetation. This represents the tidal reed beds. These are an important wet grassland resource, which have SSSI status.

3.11.5 Inter-tidal vegetation

3.11.5.1 Changes in inter-tidal vegetation communities may be linked to the presence of increased nutrients from anthropogenic sources, for example sewage treatment works. The growth of macrophytes on mudflats, for example *Enteromorpha spp*, is one indicator of eutrophication suggested by the Department of the Environment Consultation Report on the Urban Waste Water Treatment Directive.

3.11.5.2 In order to assess such changes it is necessary to undertake detailed surveys of the percentage of the inter-tidal zone covered by macro algae, and determine inter-annual changes in such. The land cover classification shown in figure 78 also includes the presence of varying concentrations of algae on the mudflats. Two classes of algae have been extracted from the data: dense algae and sparse algae lying on mud. It is the presence of dense green algae which is indicative of eutrophic conditions.

3.11.5.3 There is a distinct variation in land cover type between the western and eastern shores, with largely saltmarsh on the western shore, and more mudflats and sand beaches on the eastern shore. There is also a large amount of terrestrial type vegetation in the upper reaches of the River Test. Figure 79 and 80 show enlargements of specific areas of Southampton Water.

3.11.5.5 On the western shore, where saltmarsh dominates, algal cover is sparse, except at three sites where dense cover is seen. The first is to the north of Cadland Creek, where a thin zone of dense algae is seen at the edge of the saltmarsh (figure 79). There is then a wider zone of sparse algae extending to the edge of the channel. To the south of Eling a wide zone of dense algae is shown in the classification (figure 80). There is also a mixture of dense and sparse algal cover around Calshot Spit (figure 80).

3.11.5.6 On the eastern shore there are two main areas of algal cover, the first to the south of the confluence of the River Itchen and Southampton Water (figure 80). In this region there is little bare mud, with all mud having at least a sparse covering of algae. The densest patches are seen in the mouth of the Itchen. This region may be enhanced by the discharge of sewage effluent from Woolston sewage treatment works.

3.11.5.7 At the mouth of the River Hamble there is dense algal cover, with sparse cover extending along the shore to the south of this (see figure 80).

3.11.6 Summary of estuary

3.11.6.1 The data collected through aerial surveillance of Southampton Water has provided an overview of the environmental quality of the estuary. The estuary is more heavily industrialised than others surveyed, with little sign of agriculture.

3.11.6.2 The data collected at high water showed the presence of two large effluent discharges. These had higher temperatures than the receiving waters and extended a considerable distance downstream at this tidal state. The presence of such warmer water may affect the biological communities within the water column and on the mudflats and marshes of the inter-tidal zone.

3.11.6.3 The imagery gave no indication of discharge mixing zones associated with any of the sewage effluent discharges. Previous data collected as part of the National Coastal Baseline Survey have recorded high concentrations of nutrients at the Dockhead sampling site. This site, one of the National Marine Monitoring Plan sites, is located close to Woolston sewage treatment works. However, as there was no sign of the mixing zone in the imagery, it is not possible to state whether the sampling site is within the mixing zone of this discharge.

3.11.6.4 The results of the digital classification show small patches of dense algae close to the outfall from Woolston sewage treatment works, at the confluence of the River Itchen and Southampton Water. Additionally, there are dense patches around the discharge points of the Millbrook and Slowhill Copse sewage treatment works, south of Eling. However, most algal cover in Southampton Water is sparse.

3.11.6.5 The presence of algal growth in these three regions is not conclusively linked with the sewage discharges, with for example similarly dense patches located where there are no sewage discharges. The classification has, however, highlighted regions which may be worthy of further study. The presence of algae on the mudflats is not considered a particular problem within Southampton Water by Regional staff, due to the sparsity of cover.

3.11.6.6 The digital classification also shows the presence of saltmarsh within the estuary, particularly on the western shore. This saltmarsh, having a total area of 254 ha is an important environment, representing a highly diverse habitat.

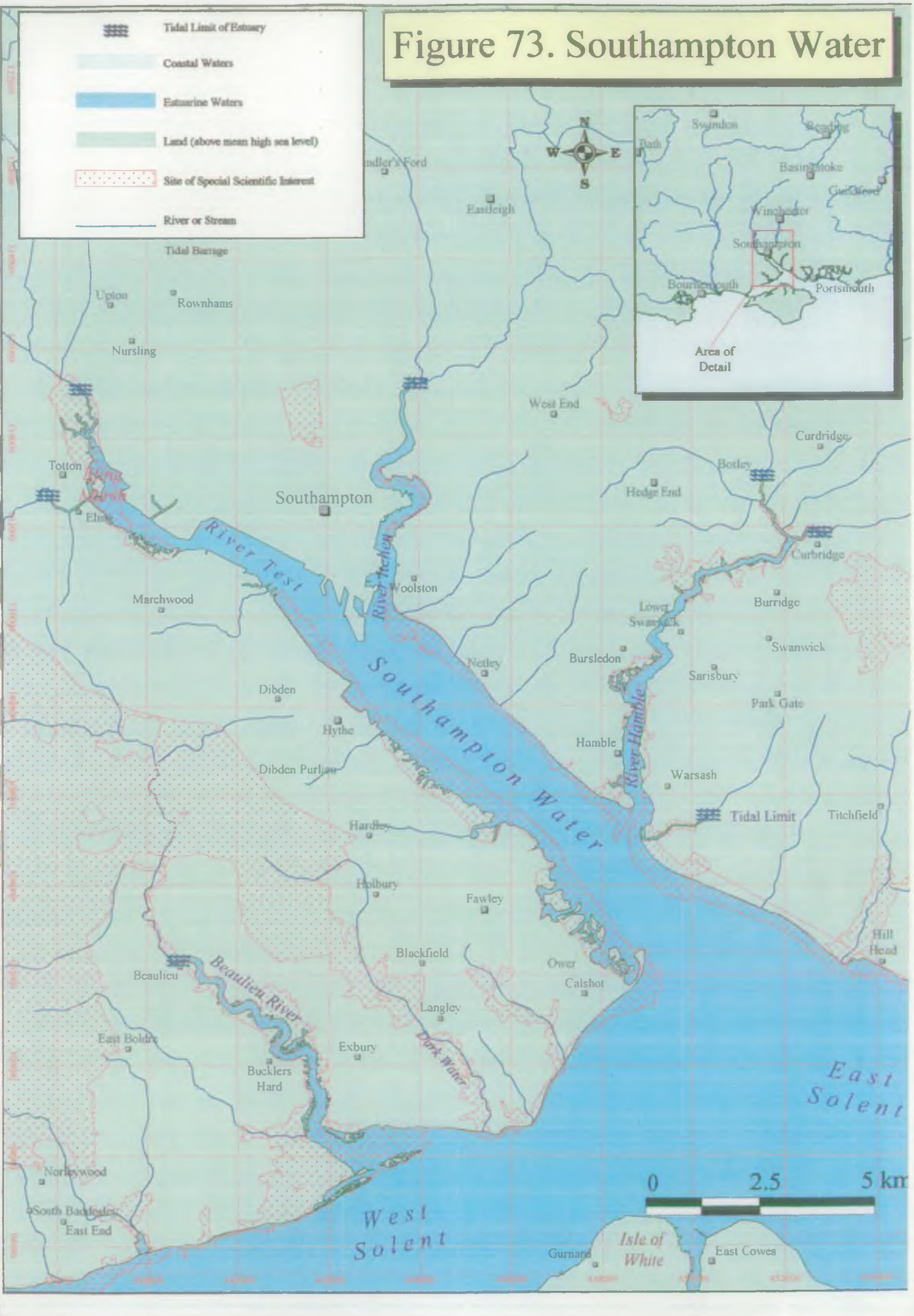
3.11.6.7 Recent studies predict an increase in sea level due to global warming of 37 cm across the UK by the year 2050 (DoE, 1996). This will be slightly increased in Southampton Water by the effects of sinking land. This sea level rise will result in flooding of the present inter-tidal zone, which will have two key consequences. Firstly, important saltmarsh habitat will be lost, as the presence of industrial development along much of the western shore will prohibit the landward progression of the marsh. Secondly, improvements to the coastal defences will be required in many regions in order to protect assets.

3.11.6.8 The classification of saltmarsh and inter-tidal vegetation may be integrated into a Geographical Information System to allow comparison with future data. If the dredging activities impact upon the spatial extent of the saltmarsh this may then be accurately assessed. Similarly, long term changes due to climate change may be mapped.

3.11.6.9 The image mosaics indicate the balance between nature and man within this estuary. Urban development is mainly restricted to Southampton at the upper end of the estuary. The rural nature of both shores has been largely maintained with industry concentrated in specific areas, such as Fawley. The size of this complex does, however, affect the aesthetic quality of this area.

3.11.6.10 Southampton Water is heavily used for recreational purposes, particularly water sports. Recent studies predict that the temperature of the south of England will increase resulting in an increase in tourism (DoE, 1996). This will place greater pressure on the sewage disposal systems, which may affect the trophic status of the estuary.

Figure 73. Southampton Water



Southampton Water
4th August 1996, Low Water.

A true colour composite of four CASI images

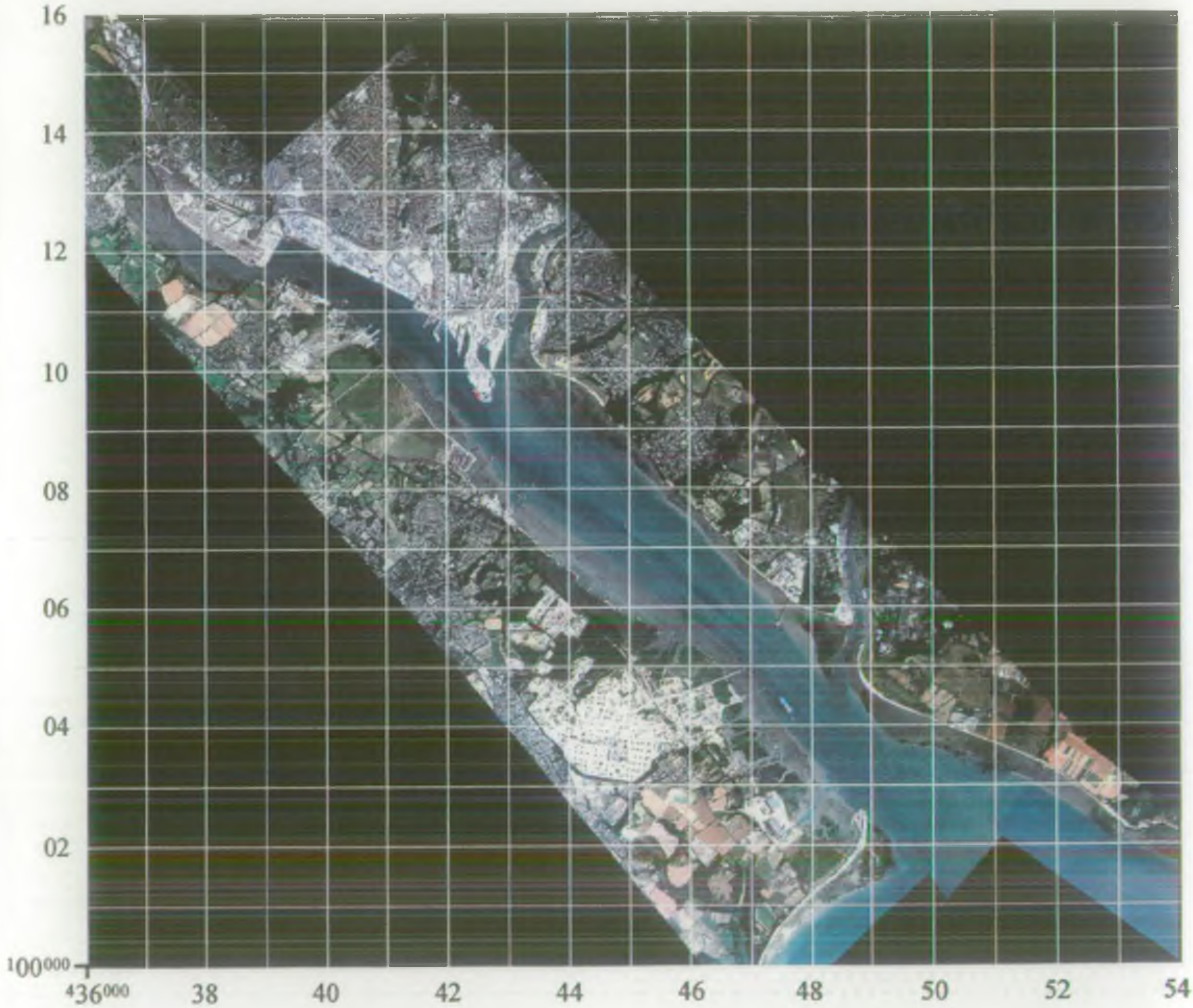


Figure 74

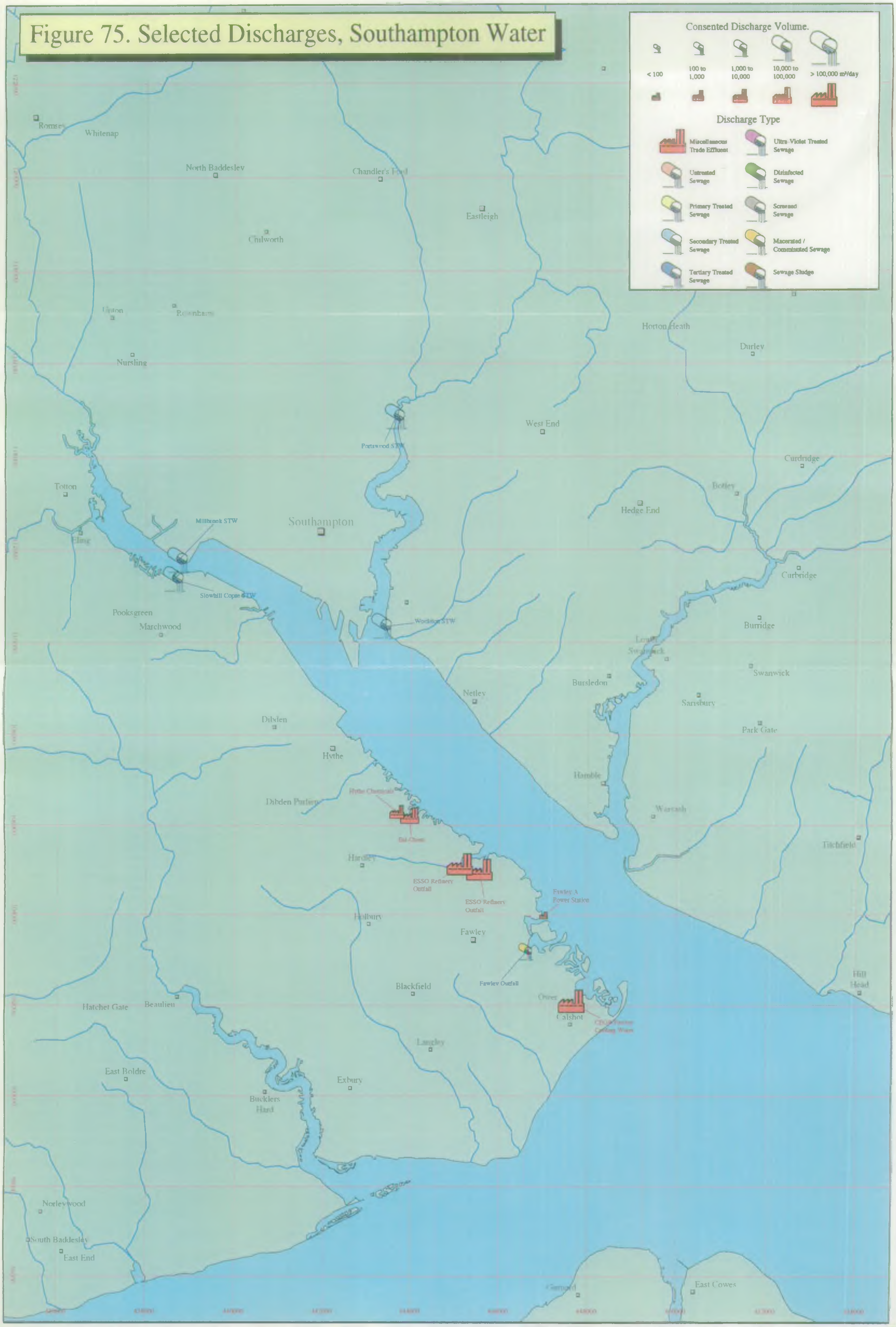


Figure 75. Selected Discharges, Southampton Water
Consented Discharge Volume.
< 100
100 to 1,000
1,000 to 10,000
10,000 to 100,000
> 100,000 m³/day
Discharge Type
Miscellaneous Trade Effluent
Ultra-Violet Treated Sewage
Untreated Sewage
Disinfected Sewage
Primary Treated Sewage
Screened Sewage
Secondary Treated Sewage
Macerated / Comminuted Sewage
Tertiary Treated Sewage
Sewage Sludge
Romsey
Whitenap
North Baddesley
Chandler's Ford
Eastleigh
Chilworth
Nursling
Horton Heath
Durley
Portswood STW
West End
Curdridge
Totton
Botley
Hedge End
Millbrook STW
Southampton
Curbridge
Slowhill Copse STW
Pooksgreen
Marchwood
Woolston STW
Burridge
Swanwick
Bursledon
Netley
Sarisbury
Dibden
Park Gate
Hythe
Hamble
Dibden Purlieu
Warsash
Titchfield
Hardley
ESSO Refinery Outfall
ESSO Refinery Outfall
Fawley A Power Station
Holbury
Fawley
Fawley Outfall
Blackfield
Hill Head
Hatchet Gate
Beaulieu
Calshot
Langley
East Boldre
Exbury
Bucklers Hard
Norleywood
South Baddesley
East End
East Cowes

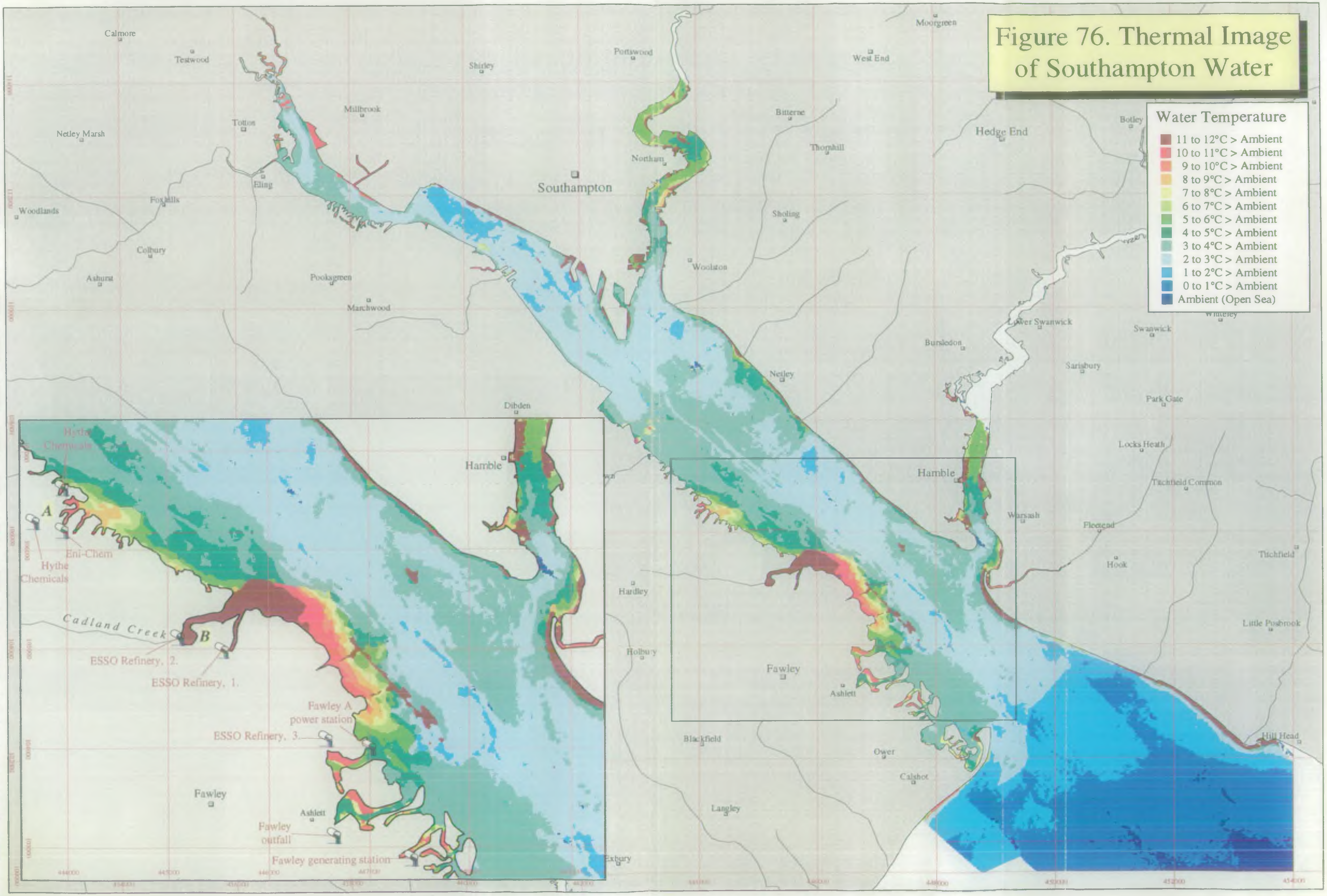


Figure 76. Thermal Image of Southampton Water

Southampton Water
4th August 1996, Low Water

A false colour composite of four CASI images

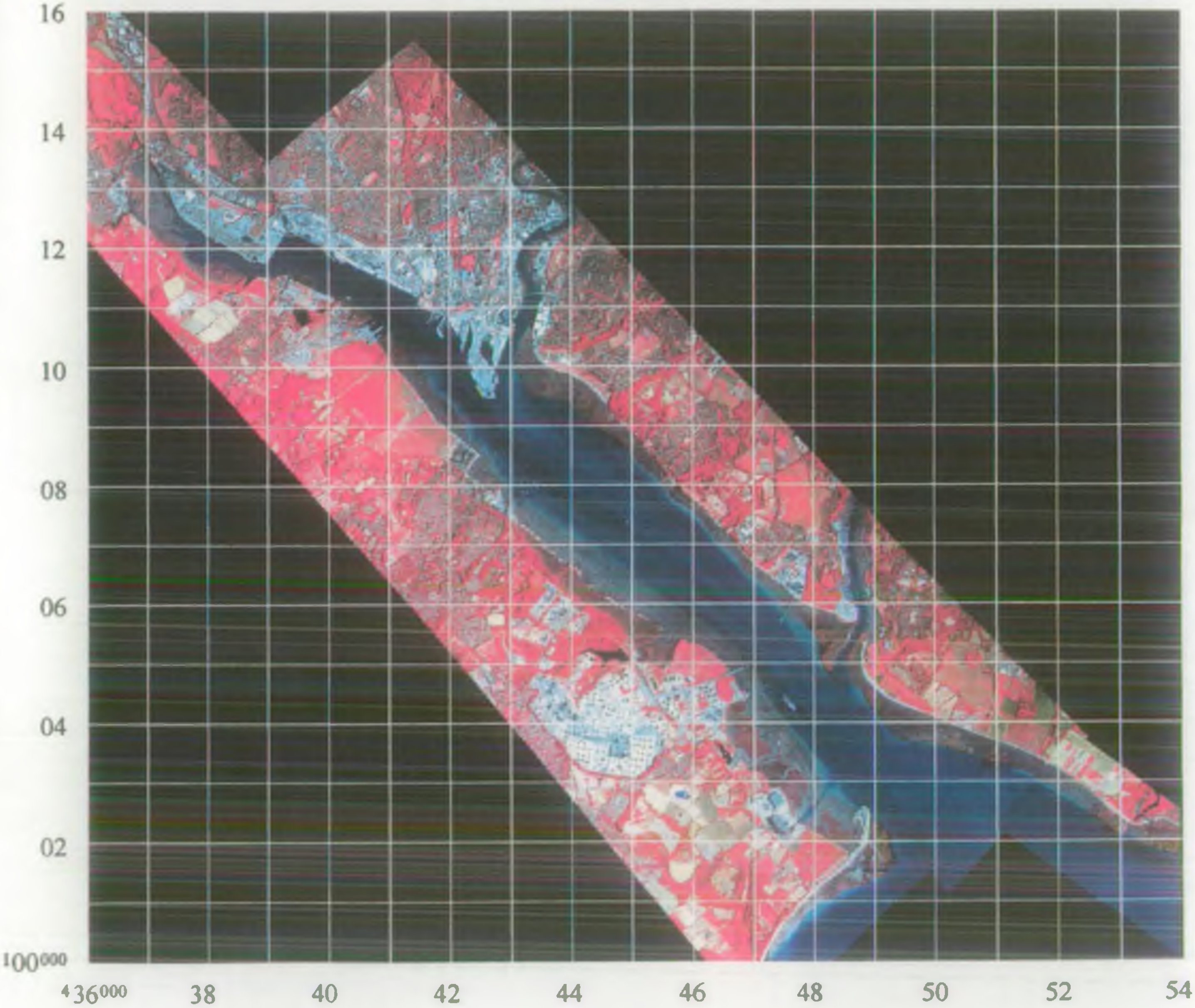


Figure 77

Southampton Water
4th August 1996, Low Water

Unsupervised classification of inter-tidal areas

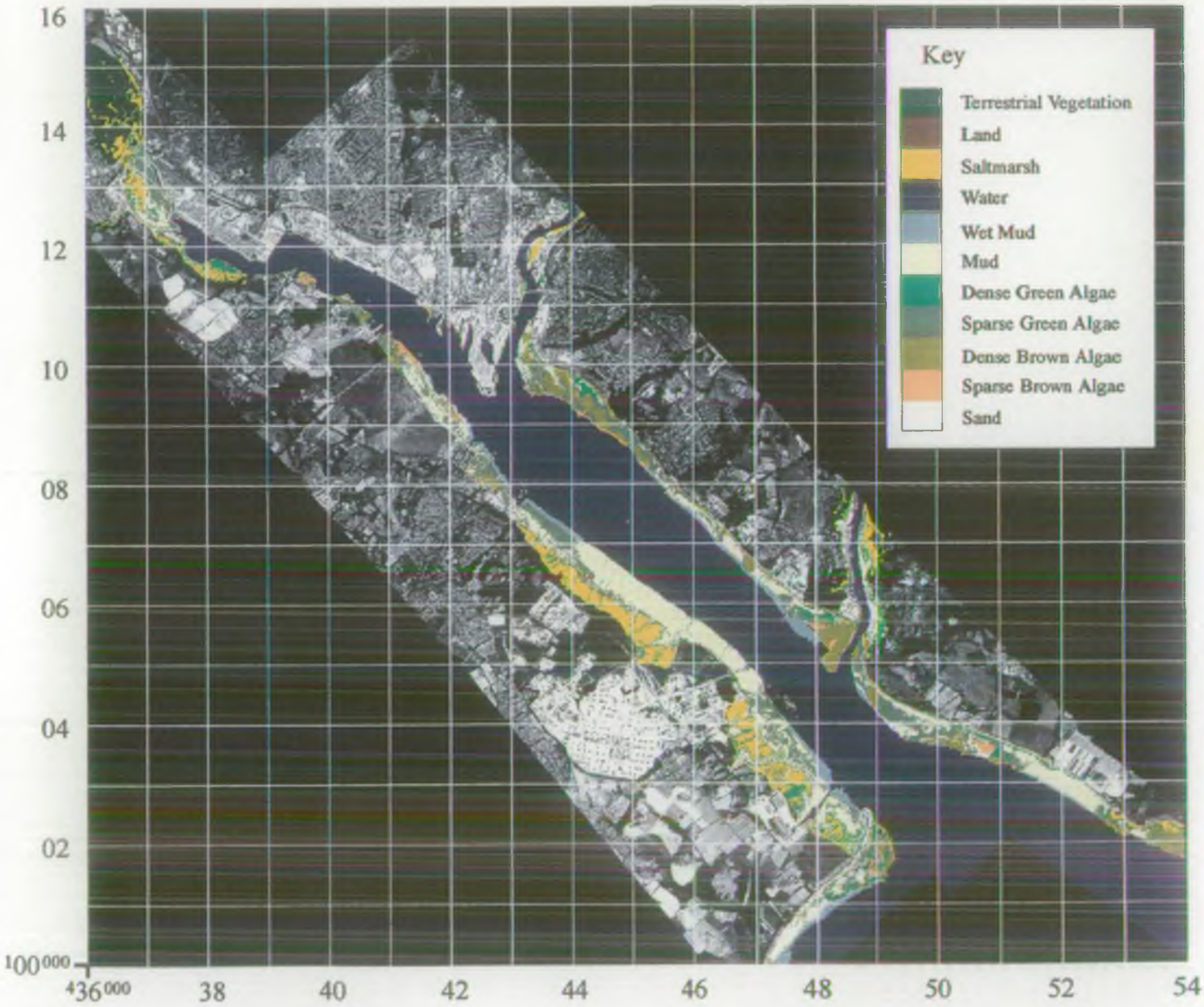


Figure 78

Southampton Water
4th August 1996, Low Water

Unsupervised classification - regions of interest

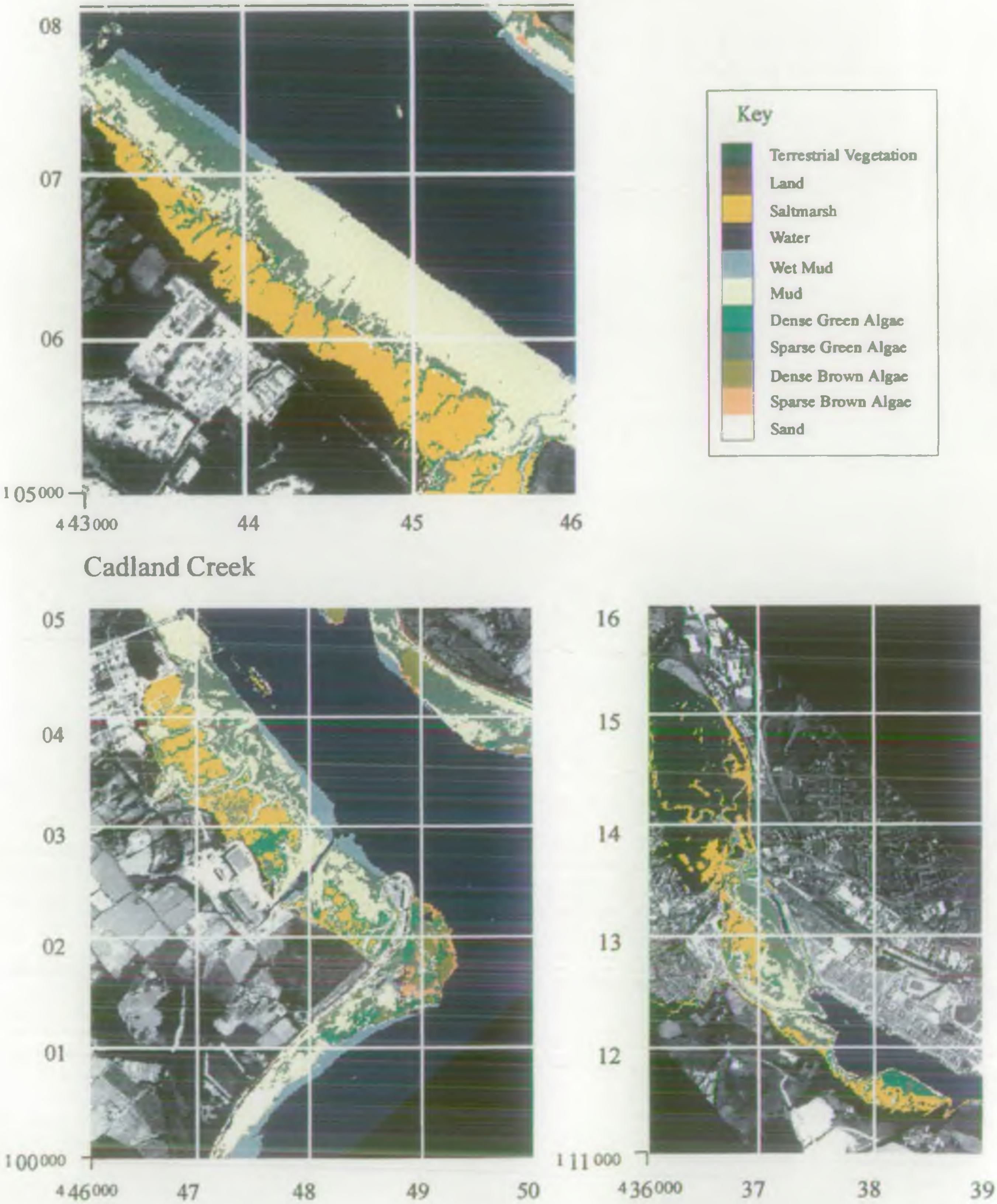
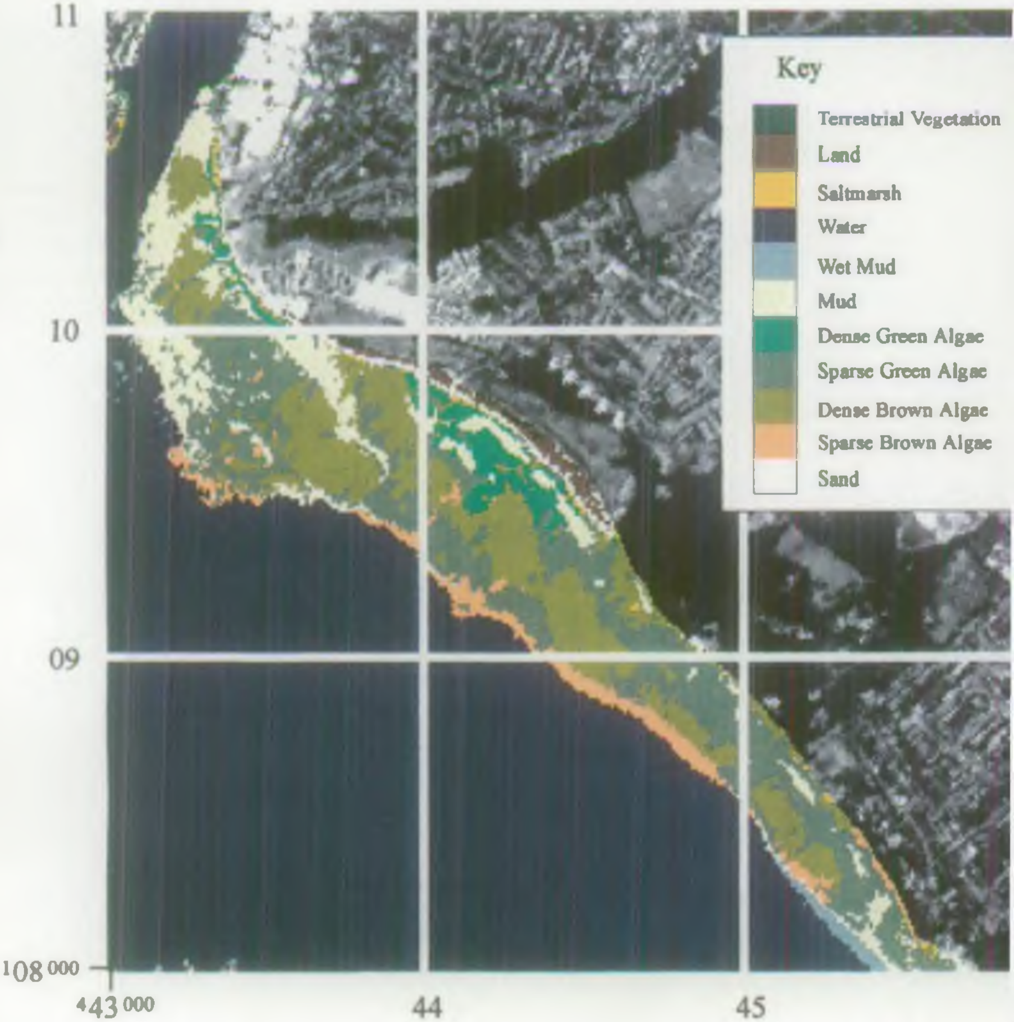


Figure 79

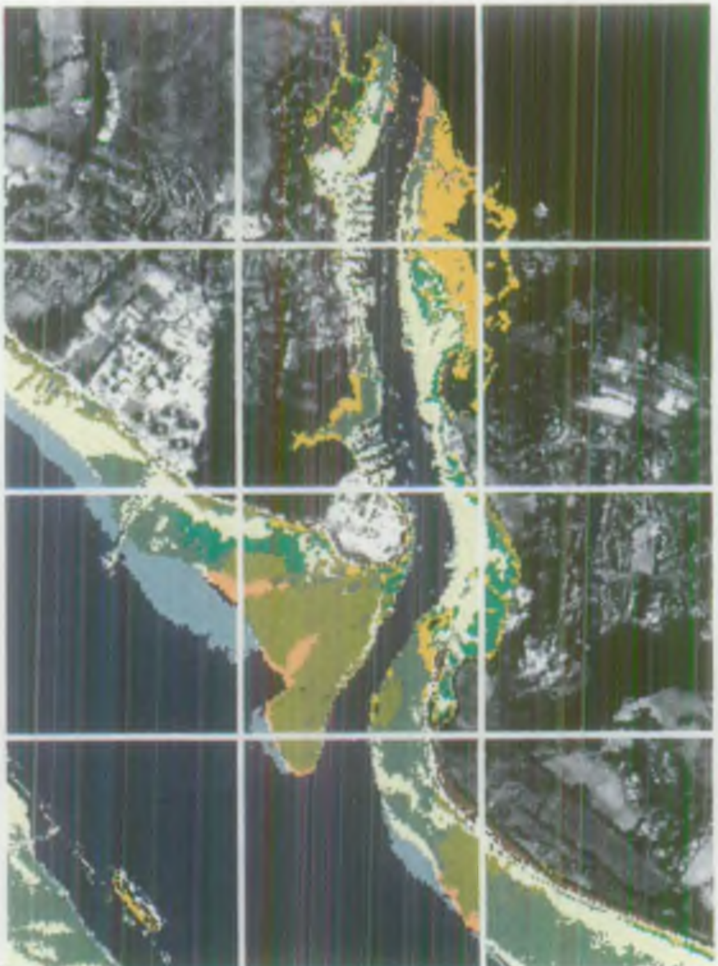
Southampton Water
4th August 1996, Low Water

Unsupervised classification - regions of interest



Woolston

Figure 80



Hamble

3.12 THE TEES ESTUARY

3.12.1 Background Description

3.12.1.1 The River Tees rises at Tees Head in Cumbria, 893 m above sea level, with the source located close to that of the South Tyne and Wear. The estuary forms a wide plain, which is heavily industrialised. The Tees Estuary was originally a coastal plain estuary but now functions as an artificial bar built estuary, due to the construction of the two piers at North and South Gare.

3.12.1.2 The region covered by this survey is shown in figure 81. This map records the positions of Sites of Special Scientific Interest (SSSI) within the estuary.

3.12.1.3 A mosaic of the imagery collected at low water over the lower reaches of the estuary is shown in figure 82. This illustrates the highly industrialised nature of the estuary, with large areas of derelict land. The hazy nature of the imagery is caused by smoke from industrial emissions to air.

3.12.1.4 The industry of the region is predominated by chemical, oil and steel manufacturing, which result in the production of large amounts of special waste. Much of the more recent development has been concentrated downstream, leaving large areas of derelict land in the older industrial areas such as Stockton-on-Tees, Thornaby-on-Tees and Middlesbrough.

3.12.1.5 Although industrial development has decreased recently, the construction of the Tees amenity barrage has resulted in the removal of much of the upper tidal reaches.

3.12.2 Discussion of major issues

3.12.2.1 The Tees Estuary is highly industrialised, having major chemical, oil and steel manufacturing complexes with corresponding extensive port facilities. Removal of land for industrial purposes has been extensive, resulting in less than 470 ha of intertidal zone remaining, in comparison with over 2,500 ha in the mid 19th Century (Davidson, 1995*a*). Despite this loss of mudflats, the presence of a number of migratory birds such as Redshank and Wigeon are now higher than in the 1950s and 1960s (Industry Nature Conservation Association).

3.12.2.2 The effects of the opening of the Tees amenity barrage in 1995 have been assessed by two major water quality surveys in 1990 and 1995. Key results show that the physical structure of the estuary has been greatly changed by the barrage, in particular with changes seen in the tidal currents measured at a water sampling station located 9.5 km downstream.

3.12.2.3 Water quality in the middle and lower reaches of the estuary has improved over recent years. This is reflected by the passage of salmon and sea trout through the Tees Barrage and the return of breeding seals to Seal Sands.

3.12.2.4 Seal Sands is the major area of remaining inter-tidal vegetation within the estuary, having regions of saltmarshes and algal development on the mudflats.

3.12.3 Discharge mixing zones

3.12.3.1 The large number of industrial discharges situated within the Tees Estuary has potential implications on the general water quality of the estuary and compliance with EC Directives. Tioxide UK Ltd discharges to Laing Basin, one of only three titanium dioxide discharges in the UK, which must be monitored under the provisions of the Titanium Dioxide Directive (78/176/EEC).

3.12.3.2 The positions of selected consented sewage and trade effluent discharges within the Tees are marked on figure 83.

3.12.3.12 Many of the industrial discharges are subject to monitoring under the Dangerous Substances Directive (76/464/EEC), and the problem of bio-accumulation of dangerous substances has been recognised by the Environment Agency (Environment Agency, 1996). Water quality surveys show an improvement in chemical water quality from 1990 to 1995.

3.12.3.4 Aerial surveillance data were collected from the Tees Estuary on 16th June 1996 between 16:20 and 17:47 GMT, with High Water at River Tees Entrance being at 15:54 GMT. A total of 14 flightlines were flown, at an altitude of 4,000 ft, encompassing the estuary from the mouth, past the tidal barrage and down to the old tidal limit near Yarm.

3.12.3.5 The airborne thermal data shows strong thermal contrast between the ambient estuarine water and the inputs from various discharges and docks. The full temperature range within the water was in excess of 12°C, with coldest temperatures offshore and warmest temperatures upstream of the tidal barrage and within effluent plumes. The CASI data also shows the presence of many effluent discharges which have clearly defined mixing zones of differing water colour.

3.12.3.6 In order to illustrate changes in water temperature, the thermal data were calibrated to relative temperature. The temperature of offshore water was then selected as the ambient temperature and graduations of 1°C above this plotted.

3.12.3.7 Teesmouth was overflown twice within the data collection period with data from set of discharges is made up of a number of chemical discharges from companies located within the old ICI complex. This channel shows temperatures more than 12°C above ambient in the earlier data collection period, with the plume to the main channel having temperatures up to 10°C above ambient. One hour later the temperatures have decreased to a maximum of 8°C above ambient.

3.12.3.8 In both images the direction of flow of the discharge is downstream which is consistent with the tidal state of 1 to 2 hours after High Water, with the effluent remaining close to the East bank. The thermal effect is clearly illustrated up to 1km downstream, at which point the plume is interrupted. There is, however, no further source of effluent at this point, which suggests some physical effect constraining the original plume, before it disperses once more downstream.

3.12.3.9 Although the plume from this discharge represents the largest inflow of water to the Tees, no samples taken to test for compliance with the Dangerous Substances Directive (76/464/EEC) have exceeded Environmental Quality Standards in recent years.

3.12.3.10 Tioxide UK Ltd. discharges to Greatham Creek, at a point upstream of Laing basin (see figure 85). The Seal Sands region has an elevated temperature relative to the surrounding estuary, due to enhanced warming in shallow water. The actual discharge has a temperature that is 3 to 5°C warmer than ambient, which is shown as a distinct mixing zone 1 to 2°C higher than surrounding waters. In order to test for compliance with the Titanium Dioxide Directive, measurements are taken of the surrounding waters prior to discharge, and subsequently within the discharge plume. This discharge has met the requirements of the Titanium Dioxide Directive at all times.

3.12.3.11 Hartlepool nuclear power station outfall is marked on figure 83. A thermal signal from this discharges is clearly shown in both figures 84 and 85, having a temperature that is 8 to 9°C above ambient. The mixing zone has a similar definition in both figures, with no apparent warming extending greater than 200 m from the discharge point and no movement of the warmer water towards the mouth of the estuary. The tidal state at the time of image collection was such that there is a strong offshore flow of water resulting in efficient dispersion of the warmer water. Data collected in previous surveys has shown that at certain tidal states the mixing zone from Hartlepool power station acts to seal the estuary, with a plume of warmer water across the mouth. This may warrant a further investigation over a tidal cycle, in addition to sampling throughout the water column to assess the depth to which this mixing zones extends.

3.12.3.12 Figure 85 shows the presence of a number of outfalls from ICI which contribute to generally warmer water close to the shoreline. The presence of shallow, slower moving water close to the shore makes the effects of this outfall difficult to define. Investigation of the CASI imagery reveals a variation in water colour signal at least 1 km downstream at this tidal state, with the greatest influence on the north west bank.

3.12.3.13 There are a large number of effluent outfalls along Billingham Beck, from the ICI Billingham complex. Although this tributary to the Tees has a higher temperature relative to the Tees itself, it is not possible to distinguish distinct outfall mixing zones within the beck in the aerial imagery due to its narrow width. The input of the beck to the main estuary causes a small but significant increase in temperature downstream of the confluence, with temperatures elevated by approximately 1°C.

3.12.3.14 Sampling to test for compliance with the Dangerous Substances Directive is carried out within the beck. Investigation of the imagery would suggest that sampling at any point within the beck itself would give a representative result as the width of the beck is such that there is a fairly homogenous temperature regime. It is not possible to state this conclusively, however, without a more detailed investigation of the temperature regime of the beck. Latest results show no failures of EQS values from these outfalls.

3.12.3.15 The Tees amenity barrage, marked on figures 81, 84 and 85 was completed in January 1995. The thermal imagery records upstream water temperatures between 4°C and 9°C greater than those downstream of the barrage. These waters, from riverine sources, have not mixed with the cooler tidal waters because of the presence of the barrage.

3.12.3.16 The presence of the barrage therefore clearly has a marked influence on the temperature regime of the estuary, prohibiting the mixing of cooler estuarine water with water upstream. Water quality surveys have shown that the presence of the barrage has changed the physical characteristics of the estuary, particularly the tidal currents, up to 9.5 km downstream (Riddle *et al.*, 1996).

3.12.3.17 All outfalls which were originally discharging to the tidal waters upstream of the barrage have been relocated resulting in the discharge of sewage effluent downstream of the barrage. Many will finally be diverted to the major new treatment plant and associated outfall at Bran Sands (see figure 83).

3.12.3.18 The first stage in the implementation of this scheme is the redirection of the Portrack sewage works, via a pipeline which is currently under construction. The Cargo Fleet sewage treatment works will eventually be diverted to this outfall, along with many industrial discharges. The scheme is set to be completed in 2002. The imagery shows no signs of effluent discharge from either the Portrack or Cargo Fleet sewage treatment works, which is contrary to ground based studies which noted an effluent plume from Portrack during water quality surveys in 1995.

3.12.4 Saltmarsh and beaches

3.12.4.1 The presence of saltmarsh and beaches within an estuarine environment acts as a defence against coastal flooding, by dissipating the wave and tide energy and by providing a physical barrier against the passage of water. Saltmarsh is also a highly diverse habitat, supporting a wide variety of flora and fauna. This provides both a feeding and breeding ground for migratory birds, particularly wader species.

3.12.4.2 The saltmarsh of the Tees Estuary has been removed by industrial development as described in section 3.12.2. The inter-tidal mudflats remain an important and growing resource with the return of seals and migratory birds to this estuary.

3.12.4.3 Figure 86 shows a mosaic of false colour composite images of the lower Tees Estuary. This image shows the presence of vegetation as red due to its high near infrared signal. There is little evidence of vegetation within the inter-tidal zone except for in the Seal Sands area. Areas of vegetated land are seen in the near shore zone which correspond to derelict land.

3.12.4.4 The CASI data have been used to produce a digital classification of land cover in the inter-tidal zone of the lower Tees Estuary. This classification relies on the variation in all spectral channels of the CASI but is particularly sensitive for distinguishing between vegetated and non-vegetated surfaces. The results of this classification are shown in figure 87, with the numerical data being held in table 14.

Land cover classes	Area (ha)	% Cover
Mud and sand	242	65
Sand	77	20
Brown algae	29	8
Dense green algae	26	7
Total	**374**	**100**

Table 14: Inter-tidal land cover classification for the lower Tees Estuary, 15th September 1996

3.12.4.5 It is clear from figure 87 that the inter-tidal zone of the Tees Estuary is narrow except for two areas close to the estuary mouth. These areas are covered by mudflats, with areas of sand only shown in the outer harbour. The classification does not distinguish any saltmarsh within this estuary.

3.12.4.6 Within Seal Sands, the classification technique classifies the surface cover as dense algae. This may be a mis-classification, with this area actually containing small amounts of saltmarsh. The sea wall of this area has recently been breached which has allowed the development of algae on the mudflats, but is also promoted the growth of pioneer saltmarsh (Donoghue *pers comm.*).

3.12.4.7 The absence of any inter-tidal mudflats along the majority of the length of the estuary means that no protection is offered to the artificial shoreline of this estuary.

3.12.5 Inter-tidal vegetation

3.12.5.1 The presence of macro-algae on the inter-tidal mudflats of an estuary may signify that this estuary is subject to eutrophication. Macro-algal growth is one of the indicators proposed by the Department of the Environment for the determination of Sensitive Areas under the provisions of the Urban Waste Water Treatment Directive.

3.12.5.2 The digital classification shows the presence of algae on the mudflats of the lower Tees Estuary. The major area of dense algal growth is found within Seal Sands. As discussed in section 3.12.4.6, this region may partially consist of pioneer saltmarsh community, since in recent years the seawall of this region has been breached, allowing a case of natural managed retreat to develop.

3.12.5.3 There are further small patches of sparse algal cover within the harbour, mostly found around the South Gare artificial barrier. The majority of sewage effluent for this region is discharged to the Seaton Carew long sea outfall shown on figure 83, outside the harbour. It is unlikely that sewage effluent is enhancing the growth. The Tees Estuary has historically recorded high nutrient concentrations from estuarine sources which may potentially be enhancing the algal growth.

3.12.6 Summary of estuary

3.12.6.1 The aerial imagery of the Tees Estuary collected throughout 1996 has revealed information on the environmental quality of the estuary. The lower reaches of the estuary are highly altered, either by past or present industrialisation, with derelict land clearly seen on both shores of the estuary. A visual estimation shows 65% of the shoreline to be developed. Remediation of areas of contaminated land is ongoing in this estuary.

3.12.6.2 The imagery has provided information on the mixing zones of a number of key effluent discharges within the Tees Estuary. This data will aid in the establishment of future monitoring studies, and may prove of use in the determination of the consent for the new Bran Sands discharge site. The imagery may also be integrated into the numerical models being developed by Environment Agency North East region.

3.12.6.3 The importance of industry in this zone is clearly illustrated, with the imagery identifying more discharge mixing zones than other estuaries surveyed in this study. The collection of data in June aided in the differentiation of discharging waters, when water temperatures had not been prone to seasonal warming.

3.12.6.4 The possible return of natural saltmarsh habitat to the Seal Sands estuary is illustrated in data collected at low water. This area is the only extensive mudflat between Lindisfarne and the Humber and presently provides an important feeding area for wading birds. Thus, the return of saltmarsh may prove detrimental to this important habitat.

3.12.6.5 The growth of this region may be monitored using aerial surveillance, with integration of digital classifications into a Geographical Information System. This will also allow assessments to be made of long-term changes due to climate change. Recent studies suggest an increase in sea level of 37 cm across the UK by the year 2050 (DoE, 1996).

3.12.6.6 An increase in sea level will result in flooding of the present inter-tidal zone, which may be marked due to the low lying nature of the estuary, with much of the current development being on reclaimed land. For large parts of the Tees Estuary the inter-tidal zone is narrow and consists of artificial structures. These will need further development to allow protection of valuable assets in terms of industrial and urban development.

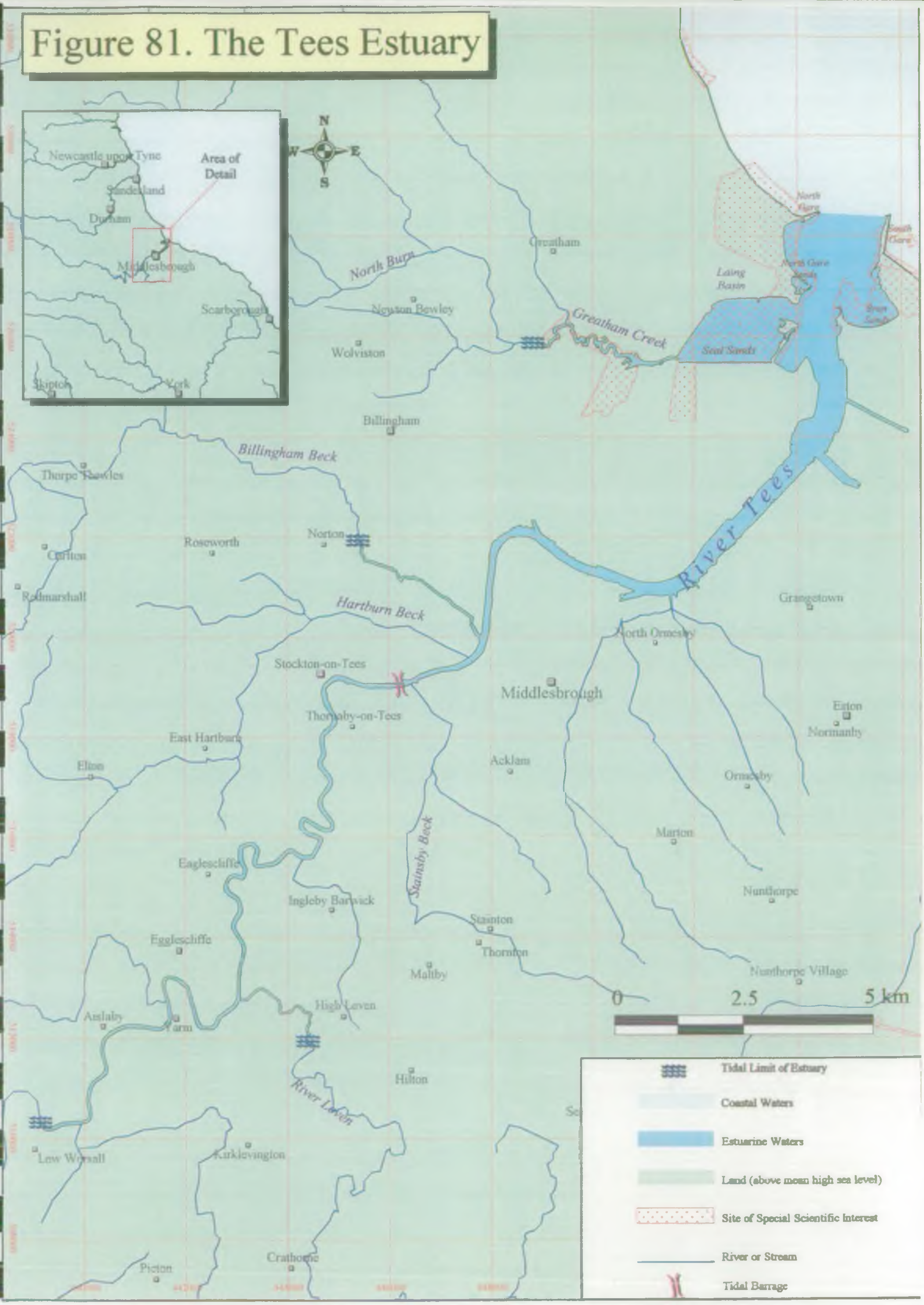


Figure 81. The Tees Estuary

Tees estuary
16th September 1996
Low water

True colour composite
of five CASI images

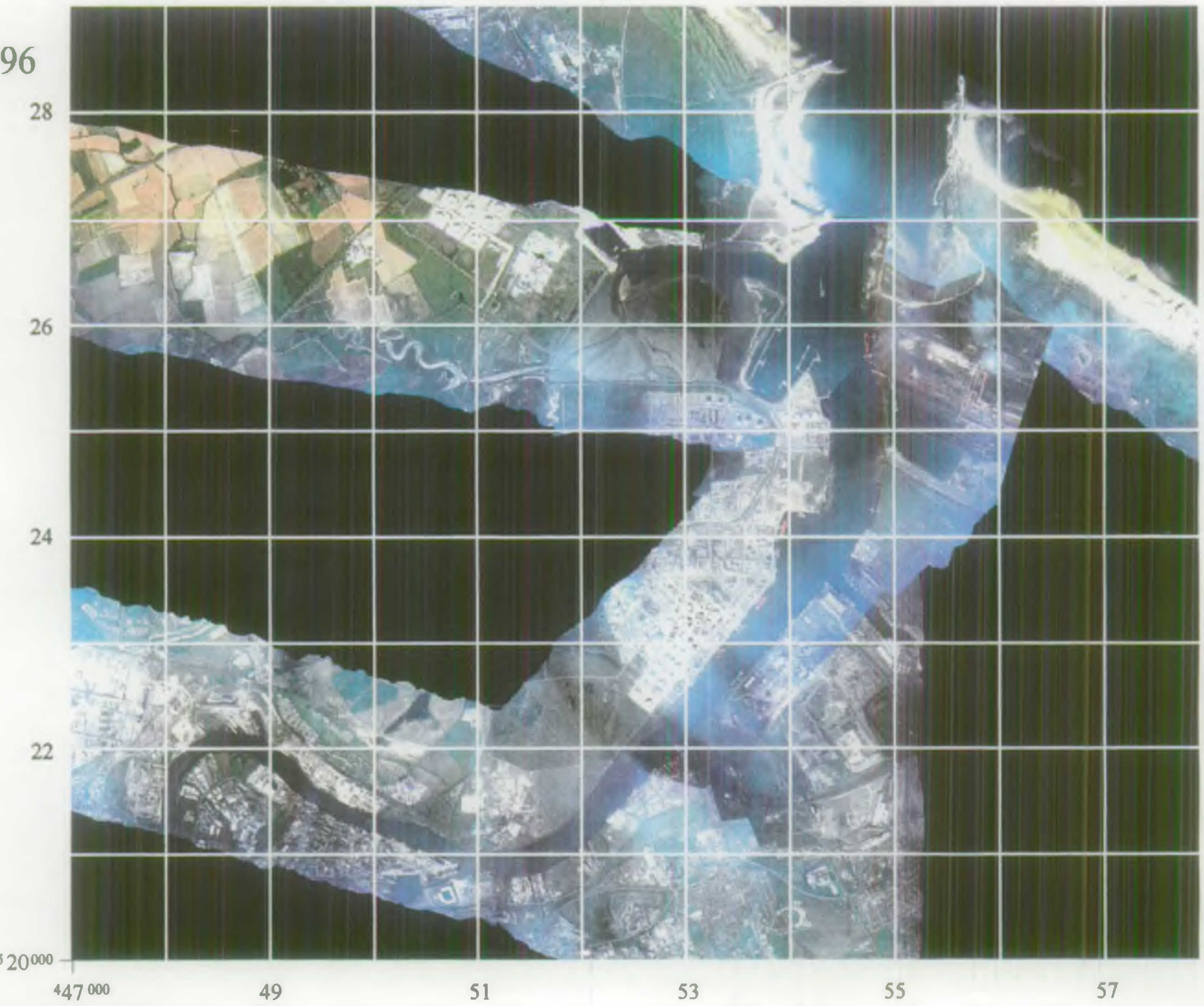


Figure 82

Figure 83. Selected Discharges, The Tees Estuary

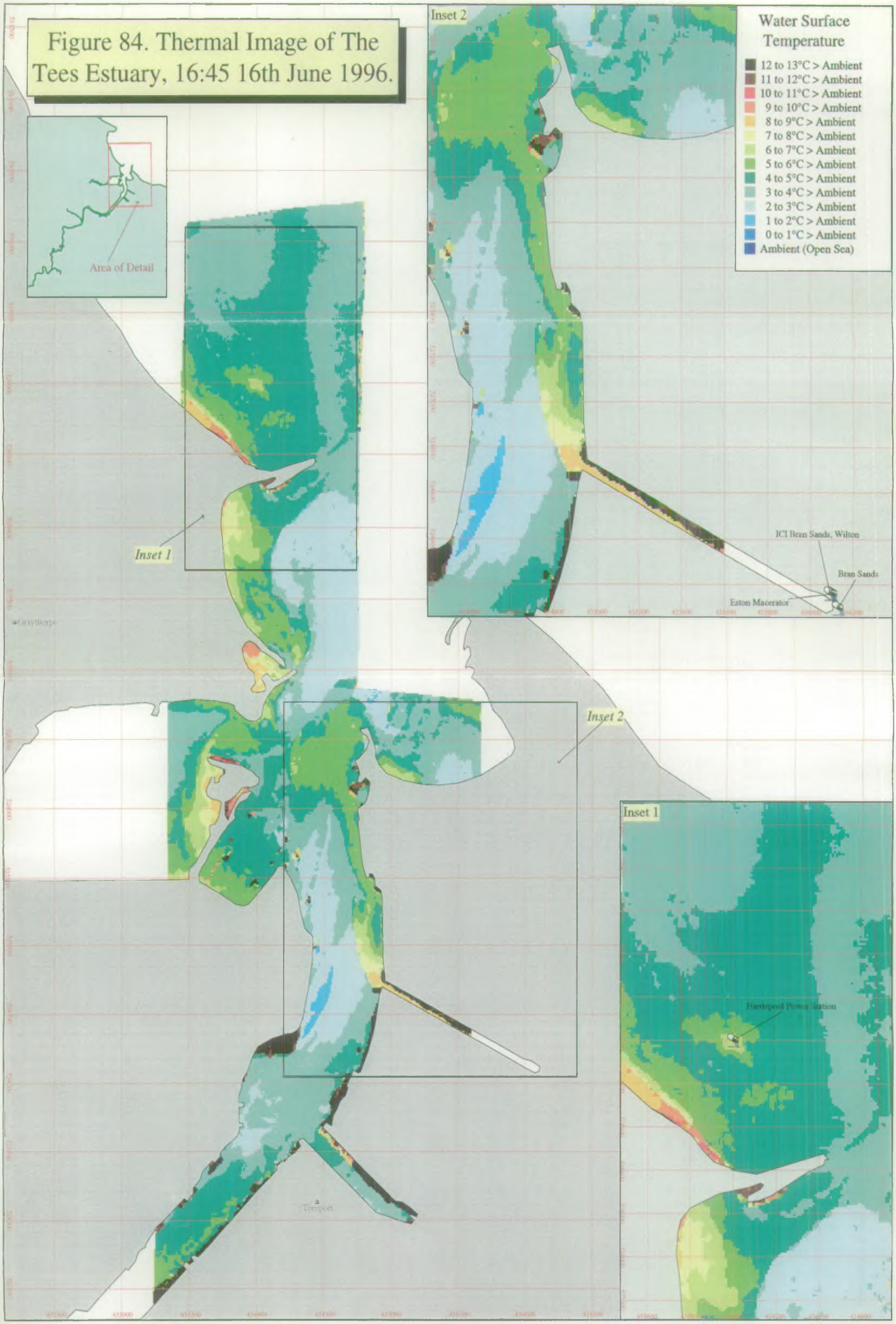


Figure 84. Thermal Image of The Tees Estuary, 16:45 16th June 1996.

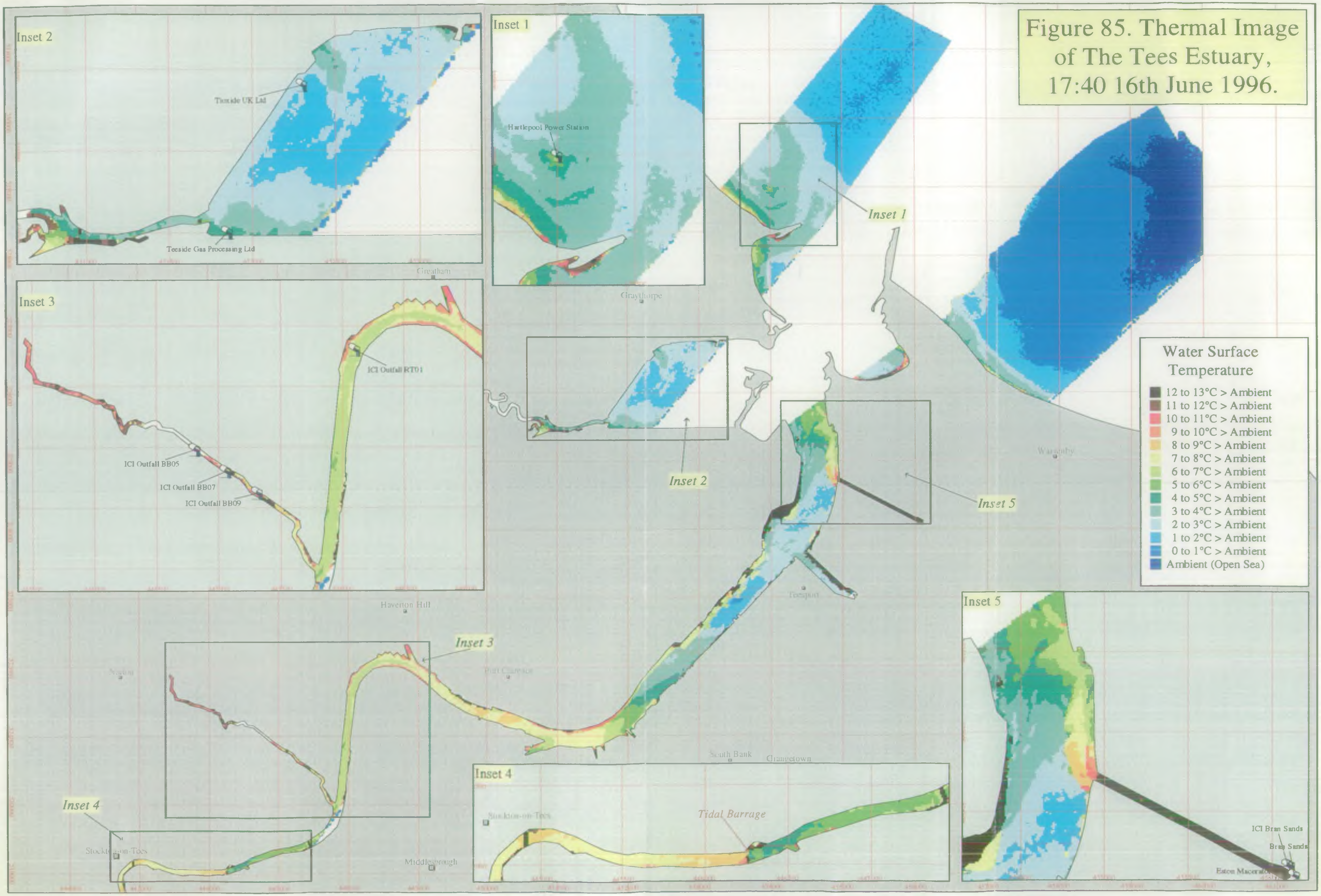


Figure 85. Thermal Image of The Tees Estuary, 17:40 16th June 1996.

Tees estuary
16th September 1996
Low Water

False colour composite
of five CASI images

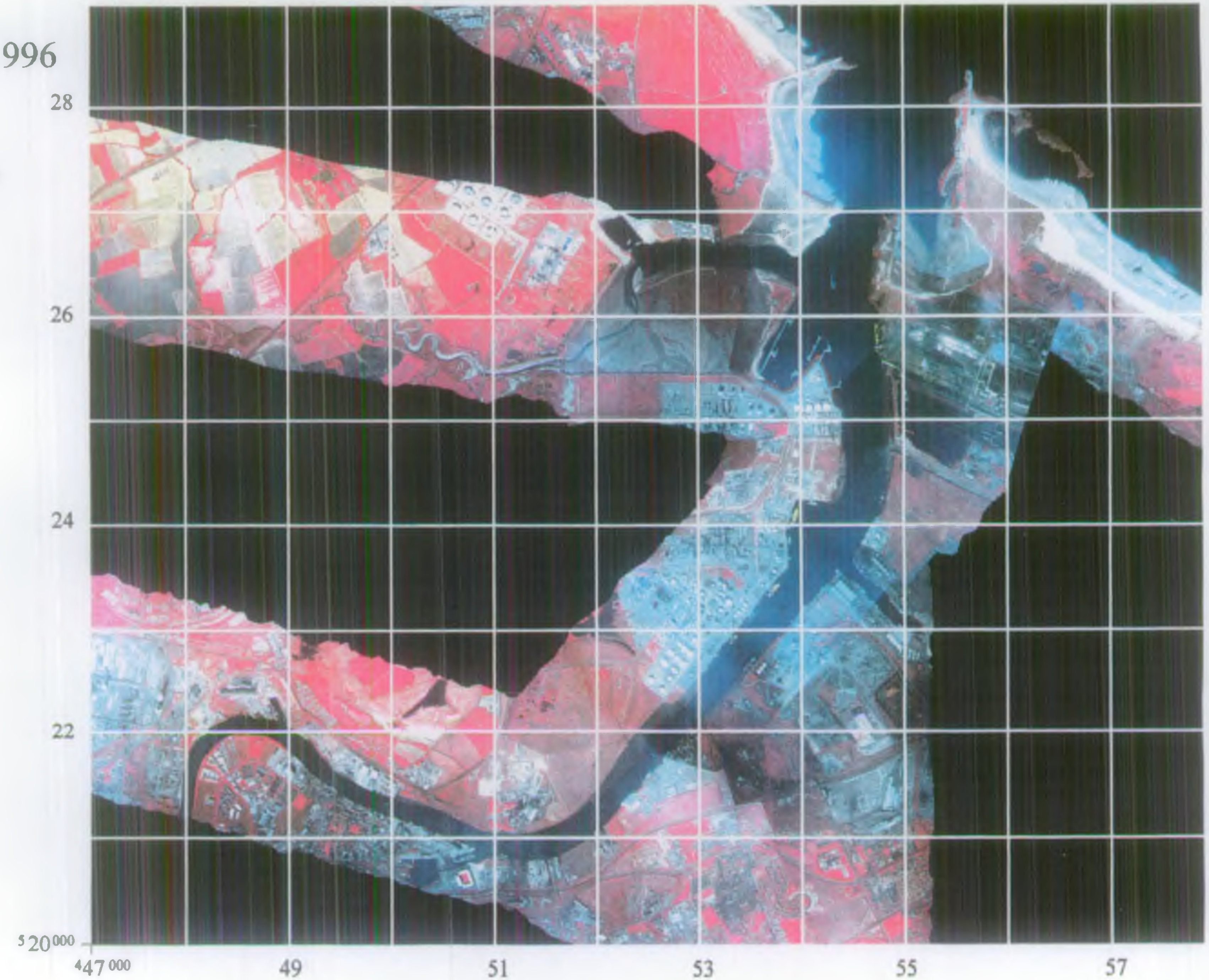
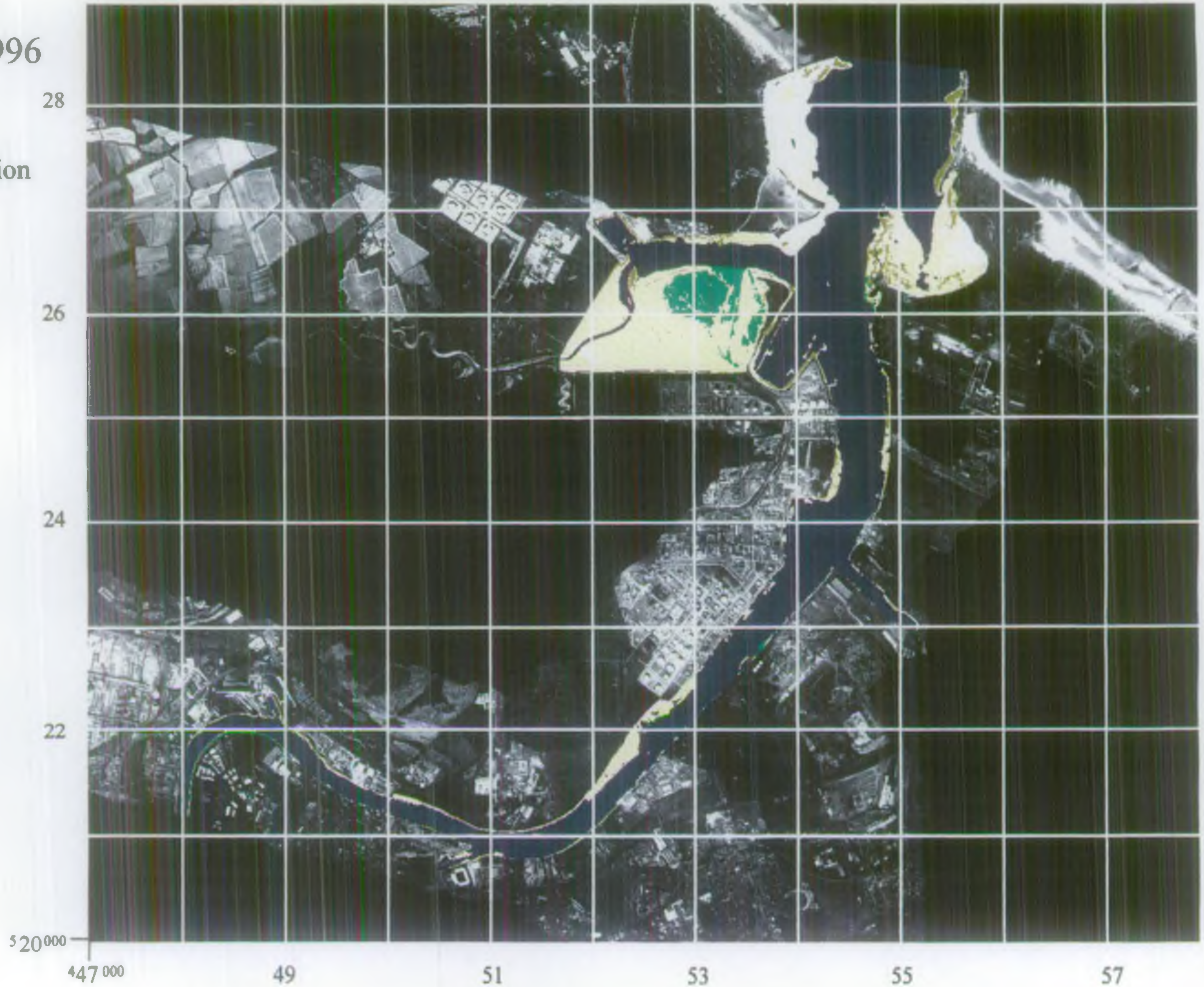


Figure 86

Tees Estuary
16th September 1996
Low Water

Unsupervised classification of inter-tidal areas



Key

- Water
- Mud
- Green Algae/Saltmarsh
- Green/Brown Algae
- Sand

Figure 87

3.13 THE TYNE ESTUARY

3.13.1 Background Description

3.13.1.1 The River Tyne has the largest river catchment within the North East region of the Environment Agency. The estuary is generally narrow and steep sided, with former areas of tidal flats near the estuary mouth having disappeared through harbour development and use of land for industrial purposes.

3.13.1.2 The tidal limit is at Wylam, approximately 30 km from Tynemouth where the Tyne reaches the North Sea. Downstream of the tidal limit the river is increasingly affected by human activity, with major development at Newcastle, Gateshead and on both sides of the estuary downstream of Gateshead. Figure 88 illustrates the estuarine area from Wylam to Tynemouth and includes those areas designated as Sites of Special Scientific Interest (SSSI).

3.13.1.3 Figure 89 shows a mosaic of true colour composite images taken at low water on 16th September 1996. The image illustrates the narrow nature of the estuary and in particular the very narrow width of the inter-tidal zone.

3.13.1.4 Heavy industry within the area, for example ship building, has declined over recent years, with lighter industry replacing this in business park type developments.

3.13.2 Discussion of major issues

3.13.2.1 The water levels of the Tyne are controlled by releases from the Kielder Reservoir, which allows water levels to be maintained during summer months.

3.13.2.2 Recently, a large number of salmon deaths have been recorded in the upper estuary, on a scale exceptional to the rest of the UK. A major study in 1995 proposed that the fish deaths were caused by poor estuarine water quality, which left fish susceptible to disease. In future years attempts will be made to decrease the release of organic loads to the estuary during summer months, whilst increasing the oxygen concentration by oxygenation, and physically assisting fish past the tidal limit at Wylam.

3.13.2.3 The water quality of the Tyne Estuary has improved over recent years with the development and implementation of the Tyne Sewage Interception Scheme (TSIS). This scheme discharges from Howdon Pans and is marked on figure 88. It collects the majority of the trade and sewage effluent from the estuarine reaches. Although 110 discharges have still to be included within the scheme, these account for only 8% of the total volumetric load. The dissolved oxygen sag which occurs within the estuary is associated with this scheme, and the discharge of organic load is therefore being decreased to improve the quality of the estuary (National Rivers Authority, 1995*d*).

3.13.2.4 Water quality monitoring in the Tyne Estuary may be broken down into three major sections: statutory monitoring, national surveillance and regional operational monitoring. National surveillance is associated with the National Water Council (NWC) Estuary Water Classification Scheme. For 1995, the estuary was classed as good upstream of Ryton and downstream of Albert Edward Dock, with fair water quality between these sites. This was a marked improvement over earlier years, with poor quality recorded in 1990 for much of the upper estuary. This improvement may be attributed to the implementation of the TSIS.

3.13.2.5 Detailed water quality surveys in 1995, however, showed a pronounced sag in dissolved oxygen concentration, particularly in summer months, which will be potentially lethal to migratory fish. The position of this sag showed it to be associated with the plume from Howdon Pans sewage treatment works, with a small but significant contribution from Rohm and Haas (NRA, 1996).

3.13.2.6 Suggestions for alleviation of this problem include a reduction of the loading of these discharges in summer months, and bringing forward the conversion of Howdon Pans sewage treatment works to secondary treatment.

3.13.2.7 The Tyne Estuary is used for many recreational activities, including both passive and active pastimes. It is anticipated that the use of the estuary for recreation will continue to increase as industry declines. The aesthetic quality of the estuary is therefore of importance.

3.13.3 Discharge mixing zones

3.13.3.1 The major discharge to the Tyne Estuary is from the Tyne Sewage Interception Scheme (TSIS) at Howdon Pans. Figure 90 shows the positions of selected consented sewage and trade effluent discharges to the Tyne Estuary.

3.13.3.2 Other significant discharges to the estuary are from Rohm and Haas at Jarrow, which is the next largest organic load after Howdon Pans, and Resinous Chemicals at Dunston (National Rivers Authority, 1995*d*).

3.13.3.3 The Tyne Estuary was surveyed on 27th of July at three tidal states: on the rising tide, at high water and on the falling tide. Six flightlines were recorded at each tidal state. Both the CASI and thermal imagery were of good quality, with high variability in the CASI signal indicating variable suspended sediment loading along the length of the estuary and at different tidal states. The thermal data did not show great variability, which is probably due to the date of collection of data. Greatest temperature variations are seen in Spring and Autumn, with temperatures in July being fairly constant. Moreover, the estuarine water will be warm and thus discharges will be less apparent.

3.13.3.4 The position and extent of major discharges evident in the imagery have been drawn on figure 91. The delineation is based on the maximum extent to which the change in either water colour or temperature is evident.

3.13.3.5 The major discharge recorded in the aerial imagery is from Howdon Pans, the site of discharge of the TSIS. The position of the mixing zone on the rising tide is shown to originate from Howdon Pans and move upstream, with signs of movement across the width of the estuary. The different penetration depths of the two techniques reveal different shaped mixing zones. The CASI imagery reveals the concentration of pollutants in the top surface layer, typically between 1 and 10 m, whilst the thermal system records the temperature only at the surface. The thermal signal is more widely spread, but does not extend to the distance of the CASI signal. This is consistent with a scenario of effluent sinking through the water column as its distance from the discharge increases.

3.13.3.6 There is no variation in the signal at the point of discharge of the Rohm and Haas outfall, and it is therefore not possible to state whether the effluent from here is contained within the plume.

3.13.3.7 The Howdon Pans discharge was also visible at high water, but had a less distinctly defined mixing zone. The direction of movement was again upstream. In the data collected on the falling tide there was no detectable discharge mixing zone at this point.

3.13.3.8 A further discharge is recorded in the imagery collected on the rising tide close to Newtown. The thermal and CASI data record a different mixing zone and it is possible that these indicate two separate discharges. The discharge register shows two sewage effluent discharges at this point although these do not discharge significant volumes.

3.13.3.9 At high water there was a large streak of highly reflective material occurring in the Dunston area, extending downstream to beneath the Tyne Bridge, where the patch had been broken down into a number of smaller regions. The signature of the substance within the CASI data is indicative of a surface film. A similar feature was recorded in data from the Wear Estuary which appeared to have source at a sewage treatment works. The source of the feature in the Tyne data is not clear, although there are a number of both sewage and trade effluent discharges in this region. Further downstream close to Elswick the data records a feature of similar spectral characteristics. Again it is not possible to discern the exact source of this feature.

3.13.3.130 The thermal data shows a plume of warmer than ambient water emanating from the docks at Dunston. This water may have been warmed by a large number of outfalls in the region. The direction of flow of the water is contrary to the tidal stream at the time of data collection. It is possible that there are currents running contrary to the tidal direction, close to the river banks.

3.13.4 Saltmarsh and beaches

3.13.4.1 The presence of saltmarsh and beaches in the inter-tidal zone of an estuary protects the shoreline from coastal flooding, by dissipating the wave and tide energy and by acting a physical barrier to the passage of water. Saltmarsh is a diverse habitat supporting a wide variety of flora and fauna and providing a haven for migratory birds.

3.13.4.2 Figure 92 shows a mosaic of false colour composite images of the Tyne Estuary at low water on 16th September 1996. In this mosaic vegetation is shown as red due to its high infrared reflectance. The CASI data has also been used to produce a digital classification of land cover types in the inter-tidal zone. This classification relies on the variation in all spectral channels of the CASI but is particularly sensitive to the changes in infrared reflectance caused by the presence of vegetation. The results of this classification are shown in figure 93, with a summary of the cover types displayed in table 15.

Land cover classes	Area (ha)	% Cover
Mud	71	31
Wet mud	64	27
Dense algae	55	24
Sparse algae	31	13
Sand	11	5
Total	**232**	**100**

Table 15: Inter-tidal land cover classification for the Tyne Estuary, 16th September 1996

3.13.4.3 Investigation of both the imagery and the table show that there is no saltmarsh within the Tyne Estuary. Tidal flats that existed previously at the mouth of the estuary have been removed for industrial development.

3.13.5 Inter-tidal vegetation

3.13.5.1 The growth of macro-algae on inter-tidal mudflats is an indicator that an estuary is potentially susceptible to eutrophication. This is one of the indicators proposed by the Department of the Environment to establish whether an estuary should be defined as a Sensitive Area under the provisions of the Urban Waste Water

Treatment Directive (91/271/EEC).

3.13.5.2 The digital classification (figure 93) shows the presence of algae on the inter-tidal mudflats of the Tyne Estuary. Although the inter-tidal region is narrow, the algal cover is dense along much of its length. This is more clearly illustrated in figure 94 which shows an enlargement of the estuary between Blaydon and Dunston. It is possible that the algal growth in this region is being enhanced by the effluent from the large number of sewage discharges. The introduction of the TSIS has led to an improvement in water quality in the region, and might be expected to lead to a decrease in the algal growth.

3.13.5.3 This enlargement also shows the collection of algae in docks, for example at Dunston. There is no ground truth data to verify the type of algae in these docks, which may be dense brown seaweed as apposed to the green algae situated elsewhere in the estuary.

3.13.5.3 The harbour at Tynemouth is also shown in more detail in figure 94. This area has the widest inter-tidal zone of the estuary, with sandy beaches on the southern side and mudflats to the north. The northern shore in particular is covered by fairly dense algae, with sparse cover over the majority of the remaining area.

3.13.6 Summary of estuary

3.13.6.1 The aerial surveillance data of the Tyne Estuary collected throughout 1996 has provided some indication of the environmental quality of this estuary. The land use in the estuary is the most heavily developed of the estuaries surveyed, being visually estimated at 80% of the shoreline, with large amounts of both urban and industrial development.

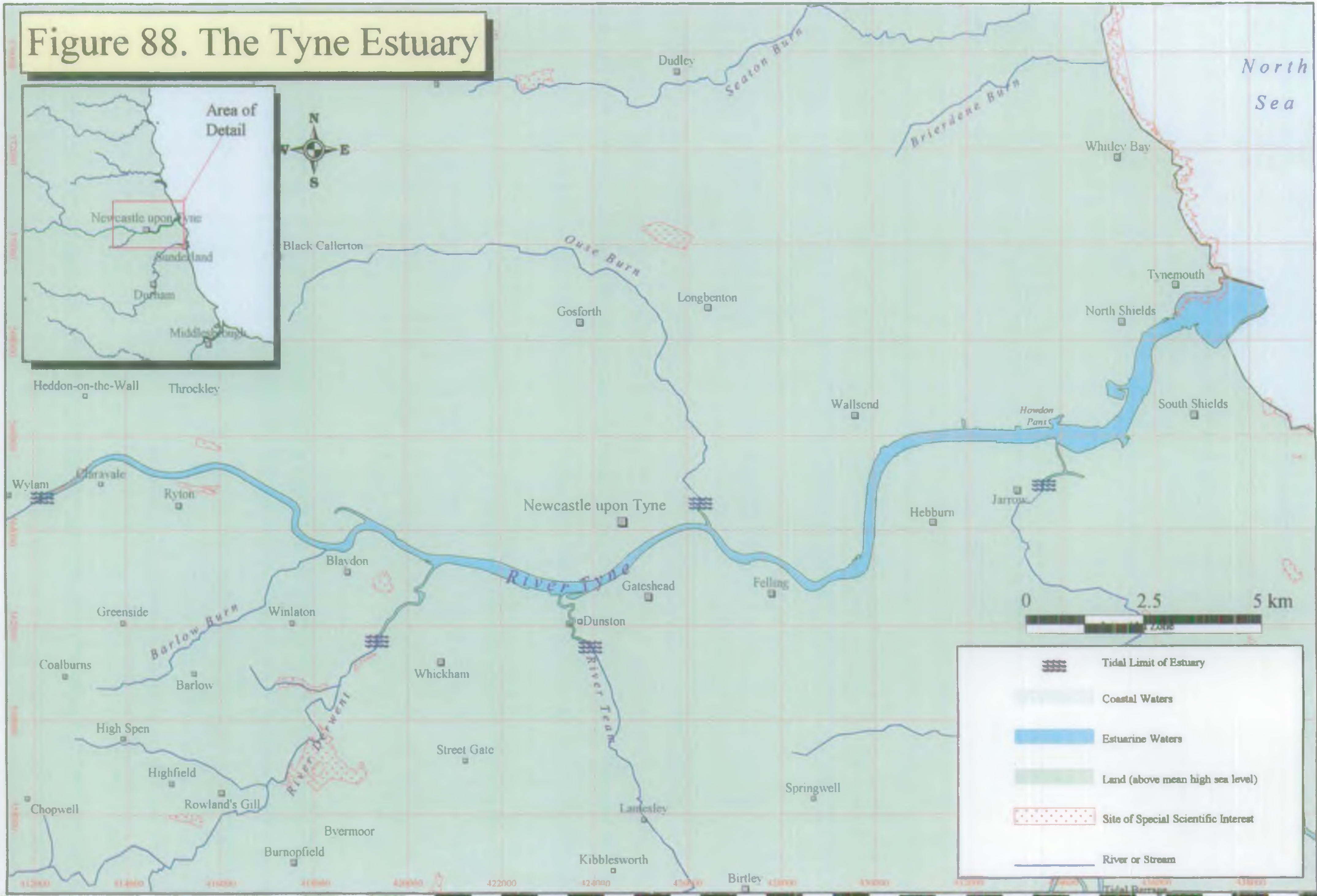
3.13.6.2 The implementation of the Tyne Sewage Interception Scheme is ongoing. This has made it difficult to establish the exact source of many of the discharge mixing zones recorded in the CASI and thermal data. The data did not record a large number of discharge mixing zones, which may be due to the diversion of most of the major discharges to Howdon Pans, which itself shows a significant signal in both the CASI and the thermal data.

3.13.6.3 This discharge has been shown by water quality surveys to affect the water quality of the estuary, resulting in a dissolved oxygen sag. Suggested measures for alleviating this are load reduction during summer months, and upgrading of the treatment facilities. The discharge mixing zones recorded in the aerial imagery show the extent to which the effects of this discharge are experienced at differing tidal states, and may add a spatial perspective to future planning.

3.13.6.4 The inter-tidal zone of the Tyne Estuary is very narrow. Although dense algal cover is seen along most of its length, the actual spatial cover of algae is small in comparison to other estuaries surveyed during this study. Ground truth data would be able to verify whether the algae is of the *Enteromorpha* type which is particularly associated with sewage effluent.

3.13.6.5 The classification showed there to be no saltmarsh within the Tyne Estuary, with only small areas of mudflat, 135 ha in total. These are under threat from sea level rise due to global warming, which is predicted as 37 cm across the UK by the year 2050 (DoE, 1996). The heavy industrial development means that hard coastal defences will require improvement to protect the many valuable assets in the region. However, there will be only minor environmental effect from climate change as little natural land remains within the estuary.

Figure 88. The Tyne Estuary



Tyne Estuary
16th September 1996, Low Water

True colour composite of six CASI images

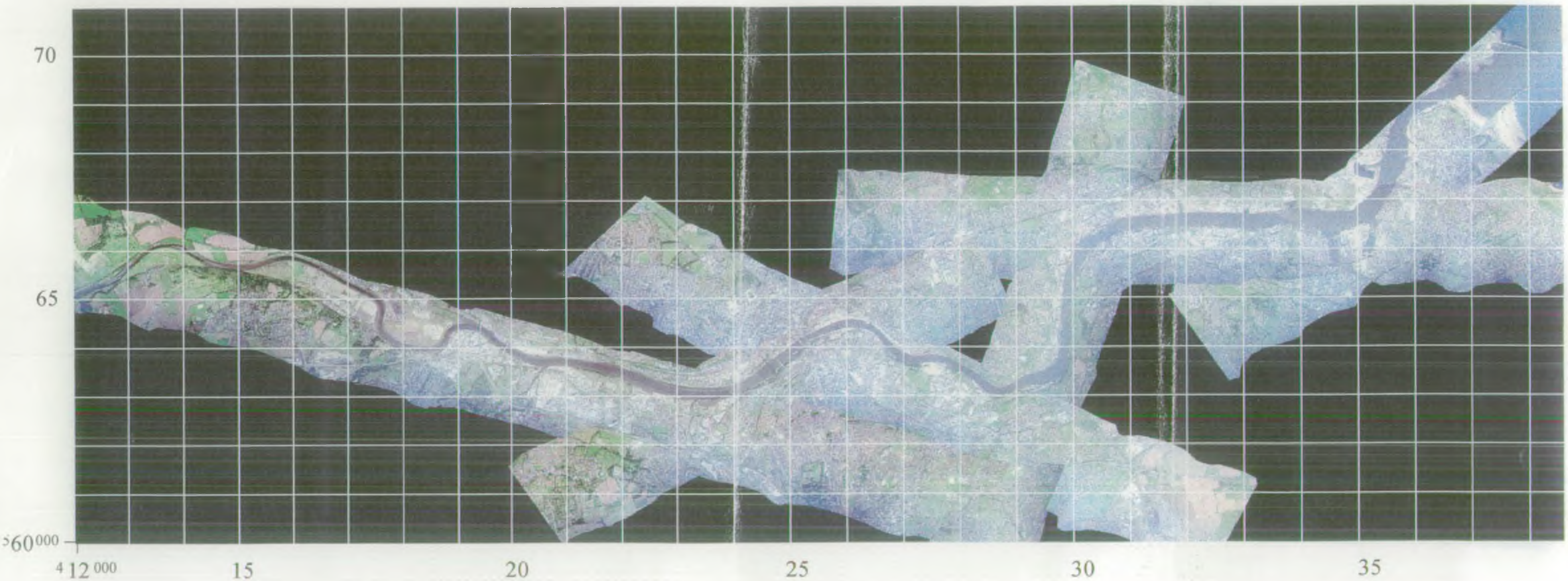


Figure 89

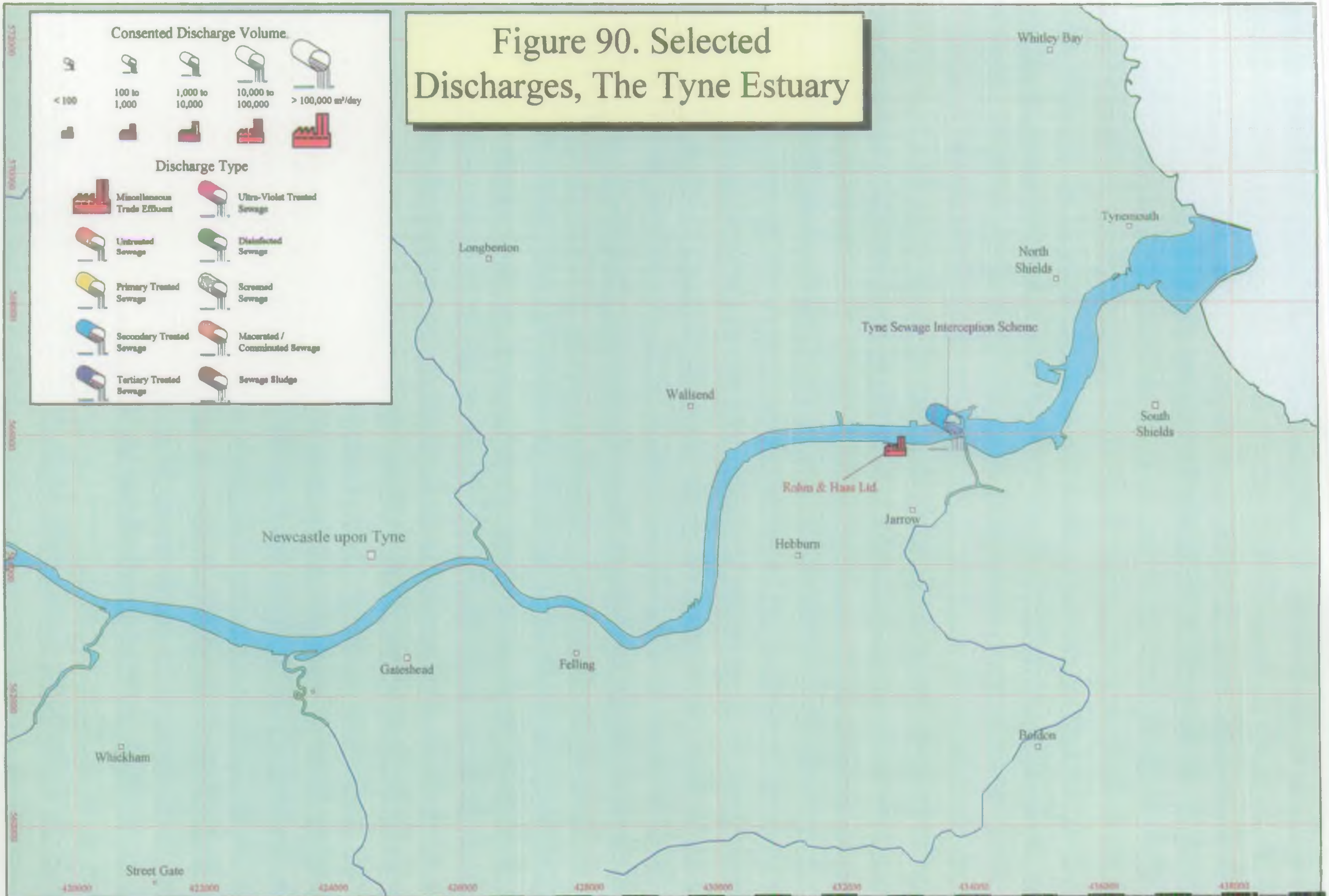


Figure 90. Selected Discharges, The Tyne Estuary
Consented Discharge Volume
< 100
100 to 1,000
1,000 to 10,000
10,000 to 100,000
> 100,000 m³/day
Discharge Type
Miscellaneous Trade Effluent
Ultra-Violet Treated Sewage
Untreated Sewage
Disinfected Sewage
Primary Treated Sewage
Screened Sewage
Secondary Treated Sewage
Macerated / Comminuted Sewage
Tertiary Treated Sewage
Sewage Sludge
Whitley Bay
Tynemouth
North Shields
Longbenton
Tyne Sewage Interception Scheme
Wallsend
South Shields
Rohm & Haas Ltd.
Jarrow
Newcastle upon Tyne
Hebburn
Gateshead
Felling
Boldon
Whickham
Street Gate

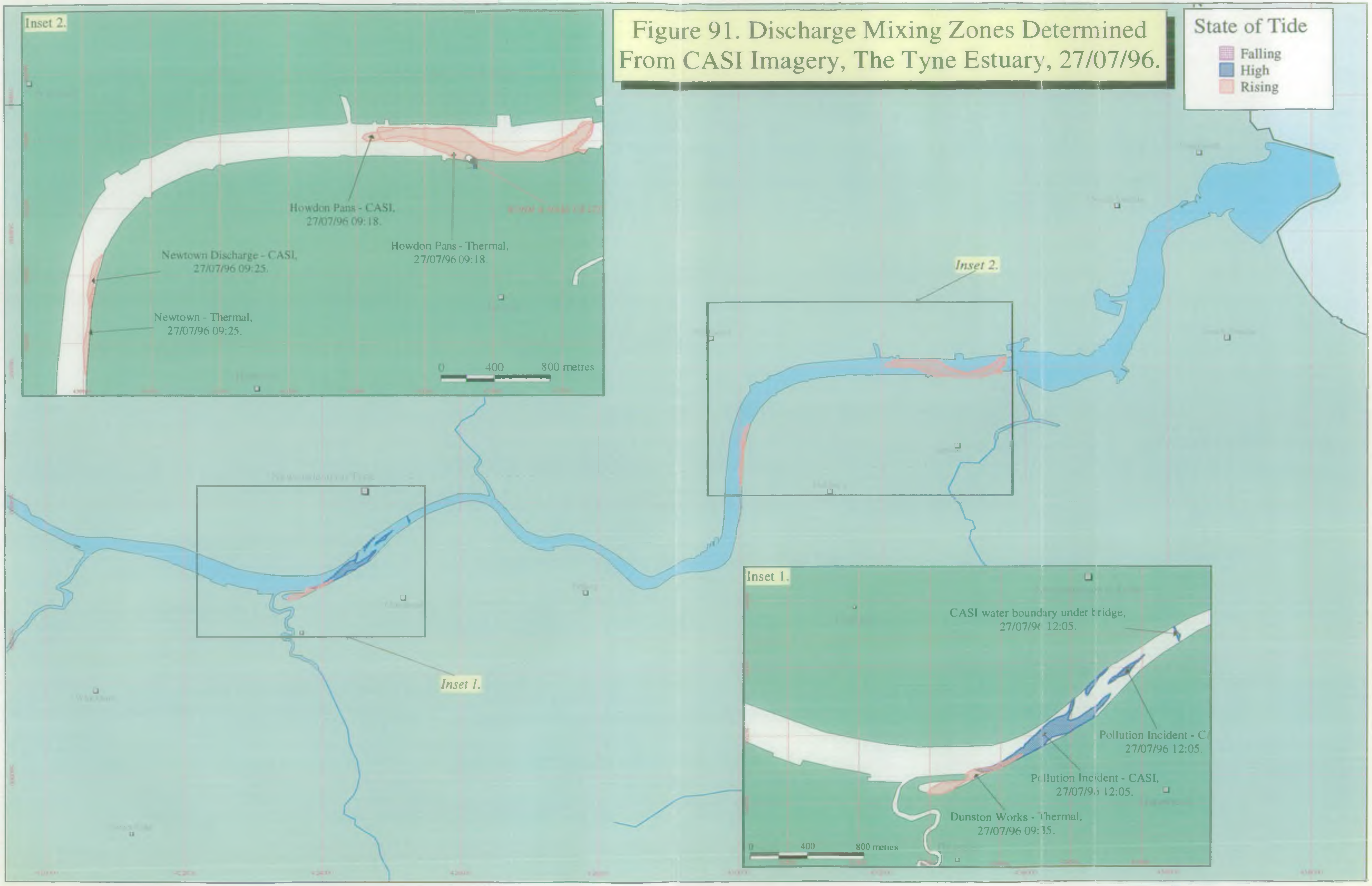


Figure 91. Discharge Mixing Zones Determined From CASI Imagery, The Tyne Estuary, 27/07/96.
State of Tide
Falling
High
Rising
Inset 2.
Howdon Pans - CASI, 27/07/96 09:18.
Howdon Pans - Thermal, 27/07/96 09:18.
Newtown Discharge - CASI, 27/07/96 09:25.
Newtown - Thermal, 27/07/96 09:25.
0 400 800 metres
Inset 1.
CASI water boundary under bridge,
Pollution Incident - CASI,
Dunston Works - Thermal, 27/07/96 09:35.
0 400 800 metres

Tyne Estuary
16th September 1996, Low Water

False colour composite of six CASI images

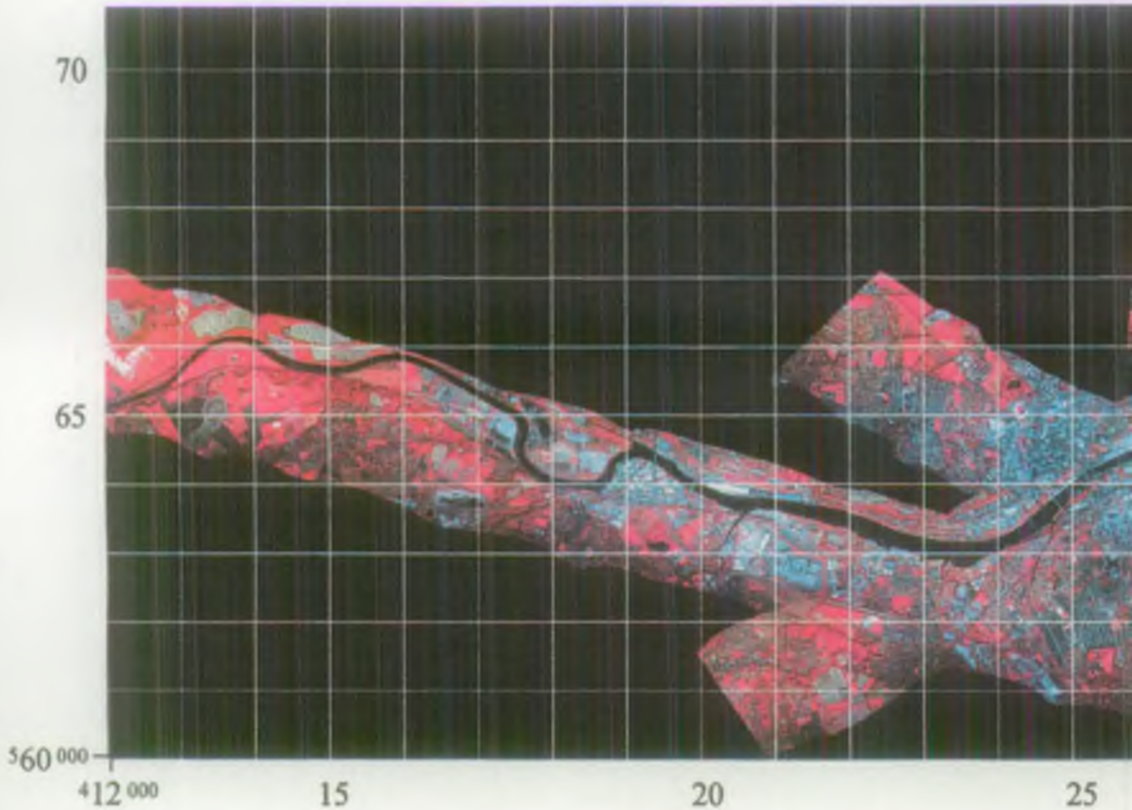
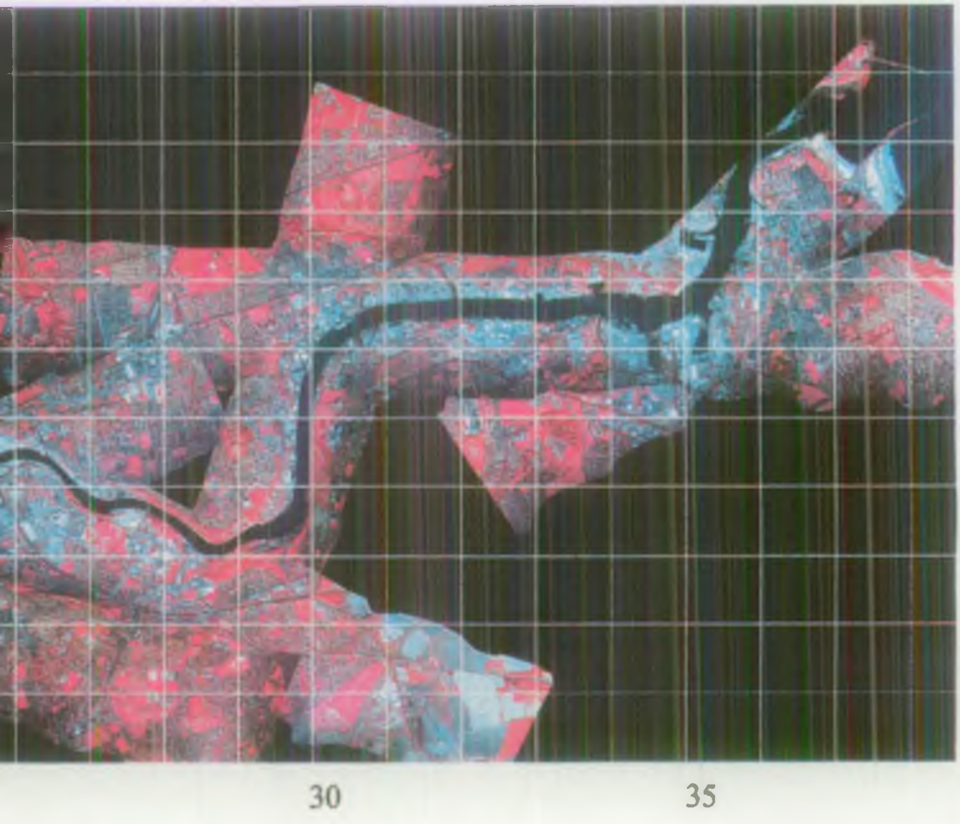


Figure 92



30
35

Tyne Estuary
16th September 1996, Low Water

Unsupervised classification of inter-tidal areas

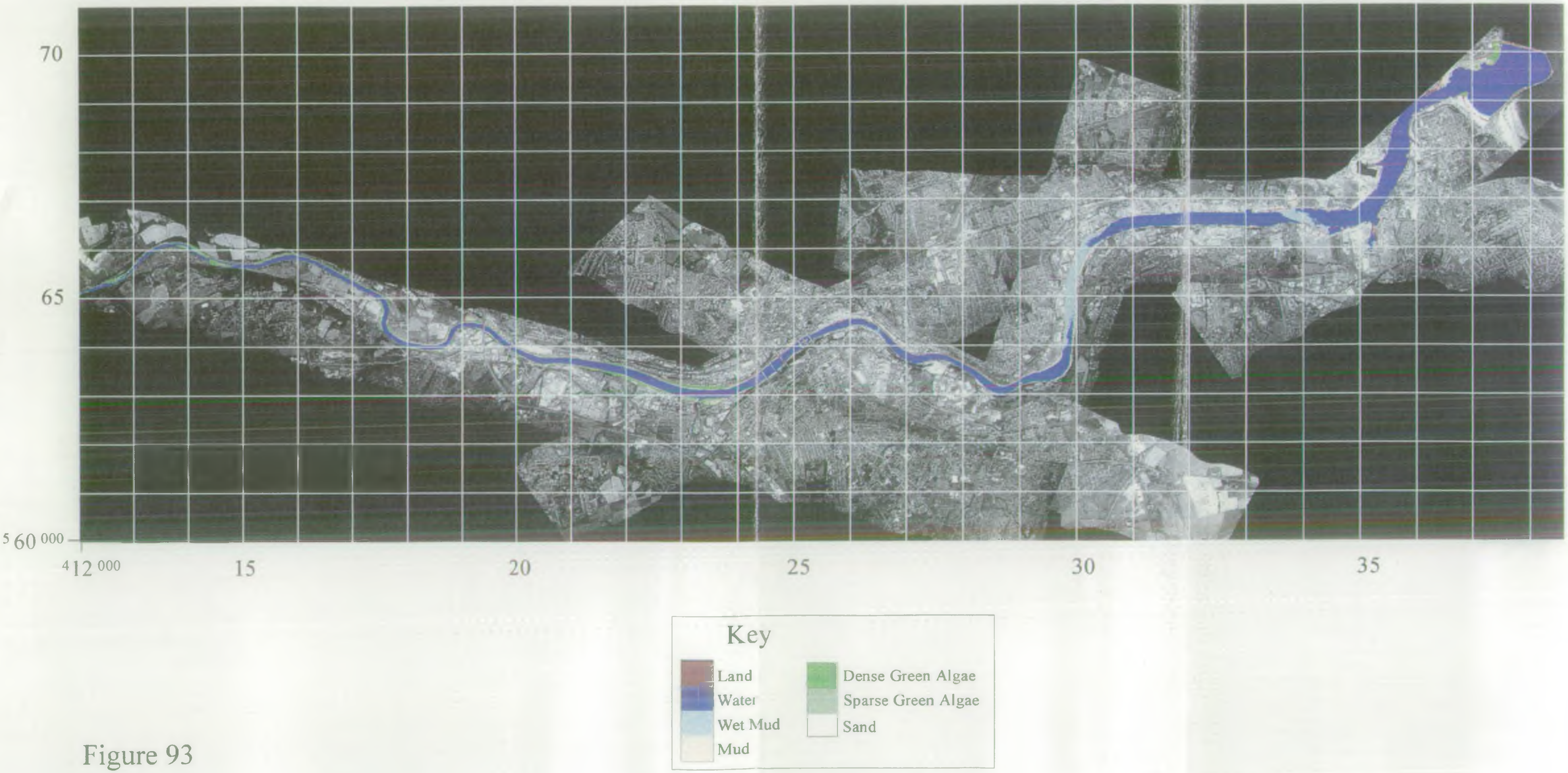
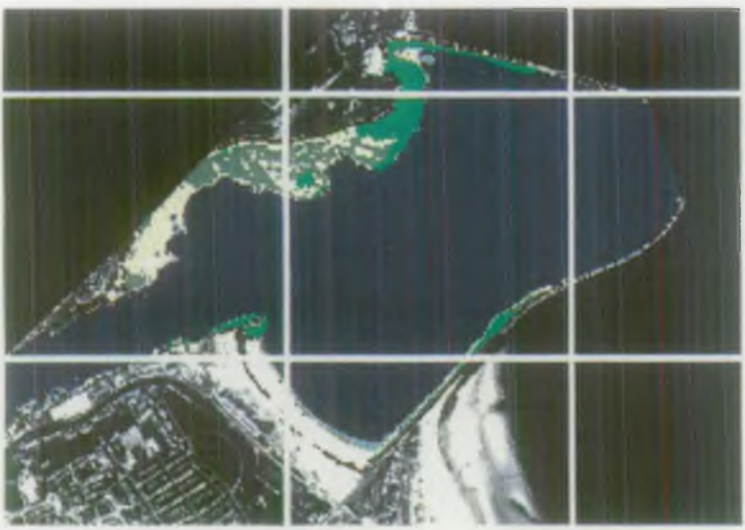


Figure 93

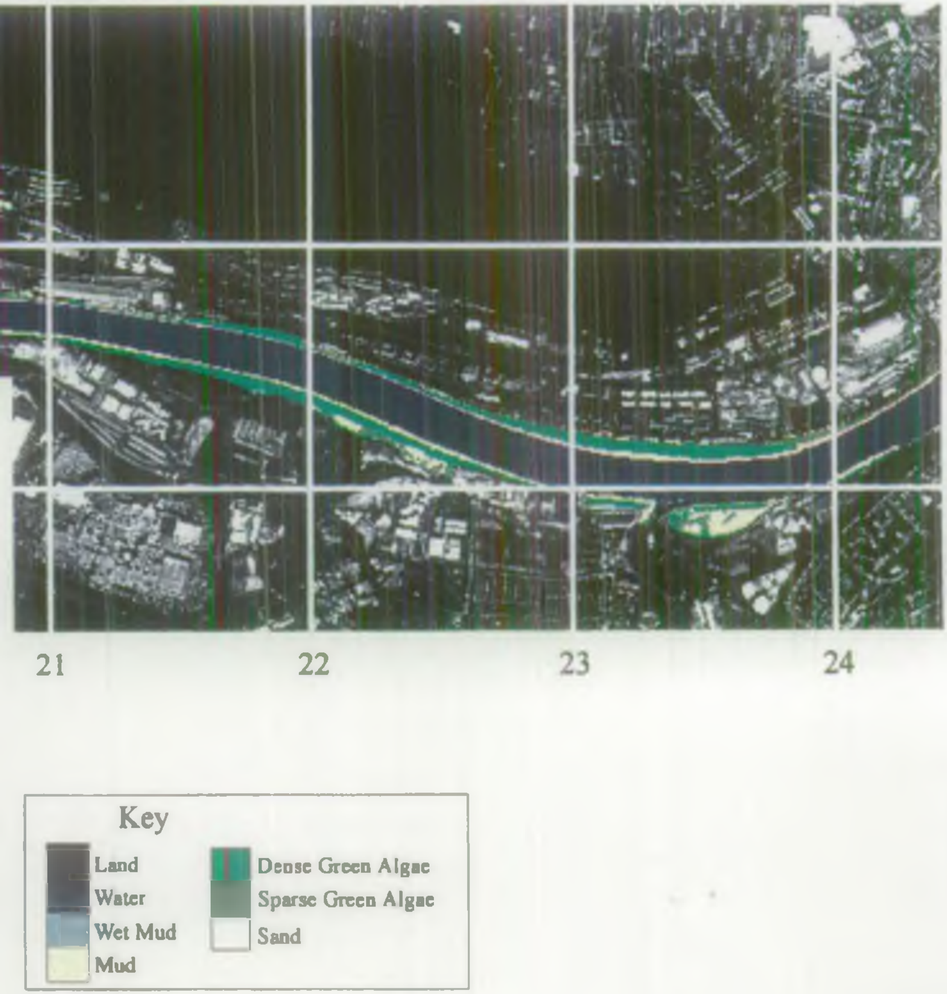
Tyne Estuary
16th September 1996, Low Water
Unsupervised classification - regions of interest

Dunston Stretch



Mouth of Estuary

Figure 94


21
22
23
24
Key
Land
Water
Wet Mud
Mud
Dense Green Algae
Sparse Green Algae
Sand

3.14 THE WEAR ESTUARY

3.14.1 Background Description

3.14.1.1 The River Wear rises at Wearhead in the Pennines, and flows eastwards to the tidal limit at Lamb Bridge, reaching the North Sea at Sunderland. The estuarine area under consideration is shown in figure 95. This figure also shows the location of Sites of Special Scientific Interest (SSSI) within the estuary.

3.14.1.2 The estuary is mostly narrow and steep sided, with greater than two thirds permanently inundated at low water. Former areas of tidal flats at the mouth have been extensively used for harbour development and industrial land reclamation (Davies, 1995*a*).

3.14.1.3 Figure 96 shows a true colour composite mosaic of two CASI images of the Wear Estuary collected at low water on 16th September 1996, which illustrates the narrow nature of the estuary, and the presence of mudflats in the middle reaches. At this tidal state there is no apparent plume of water from the harbour into the coastal waters.

3.14.2 Discussion of major issues

3.14.2.1 A major study has been carried out by Environment Agency North East region to investigate the freshwater and estuarine reaches of the Wear to provide a baseline of water quality, with particular reference to the release of pumped mine waters to the region. The Wear is presently a key river for migratory sea trout and the effects of the mine waters on the maintenance of this resource are not well understood. It is possible that removal of mine waters from the river may have a detrimental effect on the fishery by altering the balance of water chemistry in the estuary (National Rivers Authority, 1995*e*).

3.14.2.2 The estuarine study involved measurements of bio-accumulation and water column and sediment chemistry, macrobenthic invertebrate studies and estuarine fish health and population assessments.

3.14.2.3 Possible toxic effects on the macrobenthic community are being investigated by monitoring of the inter-tidal mudflats. Long term sampling at the community level has been undertaken at a number of sites in the lower estuary. This has shown the region to have low variability in species composition with relatively stable communities.

3.14.2.4 The water quality of the Wear Estuary is assessed on a national basis with respect to the National Water Council (NWC) Estuary Classification Scheme. Results from 1994 showed the estuary to be Class A or Good throughout its length. This is due to the interception of the majority of crude sewage at Hendon prior to discharge to sea (National Rivers Authority, 1995*e&f*). Isolated areas of lower water quality are associated with the remaining sewage discharges, which are due for interception by 2001 (Smith, *pers comm.*).

3.14.3 Discharge mixing zones

3.14.3.1 The Wear estuary has a relatively small number of consented effluent discharges. The largest sewage effluent discharge is from Washington sewage treatment works which is of secondary treated sewage. Trade effluent discharges are mainly from colliery sources.

3.14.3.14 The estuary was surveyed on 27th July 1996 at two tidal states: on the rising tide and at high water. Deteriorating weather conditions made collection of data on the falling tide impossible. The estuary was encompassed in two flightlines flown at 4,000 ft.

3.14.3.3 The thermal data show no sign of point discharges or mixing zones at either tidal state. Although the data were of high quality, there was little variation in the surface temperature within the water body. This may be explained by the date of data collection; by July the estuarine water temperature had been raised by insolation. Thus the temperature of effluent would not differ so greatly from that of the receiving water.

3.14.3.4 The CASI data shows similar water colour throughout the estuary with variations due mainly to water depth. The imagery at high water showed a slick of material having enhanced reflectance in the upper estuarine waters of the Wear, close to Washington. This slick has the appearance of a purely surface signal, and was recorded in imagery collected between 11:22 and 12:23 GMT. The source of the slick may to be linked with the Washington sewage treatment works, which discharges close to this point.

3.14.4 Saltmarsh and beaches

3.14.4.1 The presence of saltmarshes and beaches within an estuary acts as a natural defence against flooding from the sea. They provide a physical barrier against the passage of waves and the presence of a large inter-tidal area acts to dissipate the tidal energy before it reaches the shore. Saltmarsh is also a diverse natural habitat which provides a haven for migratory birds.

3.14.4.2 Figure 98 shows a mosaic of false colour composite CASI images of the Wear Estuary collected close to low water on 16th September 1996. This shows vegetated areas as red due to their high infrared reflectance. This data was also used to produce a digital classification of surface cover types (figure 99). Table 16 shows a summary of the statistics from this classification.

Land cover classes	Area (ha)	% Cover
Wet mud	30	34
Brown algae	17	19
Green algae	16	18
Mud	13	15
Sand	13	14
Total	**89**	**100**

Table 16: Inter-tidal land cover classification in the Wear Estuary, 16th September 1996

3.14.4.3 The classification map shows that there is no saltmarsh in the Wear Estuary. Much of the estuary has been industrialised in the past, resulting in an artificial shoreline.

3.14.4.4 Where the shoreline is natural, it generally consists of a narrow strip of mud, at most 50 m wide. However, in the region between South Hylton and Pallion, there are extensive mudflats at low water (see figure 99).

3.14.4.5 At the mouth of the Wear around Sunderland Harbour there are some areas of beach. These may act as a protection for the artificial shoreline within Sunderland Harbour by dissipating the tide and wave energy.

3.14.5 Inter-tidal vegetation

3.14.5.1 One indicator of the sensitivity of an estuarine region to eutrophication is the variation in the cover of algae on inter-tidal mudflats. This has traditionally been assessed using ground based surveys. The digital classification procedure described above also delineates the extent of algae and may therefore be used to assess algal cover.

3.14.5.2 The digital classification shown in figure 99 delineates the algal cover within the Wear. There are three main regions of algal growth these being at the estuary mouth and on the mudflats at South Hylton, Pallion and Claxheugh.

3.14.5.3 There is only one major discharge of sewage effluent to the Wear estuary, from Washington sewage treatment works (shown on figure 97). CASI data collected at high water in July showed a potential discharge from this area. Figure 100 shows an enlargement of this area. The shoreline is narrow, with areas of very shallow water. There is evidence of algal growth on the mudflats, with a series of zones parallel to the shore. Green algae is found at the edge of the channel, with more established brown algae at the landward side.

3.14.5.4 The algal cover in this part of the estuary does not seem greater than in other areas. This suggests that the discharge is not adversely affecting the trophic status of the estuary at this point, which is probably due to the level of treatment being applied.

3.14.5.5 Close to Pallion, the estuary becomes wider and more shallow, with mudflats seen within the true colour composite image. This area has many small discharges of sewage effluent. Vegetation is evident on the mudflats, shown red in the image in figure 98. Figure 100 also shows the classification for this area in more detail. The vegetation is seen to be green algae at the toe of the mudflat, with more established brown algae and terrestrial vegetation further inshore. Green algal cover is also detected on the emergent mudflats in the centre of the channel.

3.14.5.4 Regional studies have been carried out at South Hylton, Claxheugh and Pallion. These studies have investigated the effects of algal growth on the development of macro-invertebrates, which may be excluded due to excessive quantities of algae. They have taken the form of intensive land based studies to determine the species composition of the macro-invertebrates on the mudflats. These studies showed a distinct zonation in species composition of the macro-invertebrates, which could be related to changes in salinity, exposure and sediment type.

3.14.5.2 Figure 100 also shows the mouth of the estuary in greater detail. In the outer harbour there is a region giving a high near infrared signal, which is thought to be caused by the presence of brown algae. Further areas of similar surface type are found within the harbour, near to the lifeboat station, where there are also areas of green algal growth on the mudflats.

3.14.6 Summary of estuary

3.14.6.1 The aerial surveillance of the Wear Estuary carried out during 1996 has provided useful information on the environmental quality of the estuary. The highly industrial nature of the lower reaches of the estuary is immediately apparent. Visual estimates suggest that 45% of the shoreline is affected either by industry and urban development. Thus, although industry has decreased, the shoreline remains highly modified. The upper estuarine reaches are rural in nature with agricultural land along both shores.

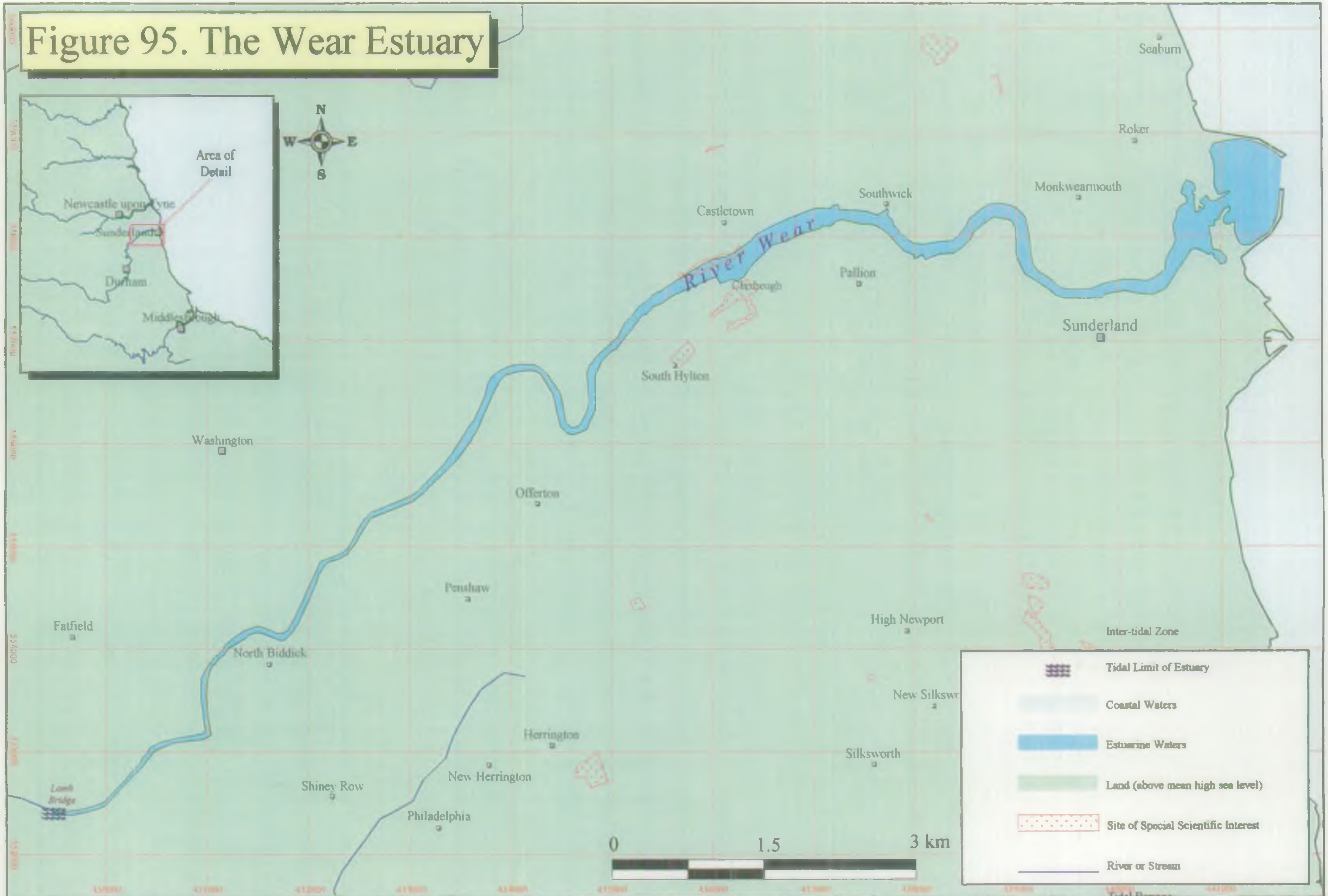
3.14.6.2 The digital classification has shown the presence of algal growth on the mudflats, particularly around Washington and Pallion. Although, there is a major sewage treatment works at Washington, the algal growth does not appear to be excessive, which may be explained by the use of secondary treatment at this site. The CASI data collected at high water shows a surface slick which may be associated with this sewage treatment works. It was not possible to track this discharge throughout the day as weather conditions deteriorated.

3.14.6.3 Close to Pallion, where there are eight discharges of untreated and primary treated sewage, there are wide bands of algae covering the majority of the inter-tidal mudflats. This may be excluding the growth of macro-invertebrates in the region.

3.14.6.4 Recent studies predict a sea level rise due to global warming of 37 cm by the year 2050 (DoE, 1996). This will increase coastal flooding which will have two major effects. Firstly, there will be a requirement to provide further hard defence to protect important assets in the lower reaches. Secondly, the narrow nature of the present inter-tidal zone will mean that little natural protection in provided for the shore based nature reserves in the upper estuary.

3.14.6.5 The information collected from the aerial surveillance may be integrated into a Geographical Information System to allow comparison with future data. This will be particularly beneficial in assessing long term alterations in the inter-tidal zone due to climate change.

Figure 95. The Wear Estuary



Wear Estuary
16th September 1996, Low Water

True colour composite of two CASI images

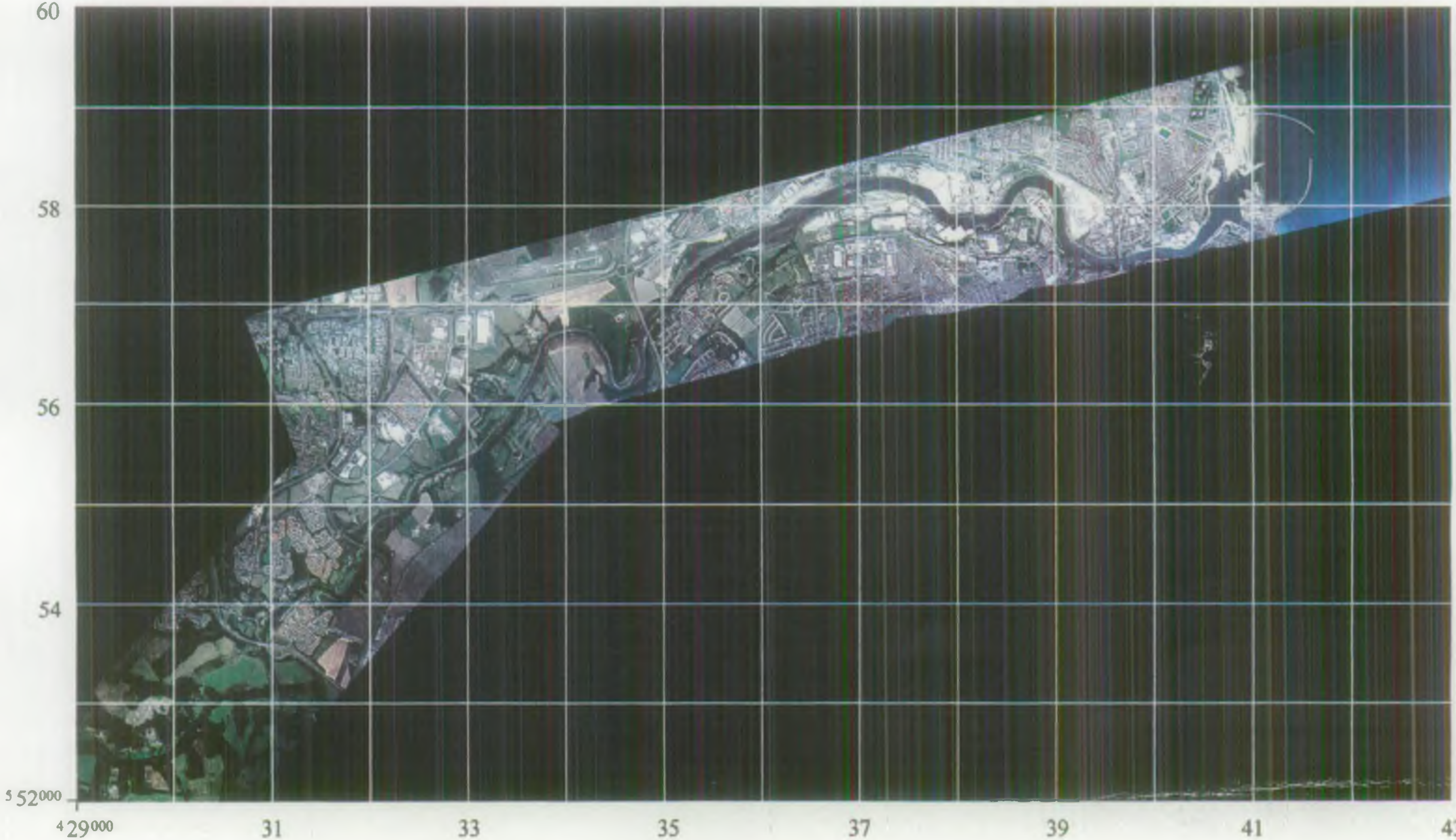


Figure 96

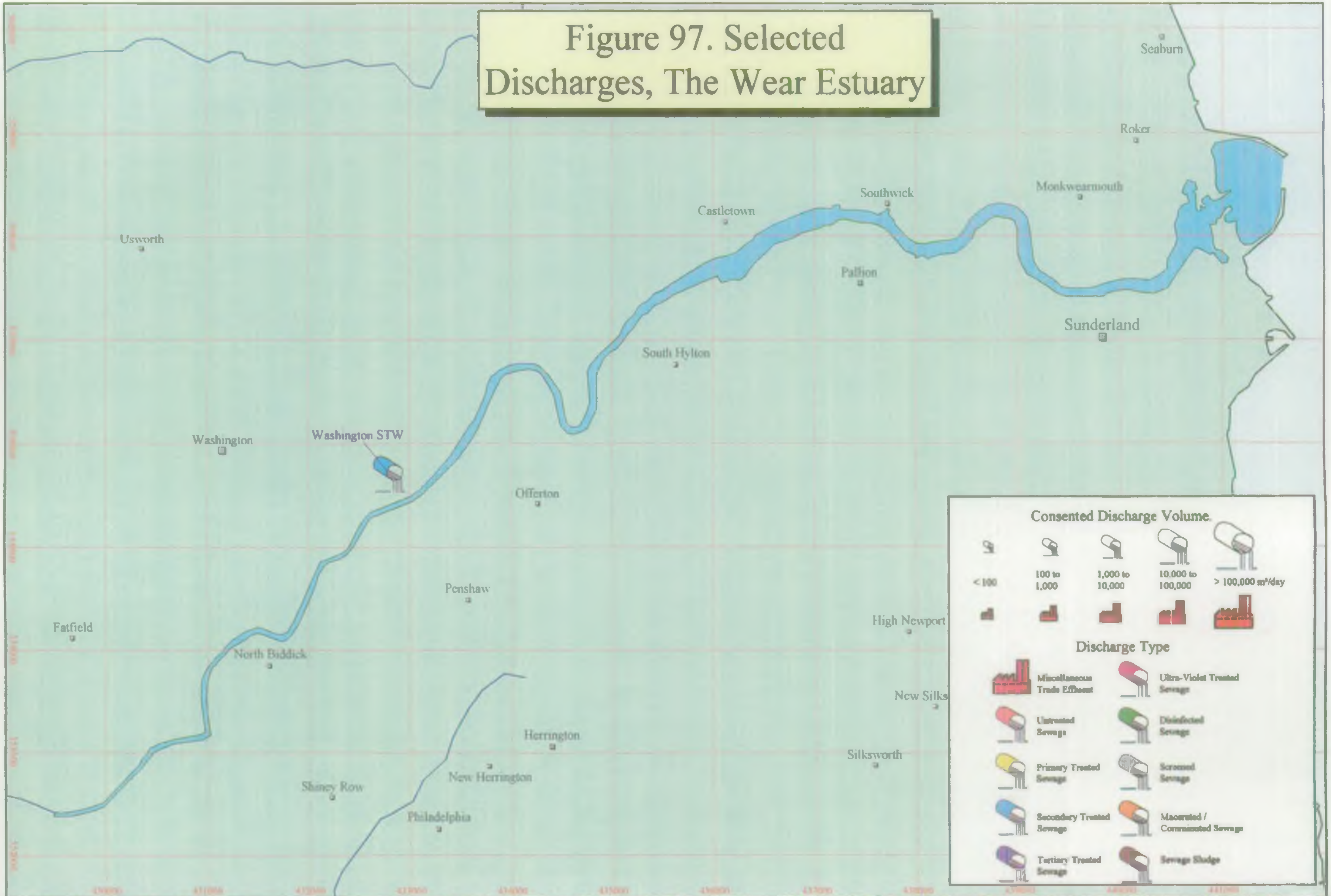


Figure 97. Selected Discharges, The Wear Estuary

Wear Estuary
16th September 1996, Low Water

False colour composite of two CASI images

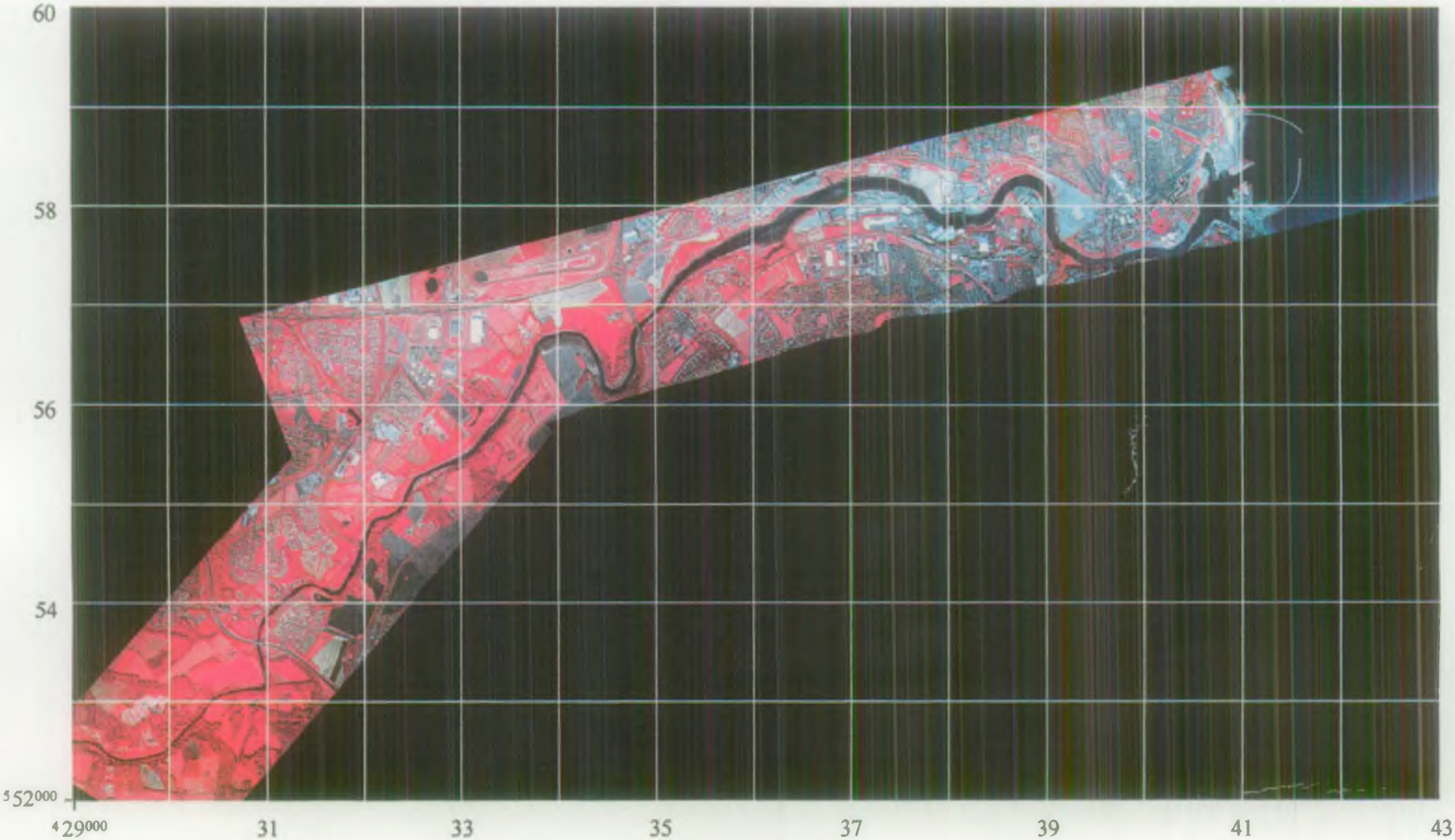


Figure 98

Wear Estuary
16th September 1996, Low Water

Unsupervised classification of inter-tidal areas

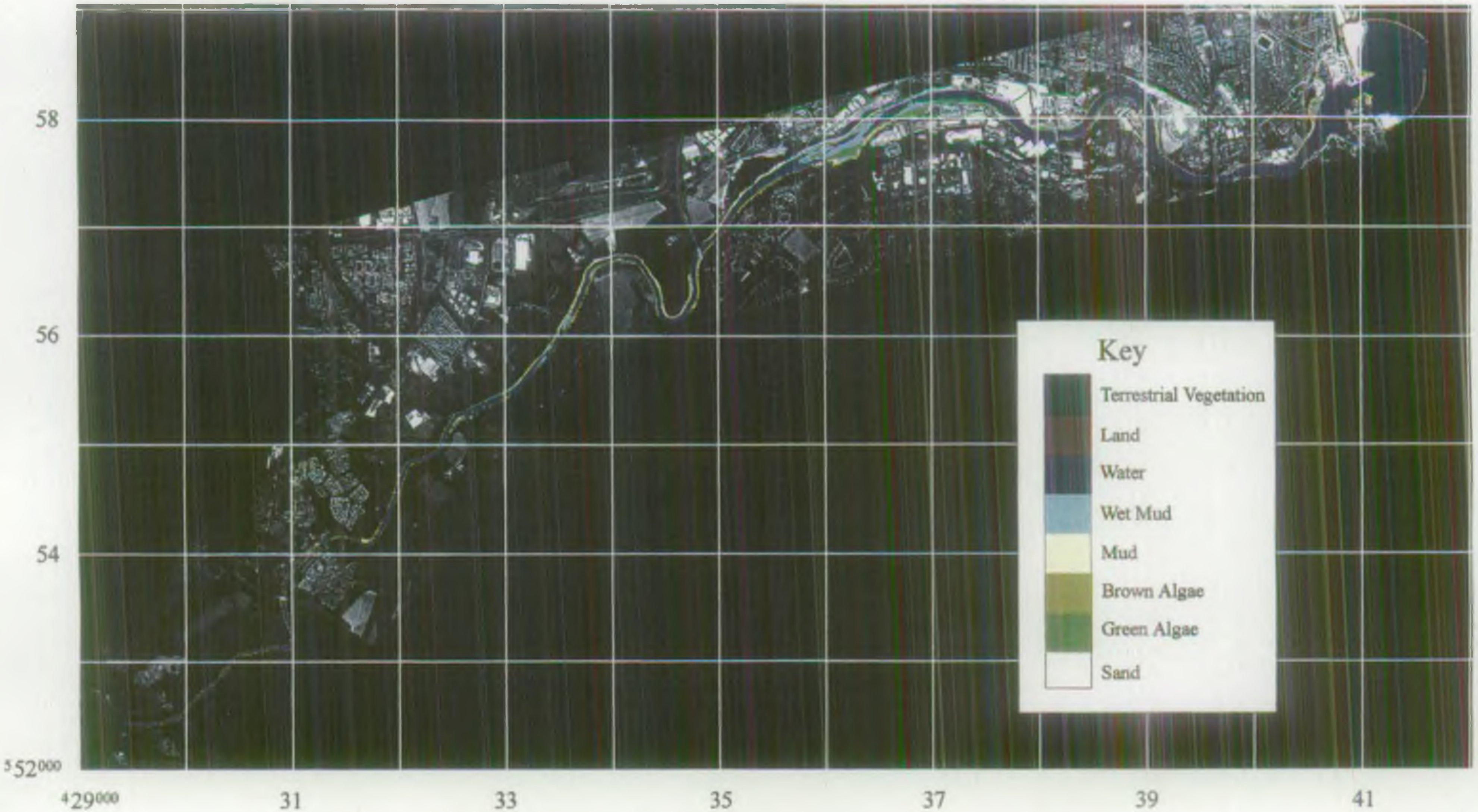
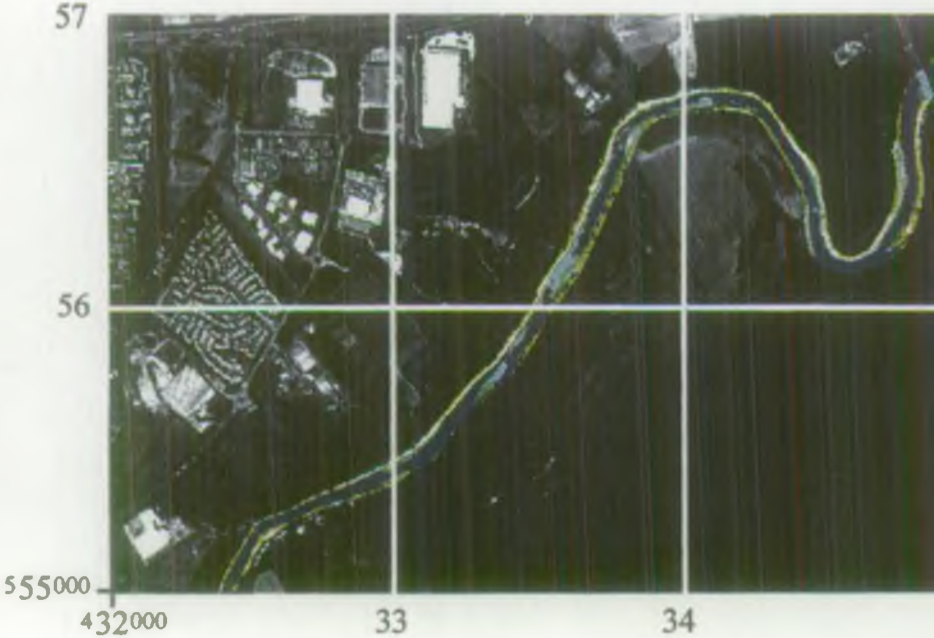


Figure 99

Wear Estuary
16th September 1996, Low Water

Unsupervised classification - regions of interest



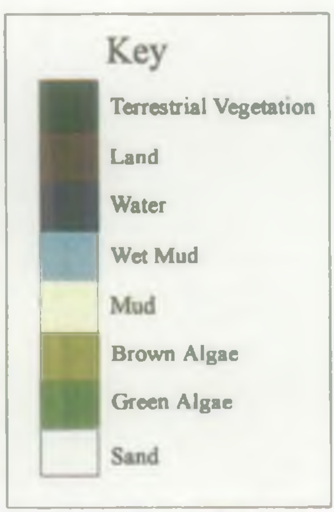
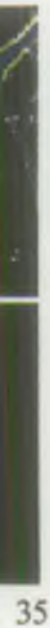
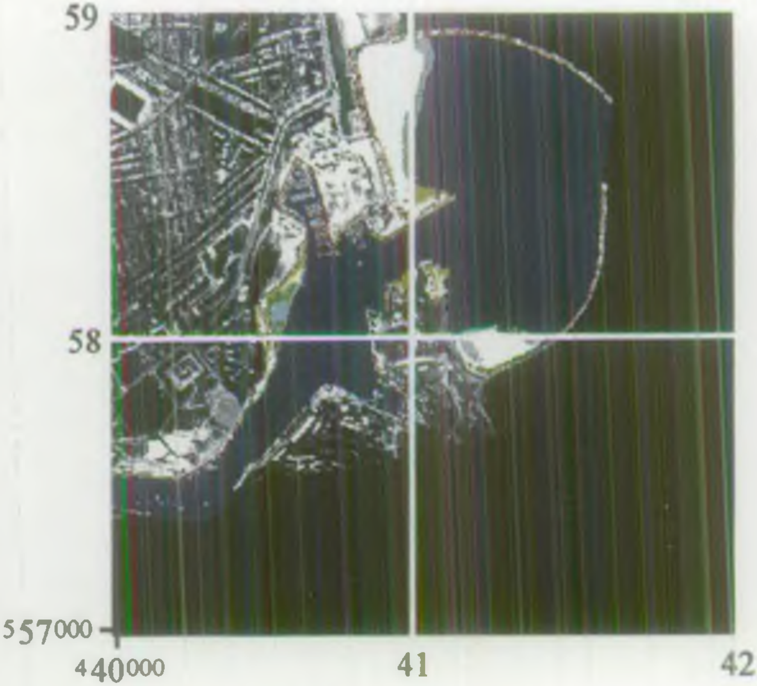
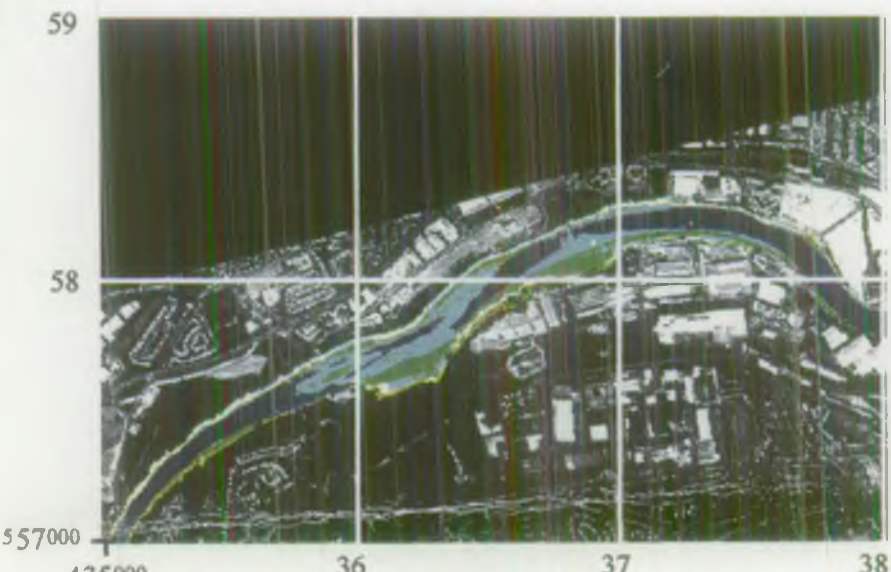


Figure 100





Mouth of the Wear Estuary



Pallion

4 OVERALL DISCUSSION

4.1 INTRODUCTION

This section discusses an overview of the detailed findings set out in Section 3 above. It comments on national trends for discharge mixing zones and how they affect water quality. The relative importance of saltmarsh and inter-tidal vegetation in each estuary are then discussed with reference to aspects of conservation and flood defence. The use of remote surveillance data in providing indices for viewpoints on the state of the estuarine environment is then considered.

4.2 DISCHARGE MIXING ZONES

4.2.1 The aerial data has revealed the presence of a significant number of discharge related mixing zones, with information on their spatial extent not accessible by other means. In particular the shape of the mixing zones and the variation of this with tidal state provides information on the dispersion capabilities of the estuarine water body.

4.2.2 Data collected from the Tees Estuary showed the greatest number of effluent discharges which could be differentiated by thermal techniques. This was due mainly to the collection of data from this estuary early in the year, when the ambient temperature of the estuarine waters had not increased enough to mask the effects of discharge waters. Due to meteorological constraints it was not possible to return to this estuary later in the year to establish whether the discharges could be differentiated in warmer conditions. The mixing zones in this estuary are closely linked to the direction of the tidal stream. Effluent is seen to flow closely against the shoreline throughout much of the estuary. This may have implications on the quality of this shoreline, although it is not possible to state this without further investigation.

4.2.3 Southampton Water also showed a number of discharges of warm water, in particular from the Fawley power station cooling water outfall. These data were again collected early in the year, in June. When this estuary was overflown in July, the thermal discharges were not evident, although the discharges could be readily detected by their colour signal. This clearly illustrates the necessity to monitor the thermal effects of effluent discharges when the temperature of the receiving water is low. The discharge from Fawley shows significant warming for more than 750 m downstream, when surveyed in June. This may have potential effects on the biological communities within this area.

4.2.4 The Humber estuary showed many effluent discharges having an easily distinguishable colour signal, and as such detected in the CASI imagery. In particular, the discharge from the Tioxide UK Ltd. titanium dioxide outfall has a clearly delineated discharge mixing zone at all three tidal states. The position of the discharge compared closely with that seen in previous imagery collected of this region. The discharge mixing zones in the Humber are elongate in nature, due to the strong tidal streams parallel to the shore. This results in efficient downstream disposal of effluent.

4.2.5 The Severn Estuary also showed a number of discharges in the CASI data. This estuary has similarly high suspended solids loading as seen in the Humber, with a number of the discharges being differentiated due to their lower solids loading in comparison to the receiving waters. The mixing zones recorded within the Severn were complex in nature, with collection of effluent around the discharge point particularly close to high water.

4.2.6 Other estuaries did not reveal such clear discharge mixing zones. The ability of remote surveillance to detect discharge mixing zones in the fourteen estuaries did not, however, show any national trend with respect to geographical location, with the major factors being the turbidity and temperature of the receiving waters and the variability of each of these within a particular estuary.

4.2.7 Estuarine water temperature is most variable in the Spring and the Autumn. By late June, the temperature is fairly constant and at an elevated temperature closer to that of typical discharge waters from sewage treatment works and treated factory effluent. This means that discharges are less clearly discernable within the imagery collected by the thermal scanning system.

4.2.8 Discharges of effluent, in particular those from sewage treatment works, may have high concentrations of suspended solids, making the discharge more easy to distinguish in aerial imagery when the receiving waters are relatively clear, for example in the coastal zone. Estuarine environments typically have high suspended solids loading, which makes discharged water less easy to distinguish.

4.2.9 Finally, estuarine environments are highly variable in both temperature and suspended solids loading. Variability may be due to the presence of varying depths of water, which will result in both a warmer temperature being recorded by the sensor and an increased reflectance due to bottom reflection. Variability may also be due to inputs from natural riverine sources which will be higher in both temperature and suspended solids loading. The differentiation of mixing zones from point source discharges is made more difficult by this natural variability in the estuary and thus in the imagery recorded.

4.2.10 In general, combined distribution methods based on the mass balance equation are used for calculating river consents. However, combined distribution methods are not appropriate for discharges to estuaries, and predictive models are generally developed by the dischargers to support their consent application. Visualisation of discharge plumes thus has considerable potential to validate the consent setting computer model, and for verification of the sample points. In the longer term, better plume detection should lead to better modelling, better understanding of the dispersion dynamics and thus better management of estuarine environments.

4.2.11 The results of this study showed that it is not possible to visualise all discharges by thermal or optical imagery. In particular, the increasing use of secondary treatment results in sewage effluent discharges that have less suspended solids and are less visible. There are techniques that could be applied to improve discharge plume detection, for example dye tracing and imaging at a season when the discharge/receiving water temperature difference is greatest, but these were not explored in this study.

4.3 SALTMARSH, SAND AND INTER-TIDAL VEGETATION

4.3.1 The presence of a wide natural inter-tidal zone within an estuarine environments acts as a protection against the effects of flooding, both dissipating the tidal energy and preventing the passage of water. This helps to protect any hard coastal defences which have been put in place.

4.3.2 Saltmarsh provides a key ecological resource, acting as a haven for migratory birds. Under the provisions of the Environment Act 1995, the Environment Agency has a responsibility to promote the conservation of flora and fauna which are dependent on the aquatic environment. The intertidal zone is a highly diverse environment, with a wide range of vegetation species, which are sensitive to changes in both the aquatic and terrestrial environments.

4.3.3 Changes in inter-tidal vegetation communities may be linked to the presence of increased nutrients from anthropogenic sources, for example sewage treatment works. The growth of macrophytes on mudflats, for example *Enteromorpha spp*, is one indicator of eutrophication suggested by the Department of the Environment Consultation Report on the Urban Waste Water Treatment Directive (DoE, 1993).

4.3.4 Land cover in the inter-tidal zone of the fourteen estuaries surveyed has been digitally classified using CASI data collected at low water. The classification relies upon the variation of the CASI signal in all 15 spectral channels, and is particularly sensitive to changes in infrared reflectance caused by the presence of vegetation.

4.3.6 The surface cover type in the inter-tidal zone of the estuaries varied greatly. In some estuaries there were large saltmarsh resources, for example, whereas others were dominated by the presence of mud flats and sand beaches. Estuaries also showed varying levels of macro-algal cover, indicating differing susceptibilities to eutrophication. Table 17 shows the relative importance of vegetation cover types in each of the estuaries surveyed.

	% of inter-tidal zone covered by saltmarsh	% of inter-tidal zone covered by mud and sand	% of inter-tidal zone covered by dense green algae
Deben	40	41	2
Fal*	1	81	4
Humber	(lower) 8 (upper) 39	(lower) 53 (upper) 40	(lower) 31 (upper) 9
Langstone and Chichester	11	49	8
Lune*	43	48	5
Mersey*	18	65	8
Milford	20	57	4
Poole	26	49	6
Severn and Avonmouth	(lower) 7 (upper) 0	(lower) 68 (upper) 92	(lower) 3 (upper) 6
Southampton Water	15	44	6
Tees*	0	85	7
Tyne	0	63	24
Wear	0	63	18

Table 17: Comparison of dominant land cover types between surveyed estuaries
* indicates that entire estuarine inter-tidal zone was not surveyed

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4.3.15 The digital classifications produced from the aerial surveillance data can be used to add a contextual layer to any further investigations into the inter-tidal zone. They may be easily integrated into a Geographical Information System to allow quantitative estimates of changes in surface cover type to be made. This has the clear advantage of producing true spatial estimates across large estuarine areas, as apposed to interpolation of results from small scale ground based studies. Although these ground based studies provide further information on species composition within the algae, this information is not required when assessing whether an estuary is either a Sensitive Area or a Polluted Water.

4.4 STATE OF THE ESTUARINE ENVIRONMENT

4.4.1 Land use and environmental resources

4.4.1.1 The surveillance requirements for this project were defined by the original objectives. Consequently, the marine and inter-tidal zones of each estuary were covered by the surveillance data, but land bordering the estuary was measured to greater or lesser degree depending on the flight planning. This is immediately obvious from the true colour composite imagery included within Section 3. Nevertheless, the work showed that aerial surveillance is highly effective in identifying land use categories.

4.4.1.2 A full digital classification of the inland vegetation was not scheduled within the project design but visual estimates have been attempted for the estuaries surveyed, and these have been included within Section 3. Of the fourteen estuaries surveyed, the Tyne and Tees have the highest urban and industrial development, with approximately 80% of the shoreline of the Tyne showing signs of development, and 60% of the lower Tees Estuary. The other estuaries surveyed showed between 10% and 30% of the shoreline to be developed, with the majority of the land cover being rural. Arable farming appeared to be more prevalent than grazing land, with exceptions in estuaries such as the Lune where the marshland in used for grazing.

4.4.2 Status of key biological populations and communities and biodiversity

4.4.2.1 This general viewpoint was not planned for in the original project design but one biological resource, area of marshland and inter-tidal muds, was addressed. A particularly useful application of remote surveillance is in the correlation of information on key indicator species with habitat overviews.

4.4.2.2 Saltmarsh habitats which form important areas for migratory birds were also assessed, with a total area of 4290 ha recorded in the fourteen estuaries surveyed. The species composition of these marshlands could be further assessed with the use of more detailed ground truth information. This will give a measure of the bio-diversity of these regions.

Marshes from the digital classification, as these are not within the inter-tidal zone.

4.3.9 Conversely, the digital classification for the Humber Estuary recorded a greater area of saltmarsh than found in the National Saltmarsh Survey. Investigation of the imagery suggests that colonisation of mudflats by saltmarsh vegetation is taking place.

4.3.10 Table 17 also shows the percentage cover of inter-tidal mudflats by macro-algae, which was found to vary markedly between the estuaries surveyed. Many of the estuaries studied in this surveillance project were subject to review by Environment Agency regional staff as being potentially Sensitive Areas or Polluted Waters under the provisions of the Urban Waste Water Treatment and Nitrates Directives (91/271/EEC and 91/676/EEC).

4.3.11 Langstone and Chichester Harbours are classed as a eutrophic problem area under investigation. They were originally put forward by the NRA Southern Region for consideration as potential candidates for the first round of designations, but were rejected by the National Panel on the grounds of insufficient evidence. The surface cover of macro-algae in this estuary has been assessed by Regional staff using false colour near infra-red aerial photography.

4.3.12 The Truro and Tresillian Rivers were initially proposed by the NRA as candidates for identification as Sensitive Areas in the first round, but were withdrawn by the Authority on the grounds of insufficient evidence. Regional staff have used a combination of the digital classifications carried out using CASI data from 1995 and 1996 with ground truth surveying to conclude that the macro-algal cover in this estuary did not meet the criteria set by the Department of the Environment to determine eutrophic conditions. The estuary did, however, record an increase in algal cover between 1995 and 1996, which may mean that this estuary is worthy of further investigation to determine whether this was due to natural variability.

4.3.13 Regional staff investigating Poole Harbour, the Lune Estuary and the Deben Estuary have also made use of the digital classifications produced from CASI imagery. None of these estuaries were proposed as Sensitive Areas or Polluted Waters for the first round of designations, but warranted investigation for the 1997 review. In the Lune Estuary and the Deben Estuary the aerial data have confirmed regional conclusions that the cover by macro-algae is not of a magnitude to suggest eutrophic conditions at present. The data from Poole Harbour show increasing concentrations of macro-algae within Holes Bay and other areas between 1995 and 1996 which supports the proposal of this region as a Sensitive Area.

4.3.14 The inter-tidal zone of the Tyne, Wear and Tees estuaries is narrow, due to the high levels of historic industrial development. This leads to apparently elevated concentrations of dense macro-algae. This is, however, concentrated in a narrow strip at the edge of the mudflats along most of the length of the estuary. None of these estuaries are being investigated as a Sensitive Area or Polluted Water under the Urban Waste Water Treatment and Nitrate Directives.

4.4.6.2 The effects of tidal changes on discharge plumes and their impacts has been discussed earlier in Section 4.2 and tidal variations are an inherent factor in the maintenance of wetlands (see Section 4.3).

4.4.6.3 The application of remote surveillance to temperature and sea level rise in estuaries as a result of global warming has wide ranging potential and is detailed below in Section 4.4.7.

4.4.7 Predicted climate change

4.4.7.1 An overall sea level rise of 37 cm by the year 2050 has been predicted for the United Kingdom due to global warming (DoE, 1996). This will be exacerbated or mitigated by the variation in the level of the land resulting in differing effects for each of the estuaries studies. These changes in land level can arise from a combination of land drainage, long term readjustment from glacial retreat (in the North) and subsidence adjacent to the North Sea sedimentary basin (in East Anglia and South East England).

4.4.7.2 The land surrounding estuaries is particularly susceptible to flooding from this sea level rise, in many cases being of low lying relief. This land is highly valuable in terms of urban and industrial assets, due to the concentration of industry and population in these regions. Similarly, there is a great concentration of environmentally sensitive land around estuaries, with a large number of Sites of Special Scientific Interest (SSSI), Special Areas of Conservation (SAC) and Special Protection Areas (SPA). These are at risk directly from flooding and indirectly from the natural landward retreats being constrained by artificial flood defences.

4.4.7.3 The estimated change, combining the effects of global warming and moving land surface, is estimated for the fourteen estuaries surveyed and tabulated below.

4.4.2.3 Additionally, the aerial data allowed the measurement and assessment of mudflats identified as critical bird feeding areas. Examples were identified in the Tees, where Seal Sands is the only major area of mud between Lindisfarne and the Humber, and in the Severn Estuary, where the mudflats around Slimbridge form part of a major bird reserve.

4.4.2.4 There is also considerable potential to categorise land-based flora species, but this also was not addressed in the original project design.

4.4.3 Compliance with existing standards and targets

4.4.3.1 The potential of remote surveillance to image discharge plumes and thus contribute to a better understanding of the effects of discharges on the environment has been discussed previously in Section 4.2.

4.4.3.2 Measurement of the quality of estuarine waters must necessarily be carried out by analysis of water samples. Aerial surveillance, however, can provide information on the characteristics of the water environment allowing interpretation of the results from water quality surveys to be placed in spatial context. This may lead to the redefinition of some statutory sampling sites (Environment Agency, 1997*c*).

4.4.4 The "health" of environment

4.4.4.1 Remote surveillance has potential to overview the health of vegetation by detailed processing of the spectral information recorded by optical systems. This was not programmed into the project design but the imagery can be re-examined at a later date to assess vegetation stress of the marshland and mainland areas covered.

4.4.5 Aesthetic quality

4.4.5.1 Although this attribute was not considered in the project design, it is obvious that remote surveillance imagery has considerable parallel with visual perceptions of beauty. For example, water clarity, urban land, derelict land, countryside land uses and woodland type can be categorised and their areas measured.

4.4.5.2 The imagery produced for this project can be re-examined at a later date, particularly if more information on attributes of public perception of beauty can be acquired as benchmark data. Additional imagery, particularly from satellites could be integrated to give information on the quality of the area around the estuary.

4.4.6 Environmental change at long term reference sites

4.4.6.1 Estuarine environments are unique in experiencing a wide range of time cycles; from extreme diurnal effects (ie. tides) to monthly tide cycles, seasonal and annual changes. Remote surveillance has particular application to the two extreme cycles; tidal changes and long term climate changes.

2050.

4.4.7.6 An increase in tourism and water sports is anticipated in the southern United Kingdom arising from the predicted climate change in the next 50 years. This increase in population would in turn exert more pressure on urban development and on sewage treatment. The beach area will be under increased usage and at the same time may be more vulnerable to reduction by steepening of the beach profile as a consequence of sea level rise.

4.4.7.7 Estimates from imagery showed large areas of the estuary shorelines to be covered by urban or industrial development which will potentially require additional flood defences to protect against high sea levels. These are likely to inhibit a significant proportion of wetlands from re-establishing as part of natural landward retreat. This is particularly evident in the Severn Estuary, Southampton Water and in Langstone Harbour. It is possible that some of these wetlands will be lost by the year 2050. The imagery can be re-interpreted with elevation information to quantify the proportion at risk.

4.4.7.8 Tourism will be expected to exert direct pressure through water recreation usage and indirect pressure through increased sewage effluent discharges in those estuaries located in Southern England. This is likely to put both designated bathing beaches and shellfish waters at increased risk.

4.4.7.9 By the year 2050 the southern estuaries may have a similar climate to the Loire Estuary in mid-France. The estuary hinterlands were not imaged sufficiently to make any comment on the availability of natural habitat corridors to assist in the northward migration of species. There is a need to acquire more background information on this, including reference imagery of estuaries such as the Loire to obtain pre-recognition of anticipated changes.

	Estimated overall increase (cm)
Deben	50
Fal	37
Humber	37
Langstone and Chichester	40
Leven	30
Lune	30
Mersey	30
Milford Haven	37
Poole Harbour	40
Severn and Avonmouth	40
Southampton Water	40
Tees	37
Tyne	32
Wear	32

Table 18: Estimated sea level rise by the year 2050 for each estuary
Estimates interpolated from figures from DoE, 1996

4.4.7.4 As a consequence of the overall sea level rise, storm events that occur through natural variability are likely to increase the incidence of storm damage and flooding. The asset values of population and industrial density under threat in each estuary will doubtless determine whether protection would be preferred to managed retreat as a policy response to flooding and erosion. Predictions are that, in general, assets will be protected by hard engineering defences. This hard engineering protection will inhibit the retreat and re-establishment of the wetland habitat, thus resulting in significant loss of inter-tidal vegetation and marshes.

4.4.7.5 Additionally, the average temperature of the United Kingdom is predicted to rise by 1.5°C by 2050. This will be either enhanced or attenuated by the geographical position of the estuary, with greater temperature rises in the south. This temperature rise will occur more rapidly than natural adaptation of species and there could be a 200 mile northward migration of species, particularly insects, by

Vulnerable Zones under the Urban Waste Water Treatment and Nitrates Directives respectively.

5.1.4 State of the environment

- CASI imagery is highly applicable to monitoring aspects of the six proposed viewpoints on the environment.

- This project was not designed to study this environmental aspect, but it is likely that estuarine environmental indicators for these viewpoints can be developed from imaging techniques. Some indicators have been proposed in Section 6.

5.1.5 Climate change

- Remote surveillance techniques have a uniquely valuable contribution to make to the issue of predicted sea level rise, both in monitoring the extent of sea level rise and in providing information for modelling options to protect economic assets without placing environmental resources at risk.

5.2 RECOMMENDATIONS

- The value of visualising the discharge plume for the validation of predictive models to establish consent conditions should be confirmed by users. Given such confirmation further studies should be carried out to develop a set of techniques for visualisation of all discharges.

- A national database of discharge locations should be compiled from the regional consents register. Additional information should be sourced from other databases on the actual location of the discharge point.

- A protected areas database should be developed within a Geographical Information System, including information for example on Sites of Special Scientific Interest and Areas of Outstanding Natural Beauty. The imagery from this study should be re-interpreted to further investigate the potential threat to protected marshland.

- Imagery of inter-tidal vegetation should be adopted as a routine component of the techniques to designate Sensitive Areas and Vulnerable Zones for the Urban Waste Water Treatment and Nitrates Directive implementation.

- Imagery from this study should be re-interpreted to develop a preliminary set of indicators for assessing Viewpoints of the State of the estuarine environment. A tentative set is given in Section 6.

5 CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

5.1.1 Discharge mixing zones

- Consent setting for estuarine discharge is too complex to be represented by combined distribution approaches, and computer modelling is commonly used. Discharge plume visualisation from remote surveillance techniques should therefore be useful to validate predictive models.

- This study showed that many, but not all, discharges could be imaged by CASI and thermal sensing. A major omission was secondary treated sewage effluent which does not contain enough suspended solids to be readily detected against receiving waters.

- Further development is needed to provide an optimal arrangement for plume detection. Examples include the use of dye tracing and the focussing of surveillance at seasons when temperature differentials are greatest.

5.1.2 Saltmarsh classification and mapping

- This application was highly successful providing accurate digital maps of saltmarsh extent in each of the estuarine environments. Saltmarsh was found to be the dominant land cover class in the inter-tidal zone of the Deben and Lune estuaries covering more than 40% of inter-tidal zone. Saltmarsh is absent from some estuaries in the North East, such as the Tyne and Wear.

- Some information on the nature of marsh protection was obtained for this study, with SSSI marshland being identified. However, the protected area information base should be enhanced.

- Indications are that much of the protected marshland is under threat from sea level rise due to climate change. Imagery identified sites where managed retreat was feasible, and those where this conservation option would be constrained by the presence of hard flood defences of assets.

5.1.3 Inter-tidal vegetation

- This application was highly successful allowing digital mapping of inter-tidal vegetation in each of the estuaries surveyed. This showed that cover by dense green macro-algae varied from 4% to 31% of the inter-tidal zone.

- Imagery of the extent of inter-tidal vegetation is valuable in the characterisation of areas subject to eutrophication and for supporting applications for Sensitive Areas and

6 REMOTE SURVEILLANCE ENVIRONMENTAL INDICATORS

1. Land Use / Environmental Resources

Categorise the surface area into:
urban / grass / arable/ semi-natural / protected land / forest
river / lake / coastal water

2. Biological Resources

Map the positions of:
marshland / wetland / vegetation / inter-tidal vegetation /
natural corridors for species movement
Correlate faunal species populations with land cover to define boundaries

3. Chemical Classification

Interpretation of impact of discharge plumes
Change in channel morphology and re-suspension of contaminants
Diffuse pollution modelling via terrain height, crop type, chemical loadings, soil type

4. Health of Environment

Vegetation stress
Acid rain / tree health
Algal blooms
Intertidal vegetation

5. Long Term Changes

Direct climate change: relative local sea level rise to land level change
Indirect climate change: managed retreat of wetlands / protection of urban assets / migration north of vegetation species / barriers to animal migrations
effect of tourism increase in south
Overall changes in land use categories with time - change detection

6. Aesthetic Quality

Built up areas: % urban land, % green spaces in urban areas, %derelict land in urban areas
Countryside: weighting system including variability and hills factors for:-
urban / park / arable / grazing / conif. forest / decid. forest / heath-moor
river / lake
Coastal: water colour-clarity / beach / mud % built up coastline / coastal strip land use and aesthetics

- Imagery from this study should be supplemented with LIDAR height imagery to study the possible effects of climate change on estuarine environmental assets.

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