National Marine Baseline Survey 1995

Littoral Cell 11
Great Orme to the Solway Firth

ENVIRONMENT AGENCY

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Foreword

In recent years we have carried out National Baseline Surveys of the coastal zone which have involved analysis of samples taken at specific locations in coastal waters around England and Wales for a wide range of determinants. These data have been supplemented by further continuous analysis from the Coastal Survey Vessels and by spatial data from airborne remote sensing operations.

The dissemination of information from these data in an easily digestible form has proved to be a difficult task. To try to overcome this problem the data for the 1995 surveys have been distilled into a summary for each littoral cell.

The information in these summaries is meant to reflect the main features of the littoral cell. More extensive data as well as data collected in previous surveys are held at the National Centre and can be made available on request.

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Introduction

The object of this report is to present an overview of the results of the four 1995 surveys in a compact form. The report is accompanied by the full laboratory analysis results and a catalogue of image data stored on CD-ROM and video. In total there are seventeen parts to the report, and those parts included in this pack are listed at the end of this section.

The coastline has been divided into coastal cells, known as littoral cells using the procedure developed by HR Wallingford (Motyka and Brampton, Report SR 328, January 1993). A map of the divisions between these cells is shown in Figure (i). The rationale of these cells means that any changes within a cell should not affect adjacent cells. In addition each cell has a significantly different character to adjacent cells, in terms of geology or biology. The divisions were defined principally for coastal defence construction, but the position of boundaries have implications on water quality variations. For example, effects from effluent outfalls should not be transferred across boundaries.

The water chemistry results for each cell have been reviewed for each season. In particular the nutrient results have been investigated for high concentrations in Summer which may be linked to anthropogenic sources, and which may result in eutrophic waters. In parallel with this the chlorophyll-*a* concentrations have been studied for any increases which are linked to high nutrient values, by two techniques. Firstly, the individual samples have been investigated, and secondly, maps of the entire coastal zone have been produced to allow spatial estimates of eutrophic waters to be made.

The absolute concentration of chlorophyll-*a* is compared with a concentration of 10 µg/l. This is the level suggested as representative of a bloom event by the Department of the Environment in their document "Criteria and Procedures for Identifying Sensitive Areas and Less Sensitive Areas" which was produced as a response to the EC Urban Waste Water Treatment Directive. Although this level signifies the presence of a phytoplankton bloom, it must be associated with other indicators to show that waters are effected by eutrophication.

Dissolved metals concentrations have been investigated in terms of their relation to the Environmental Quality Standard (EQS) levels. These levels are established in response to the EC Dangerous Substances Directive. The definition of the EQS level is as an annual mean. This has been calculated for any sites in which an individual sample exceeds the EQS. Organic contaminants have also been compared with EQS levels where they exist.

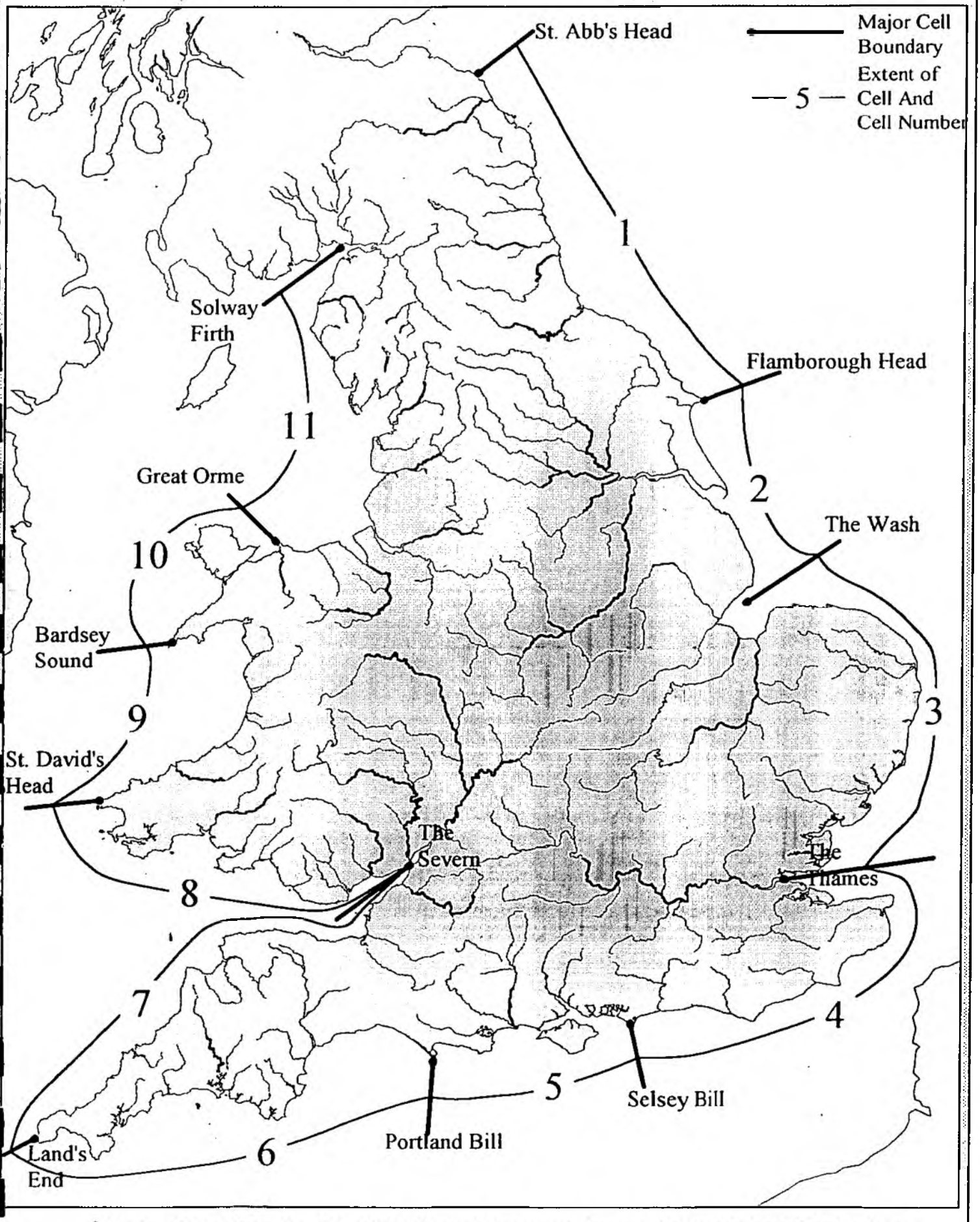
Consideration has been given to the position of the baseline sampling sites in relation to estuaries or major oceanographic features.

The image data and underway data have been investigated for major oceanographic features and changes in water quality. These may be manifested in the image data in two ways. Features are seen in the CASI imagery if they result in an alteration in the ocean colour signal. This usually requires a change in the amount of light scattered or absorbed by particles in the water column. Features such as estuarine plumes have higher particulate matter loading which increases the ocean colour signal. Phytoplankton blooms increase the absorption of light in selected wavebands and moreover result in fluorescence being detected in other wavebands. Some features do not record a CASI signal but have a difference in water temperature. The thermal video systems used in the baseline survey record only the surface temperature of the water, but clearly show features such as effluent discharges and outfalls from power station cooling systems, in addition to river plumes.

The underway data illustrates changes in temperature, salinity, dissolved oxygen, transmission and fluorescence. The longitudinal profiles from the underway systems have been investigated for major changes which may be associated with estuarine inputs or fronts between different water bodies. Data from the Skalar continuous monitoring nutrient analyser have been investigated to determine the geographical extent of elevated samples in the laboratory analyses.

Summaries have been produced for each littoral cell which provide a statement on the water quality of the region recorded by the baseline survey. The key local oceanographic features are also summarised.

Figure i. The Major Littoral Cells of England and Wales, After Motyka and Brampton*, 1993.



* Motyka, J.M. and Brampton, A.H. (1993), "Coastal Management, Mapping of Littoral Cells", HR Wallingford.

Littoral Cell 11: Great Orme to the Solway Firth

Executive Summary

This littoral cell extends from the Solway Firth to the Great Orme headland on the coast of North Wales. This represents a wide range of coastal morphology and varying degrees of industrialisation.

There are no sites within this cell which exceeded the Environmental Quality Standards (EQS) for dissolved metals, and no sites recorded concentrations of organic contaminants in excess of the laboratory minimum reporting value (MRV).

Chlorophyll-*a* concentrations in this region were high, with the Formby sampling site exceeding the Urban Waste Water Treatment Directive (UWWTD) level to signify the presence of a phytoplankton bloom, during the summer survey. Moreover, this is associated with elevated nutrient concentrations, in particular nitrite, suggesting that this is an area potentially subject to eutrophication.

Spatial chlorophyll-*a* results showed moderate concentrations in this cell at the time of sampling. One area recorded elevated concentrations, close to Rhyl, but concentrations do not exceed 10 µg/l. The Formby area did not record a high concentration in this data, which suggests that the laboratory sample may represent a local maximum.

Underway data from the survey vessel recorded the variation in water quality within this region, and its relationship to the major riverine inputs of the Dee and Mersey. The imagery showed the movement of suspended particulate matter along the Welsh coast and in Cumbria. In particular, the varying flow direction of riverine inputs on the Cumbrian coast was clearly seen, with the River Duddon being deflected to the South and the River Calder to the North. Between the Dee and Morecambe Bay the imagery was dominated by the presence of mudflats and sandbanks. The CASI imagery revealed the position of channels within these banks, many of which have changed relative to the Admiralty Charts. The extent of influence of the Heysham power station outfall in Morecambe Bay was revealed in the thermal imagery.

1. Introduction

This littoral cell stretches from Great Orme on the coast of North Wales to the Solway Firth on the English / Scottish border. This is illustrated in Figure 1.

The area of coastal waters for which the Environment Agency has responsibility for controlled water within this cell is approximately 3600 km^2, of which 1030 km^2 are estuarine waters. Continuous data and water samples for laboratory analysis were collected by Coastal Guardian in early Spring (March), late Spring (June), Summer (July) and Autumn (September). Aircraft

surveys were completed in July and September.

The littoral flow direction is complicated along this section of coastline. There is an easterly flow from Great Orme to Liverpool Bay, with a similar flow north-east up the Solway Firth. Between this there are sections of coastline which experience return flow, in particular around Blackpool, Liverpool Bay and between Walney Island and St Bees Head. Similarly the coastal morphology alters along the coast, with the North Wales and Cumbrian coast having narrow sandy beaches, but with large mud and sand banks located between Liverpool Bay and Morecambe Bay.

2. Water chemistry results

2.1 Background

Water samples for laboratory analysis of chemical determinands are taken at eighteen sites, situated approximately 15 km apart. The water quality is closely related to the position of riverine inputs within the cell, particularly those with industrialised catchments such as the Dee and Mersey.

2.2 Nutrients and chlorophyll-*a*

2.2.1 Total Oxidised Nitrogen (TON)

TON concentrations were highest in early Spring, with a maximum concentration of 575 µg/l N at Blackpool (173). In late Spring concentrations were lower, with a maximum of 201µg/l N at North Wirral (170). Summer concentrations were generally low, but showed a peak concentration of 388.4 µg/l N at Gut (172). Similarly in Autumn most sites recorded low concentrations, but the Formby Point (171) site recorded a concentration of 253.1µg/l N.

2.2.2 Silicate

Silicate concentrations also showed a maximum at Blackpool (173) in early Spring, equal to 578.7 µg/l Si. Concentrations were lower in late Spring, with a maximum of 126 µg/l Si at Duddon (176), with Summer concentrations decreasing further, having a peak at North Wirral (170) equal to 94.33 µg/l Si. Autumn concentrations were generally low, but showed a high concentration at Formby Point (171) equal to 310.6 µg/l Si.

2.2.3 Orthophosphate

Orthophosphate concentrations show an early Spring maximum at Blackpool (173) of 58.8 µg/l P, but this is not a marked peak. In late Spring, concentrations were lower, with a maximum of 30.1 µg/l P at Calder Hall (178). The maximum concentration in Summer, of 121µg/l P, was located at North Wirral (170). In Autumn, most concentrations were low, but Formby Point (171) recorded a concentration of 99.5 µg/l P.

2.2.4 Total Ammoniacal Nitrogen (Ammonia)

Ammonia concentrations showed the most marked peak at Blackpool (173) in early Spring, equal to 132 µg/l N, with surrounding sites having concentrations of 6.4 and 11.8 µg/l N.

Late Spring concentrations are variable and are all below 40 µg/l N. There was a Summer concentration peak of 552 µg/l N at North Wirral (170), and a peak in Autumn at Formby Point (171) equal to 136 µg/l N.

2.2.5 Nitrite

Nitrite concentrations were highest in early Spring at Blackpool (173), equal to 13.4 µg/l N, with the highest concentration at North Wirral (170) in late Spring equal to 10.2 µg/l N. The peak concentration in both Summer and Autumn was found at Formby Point (171) equal to 32.2 µg/l N and 61.1 µg/l N respectively.

2.2.6 Chlorophyll-a

Chlorophyll-*a* concentrations were low in early Spring, with all sites recording values below 2 µg/l. The late Spring survey recorded the bloom in phytoplankton with a maximum chlorophyll-*a* concentration of 28.6 µg/l at Hilpsford (175) off Morecambe Bay. Concentrations above 10 µg/l were also recorded at Great Orme (165), Maryport (180) and Selker (177). In Summer, however, only one sampling site recorded a concentration above 10 µg/l at Formby Point (171). A number of sites during the Autumn survey record results above 10 µg/l which probably signifies the presence of a natural autumnal bloom.

2.2.7 Nutrients/chlorophyll-a Summary

Nutrient concentrations showed a seasonal cycle with highest concentrations in the early Spring. Moreover, there was a clear geographical pattern for each season. In early Spring all nutrients were maximum at Blackpool (173), in Summer at North Wirral (170) and in Autumn at Formby Point (171). The high chlorophyll-a concentration at Formby Point (171) in Summer was in association with a peak of 32.2 µg/l N in nitrite concentration, and elevated concentrations of other nutrients. This area is therefore potentially subject to eutrophication according to the limit suggested by the Department of the Environment.

2.3 Suspended Solids

Suspended solids concentrations were highest in early Spring and Autumn, with a maximum concentration of 25 mg/l at Hilpsford (175) and 13 mg/l at Shell Wharf (174). Lower concentrations were recorded in Spring and Summer with many sites having concentrations less than the laboratory MRV of 3 mg/l, although a peak of 31 mg/l was recorded at Hilpsford (175) in Spring.

2.4 Metals

2.4.1 Total Mercury

Total mercury concentrations were low in all surveys, with the highest concentration recorded in early Spring equal to 0.16 µg/l Hg which is approximately 50% of the EQS value of 0.3 µg/l Hg.

2.4.2 Dissolved Cadmium

Dissolved cadmium concentrations were low, seldom exceeding the laboratory MRV of 0.042 µg/l Cd. The maximum concentration was recorded in Summer at Shell Wharf (174) equal to

0.219 µg/l Cd, compared with an EQS level of 2.5 µg/l Cd.

2.4.3 Dissolved Copper

Dissolved copper concentrations were low in early Spring, with the highest concentration, equal to 1.97 µg/l Cu, found at Welsh Channel (168). The highest concentration in late Spring was recorded at Calder Hall (178), equal to 1.16 µg/l Cu. In Summer the concentration at Shell Wharf (174) exceeds the EQS level of 5 µg/l Cu, being 12.5 µg/l Cu. When the annual mean was calculated for this site from the four baseline samples, however, it was below the EQS level. In Autumn all concentrations were less than 2 µg/l Cu.

2.4.4 Dissolved Lead

Dissolved lead concentrations were generally low with respect to the EQS of 25 µg/l Pb in all surveys. The maximum concentration recorded was at Shell Wharf (174) in Summer equal to 8.4 µg/l Pb, with most concentrations less than 1 µg/l Pb.

2.4.5 Dissolved Arsenic

Concentrations of dissolved arsenic were low in early Spring, but at other seasons recorded the highest values for the entire survey. In late Spring the highest value is 2.2 µg/l As at He 1 Buoy (169). In both Summer and Autumn the highest concentration is found at Formby Point (171), being 2.6 µg/l As in Summer and 3.1 µg/l As in Autumn. No sites exceeded the EQS level of 25 µg/l As.

2.4.6 Dissolved Zinc

Dissolved zinc concentrations are highest in early Spring at Duddon (176), equal to 25.9 µg/l Zn which is above 50% of the EQS value of 40 µg/l Zn. In late Spring concentrations were generally lower, with a maximum of 8.42 µg/l Zn at Calder Hall (178). Shell Wharf (174) recorded the highest concentration in Summer, equal to 24.2 µg/l Zn, with the highest concentration in Autumn seen at Formby Point (171), equal to 7.94 µg/l Zn..

2.4.7 Dissolved Chromium

Dissolved chromium concentrations were low at all seasons except for a concentrations of 3.18 µg/l at Blackpool (173) during the early Spring survey. Many other sites recorded concentrations less than the laboratory MRV of 2 µg/l Cr.

2.4.8 Dissolved Nickel

Dissolved nickel concentrations showed some geographical pattern, but were low throughout the four surveys. The maximum concentration was recorded at Shell Wharf in Summer equal to 2.24 µg/l Ni, compared with an EQS of 30 µg/l Ni.

2.4.9 Metals Summary

Dissolved metals concentrations showed a clear geographical pattern in each season. In early Spring, the Welsh Channel (168) sampling site showed highest concentrations, in late Spring it is the Calder Hall (178) sampling site, in Summer it is the Shell Wharf (174) sampling site and in Autumn it is Formby Point (171).

2.5 Organic Determinands

Water samples were analysed for twenty three trace organic determinands at nine baseline sites within this littoral cell. In the national survey, with the exception of a few PCBs, only γ-HCH and α-HCH gave positive analyses. The other 22 determinands were not detected at their laboratory MRVs of 0.001 µg/l for the entire survey.

No samples recorded positive analyses for any organic determinand within this cell.

3. Spatial chlorophyll-*a* results

The CASI imagery has been used in combination with the laboratory baseline samples and the underway fluorimeter to produce maps of chlorophyll-*a* concentration of the coastal zone. The technique used involves calculation of the Fluorescence Line Height (FLH) of the imagery and correlation of the three measuring techniques.

Figure 2 shows the chlorophyll-*a* concentration during Summer 1995 for this littoral cell, as derived from the FLH technique. The Morecambe Bay area has missing data due to the presence of sandbanks, which effect the applicability of the algorithm. This map shows most of the region to have chlorophyll-*a* concentrations between 2 and 6 µg/l at the time of survey. The Solway Firth recorded the highest concentrations with results up to 8 µg/l. Morecambe Bay and the Cumbrian coast recorded the lowest concentrations.

Figure 3 shows the chlorophyll-*a* concentration calculated from calibration of the underway fluorimeter. This map shows similar concentrations, with higher values again being recorded in the Solway Firth. In addition, concentrations up to 10 µg/l were found close to Prestatyn. This was not seen in the FLH imagery which may be a result of smoothing by the FLH technique, or may be due to a time difference between the two data collection exercises.

Neither of these techniques show high concentrations in excess of 10 µg/l. Laboratory data showed the Formby Point (171) baseline sampling site to be in excess of this figure in Summer. This region is not shown in-Figure 3, but the lack of any increase in Figure 2 suggests that this is a localised high concentration. The Irish Sea commonly has high concentrations of chlorophyll-*a*. The above figures do not record this, but it must be stated that the maps are representative only of the conditions at the time of data collection.

4. Local oceanographic descriptions

Underway measurements have been investigated in order to show which areas within this littoral cell show most variability in the underway parameters measured, namely temperature, salinity, fluorescence, transmission and dissolved oxygen. In addition the imagery has been studied for variation in ocean colour signal and temperature signal, or where discrete bathymetric and oceanographic features are visible during either July or September.

These areas will be discussed in more detail below, in terms of results from remote sensing imagery, laboratory sampling and underway measurements. This will provide an overview of the results for this section of coastline. The areas are as follows.

1. Cumbrian coast
2. Blackpool
3. Heysham power station outfall
4. Morecambe Bay
5. Water flow along the Welsh coast
6. Nutrients concentrations at Formby Point

4.1 Cumbrian coast

CASI data were collected in a single flightline from Barrow-in-Furness to St Bees Head on the Cumbrian coast. No data were available in July, but the data from September are shown in Plate 1. This section of coastline is highly variable, inputs to the coastal environment forming plumes, with a variation in direction of deflection along the coastline. Major inputs are seen at Duddon Sands, Ravenglass and Sellafield.

The tidal streams at this time are directed southwards, but are small in magnitude. These do, however, account for the deposition of sediment within river mouths, particularly at Ravenglass. The direction of flow is due to the littoral drift, which is weak and variable in this region. Some river mouths are deflected northwards and some southwards indicating little nett transport. This is shown in the CASI imagery, where the River Calder is deflected to the north and the River Duddon to the south.

The position of the plume from Duddon Sands has implications on the results from laboratory analysis of samples at the Duddon (176) sampling site. This site shows high concentrations of dissolved metals, in particular of dissolved zinc in the early and late Spring surveys. It is probable that the sampling site is within the effects of the plume at this time. However, there are no coincident image data to verify this. Detailed current meter or ADCP studies would show the full current regime in this region. Alternatively, collection of regular CASI imagery over a time period of a few days may reveal the behaviour of the plume.

The underway data from this section of coastline shows some variation in % transmission which indicates variation in suspended solids concentration. In particular, during the Autumn survey, when suspended solids are reasonably high, a large drop is seen in % transmission

around the entrance to Duddon Sands, with a smaller drop at Ravenglass. The Duddon Sands area also shows an increase in fluorescence which indicates that the riverine input may contain more highly productive water from a terrestrial source.

4.2 Blackpool

CASI imagery from the Blackpool flightline in 1994 showed an ocean colour signal from the Manchester Square sewage outfall located between the two main piers. There is no sign of this outfall in 1995 imagery from either July or September. This is probably because the imagery does not coincide with discharge of effluent which is timed to occur at High Water. Both images were collected before High Water, the July image four hours before, and the September image two hours before.

The imagery does however show interesting sediment flow patterns, which are contrary in places to the expected littoral flow from estuaries. In Plate 2 there is a flow of sediment from the River Wyre south towards Blackpool, whereas the littoral flow shows a convergence at this point which would mean a northerly flow. There is also evidence of a flow out of the Ribble estuary northwards towards Blackpool. There is no obvious sign of convergence of these two flows at Blackpool.

The two images, although both collected before High Water show very different tidal states, with sandbanks at the mouth of the Ribble and the Wyre covered in July (Plate 2(i) and exposed in September (Plate 2 (ii)). This is because the July image is taken at Spring tides when the tidal range is greatest.

The sampling station at Blackpool records elevated nutrient levels during the Winter survey. This water sample was taken at two and a half hours after High Water, when the discharge would still have been in operation, which might explain the high levels seen. These high concentrations are not seen in the other three vessel surveys. An alternative explanation for these high nutrient concentrations might be the convergence of flows from the Rivers Ribble and Wyre close to Blackpool.

4.3 Heysham power station outfall

The outfall from Heysham power station in Morecambe Bay is seen in both CASI and thermal video imagery. The CASI imagery shows the outfall, just to the south of the harbour, due to the turbulence of the input which causes whitecapping on the surface, which has a higher ocean colour signal (see Plate 3). This feature is evident in both July and September.

The thermal imagery shows the extent of influence of the plume during the September survey. The water being pumped from the power station is warmer than the ambient temperature of the coastal water into which it is flowing. These two overpasses were taken six minutes apart on September 20th 1995 (Plate 4). The major tidal stream is directed towards the coast at

this time, although it is apparent from the imagery that there is also a flow to the north along the coast. The dissipation of a small eddy structure is seen between the two images.

The video imagery is not calibrated for absolute temperature, but it is obvious that the power station outfall changes the water temperature for a substantial distance up the coast. Whether this has implications on the ecology of the region may not be established from the measurements taken by the baseline survey. Further investigation would be required if this were thought to be appropriate.

4.4 Morecambe Bay

All CASI images from Morecambe Bay in 1995 were collected close to Low Water conditions, which allows little discussion of water quality. The low water conditions do however allow the positions of channels within the bay to be mapped. This region is subject to channel change, as the majority of channels are no longer maintained. This is particularly evident in imagery of the approaches to Grange-over-Sands, where the main channel is located to the east of that shown on Admiralty charts, as illustrated in Plate 5.

4.5 Water flow along Welsh coast

The coast of North Wales from Great Orme to the Mersey shows the least complicated flow of sediment for this littoral cell, with a moderate to high eastward flow of sand, and a low eastward flow of shingle. This is illustrated in CASI imagery of this area, as for example shown in Plate 6 which shows the transport of suspended sediment around Great Orme, and easterly movement off piers. The suspended sediment records a higher ocean colour signal due to the increase in scattered light.

This easterly flow of sediment towards the Dee and Mersey estuaries is shown in the thermal imagery to be fairly swift. This results in the entrapment of water within embayments, forming fronts between warmer inshore water and the colder water flowing past offshore.

Underway data from each of the surveys shows a decrease in % transmission along this coast towards the Dee, signifying an increase in suspended sediment concentration. This is also seen in the laboratory analysis of water samples. An increase in temperature and a decrease in salinity is shown in the data, which is due to the influence of riverine inputs such as the Dee and the Mersey. This estuarine influence extends to approximately Great Orme in each of the surveys.

The overall easterly flow of water along this coast would result in little exchange of waters from the Dee and Mersey with more open coastal waters, which could have potential implications for water quality within the region between the Dee and the Ribble. This is shown in the laboratory data collected in 1995. Nutrients and dissolved metals repeatedly showed concentration peaks at baseline sampling sites in this region.

4.6 Nutrient concentrations at Formby Point

Laboratory analysis of water quality samples showed a clear geographical pattern, with maximum concentrations found at Blackpool (173) in Winter, North Wirral (170) in Summer and Formby Point in Autumn (171) for all nutrients.

Figures 4 - 6 show Skalar continuous nutrient analyser data for this region from Spring, Summer and Autumn. The scales for these figures are determined from national averages, allowing national comparisons to be made. TON concentrations in this region are not high with respect to national averages, but ammonia concentrations were clearly very high to the north of this region in Summer, with similar concentrations seen around Formby in Autumn.

Data from each survey shows a maxima close to Formby, which is associated with the outflow of waters from the Mersey Estuary. During the Summer survey, which recorded highest concentrations at Formby Point, there is no Skalar data for comparison, but concentrations to the south, are elevated.

These high nutrient concentrations may have potential implications on the development of phytoplankton blooms in the Irish Sea. This region has historically recorded high chlorophyll-a concentrations with persistent blooms throughout the Summer. A high chlorophyll-*a* concentration of 10.9 µg/l was recorded at Formby Point (171) in the Summer survey. There is no Skalar data for this area, but it is apparent that nutrient concentrations are generally elevated in this region.

5. Conclusions

This littoral cell covers a wide geographical area, with great variation in coastal morphology. Morphology changes from narrow sand beaches in the north, to wide expanses of mud between Morecambe Bay and the Dee, and then sand and shingle beaches along the Welsh coast. In addition there is wide variation in the water quality, between the highly industrialised region of the Dee and Mersey and the more underpopulated regions of the Cumbria coast.

Laboratory water samples showed a geographical pattern in many of the parameters measured, both nutrients and dissolved metals. In Winter, the Welsh Channel sampling site showed high concentrations of dissolved metals with highest concentrations in Spring at Calder Hall, in Summer at Shell Wharf and in Autumn at Formby Point. The high concentrations found here may be attributed to the position of local riverine outflow. No baseline sampling sites were found to be in excess of the EQS level for any determinand. Nutrient concentrations were high at Blackpool in Winter, North Wirral in Summer and Formby Point in Autumn.

The nature of the coastline results in much of the aerial imagery being dominated by mudflats, which means that water quality may not be examined. A positive aspect of this is the use of CASI imagery to establish the shifts of channels, for example in Morecambe Bay.

The underway data provides a spatial perspective to water quality variations in the region. In combination with the aerial imagery, it allows the influence of riverine inputs to be better understood. The variation in flow direction of rivers entering the Cumbrian coastal waters is also apparent. The imagery also identifies the extent of influence of the Heysham power station outfall in Morecambe Bay, as the water pumped out has a higher temperature than the coastal water.

Figure 1.

Littoral Cell 11, From Great Ormes Head to Solway Firth.

* *After Motyka, J.M. and Brampton, A.H. (1993), "Coastal Management, Mapping of Littoral Cells".*

Figure 2.

Calibrated CASI Fluoresence Line Height Image, Summer 1995.

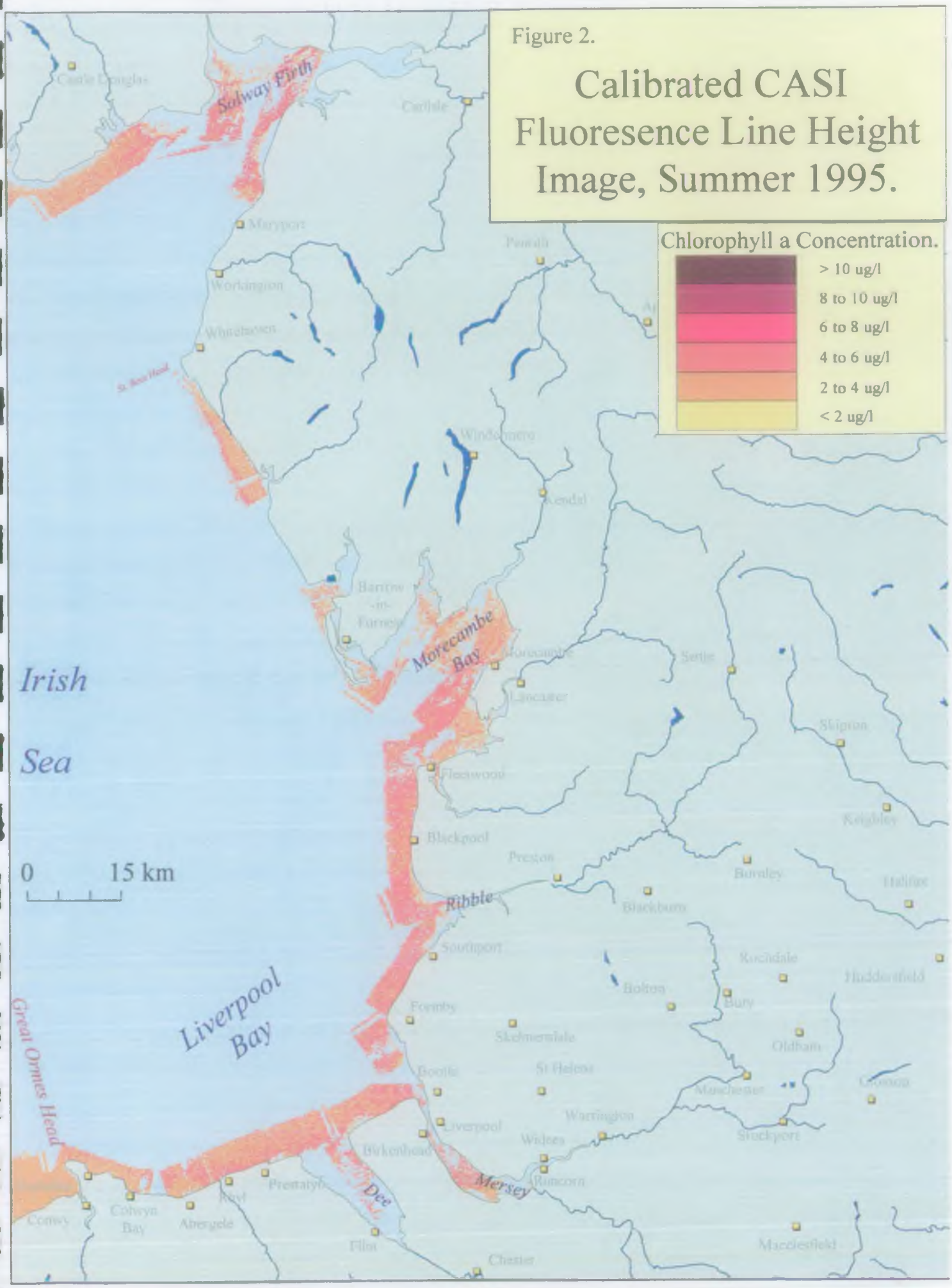
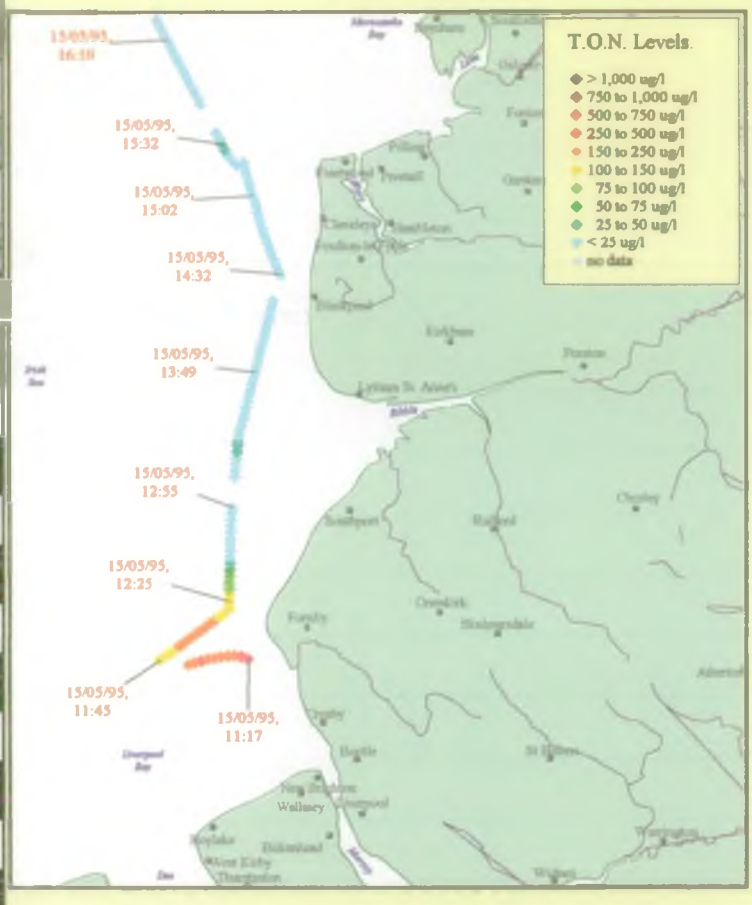


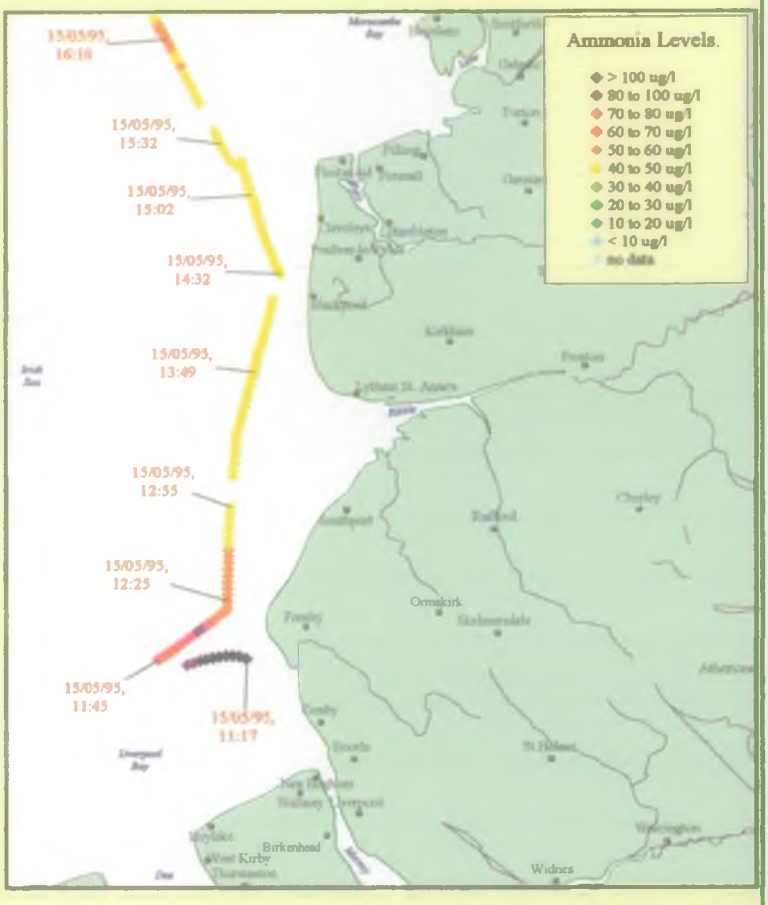
Figure 3.

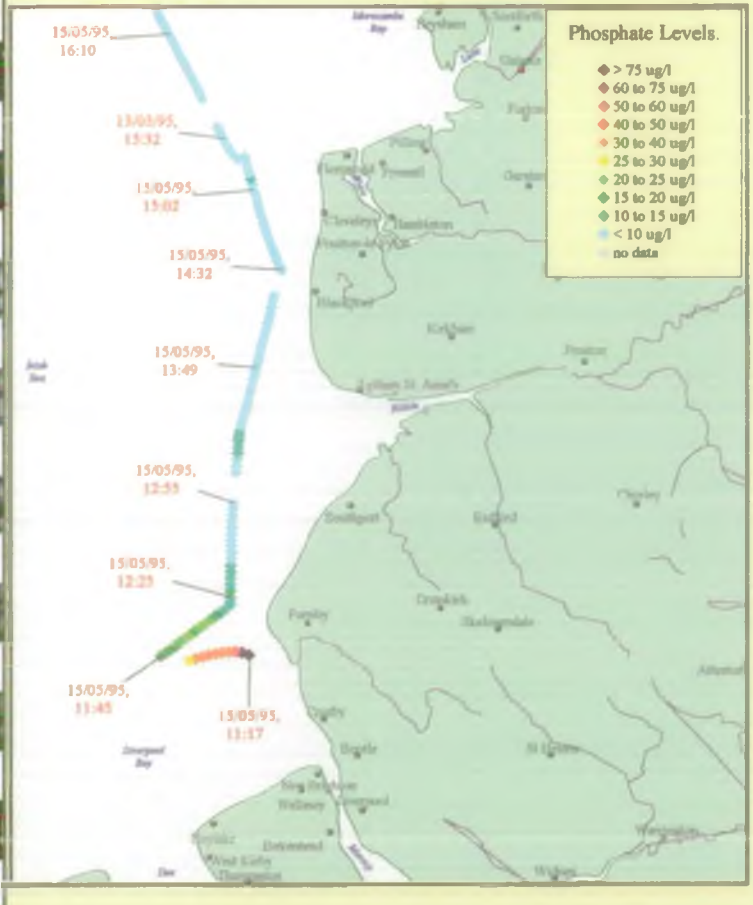
Calibrated Continuous Track Fluorimeter, Summer 1995.

Figure 4.

Skalar Nutrient Data from The Dee Estuary to Morecambe Bay , Spring 1995.







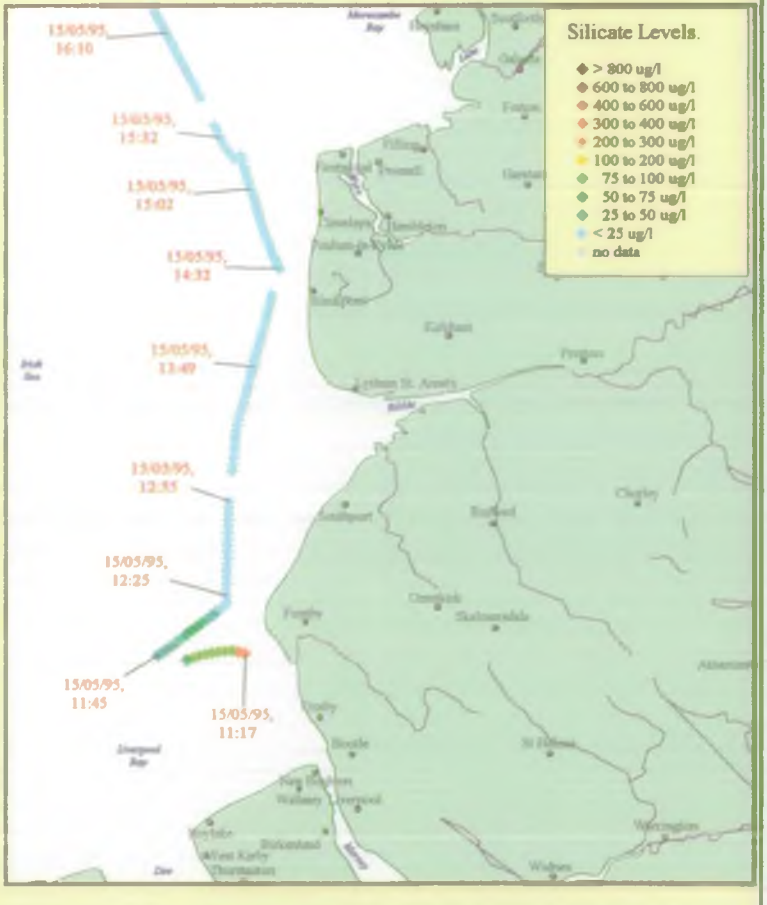
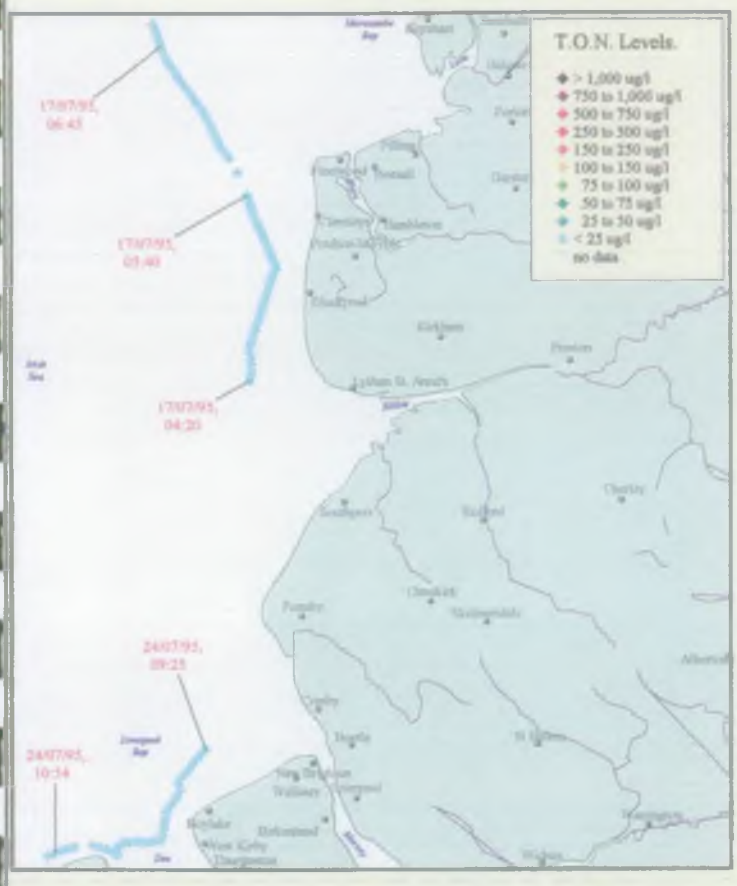
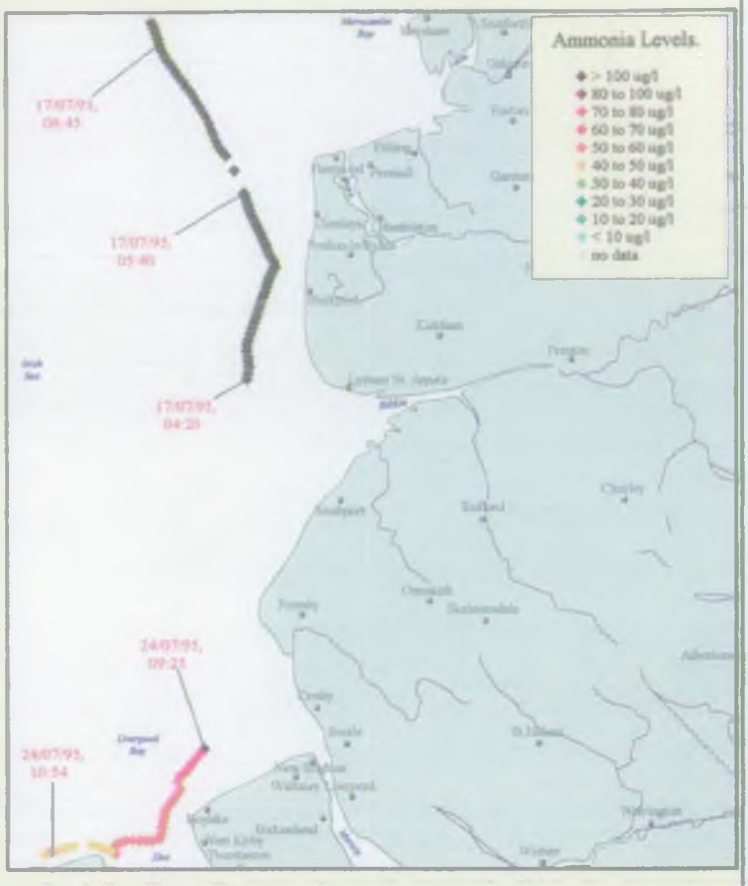
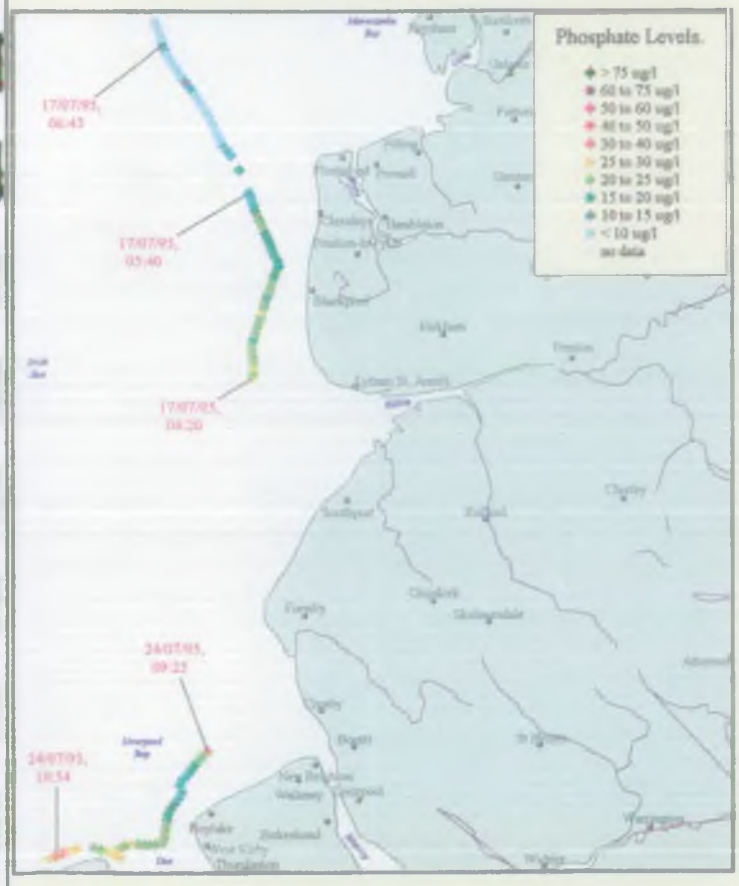


Figure 5.

Skalar Nutrient Data from The Dee Estuary to Morecambe Bay , Summer 1995.







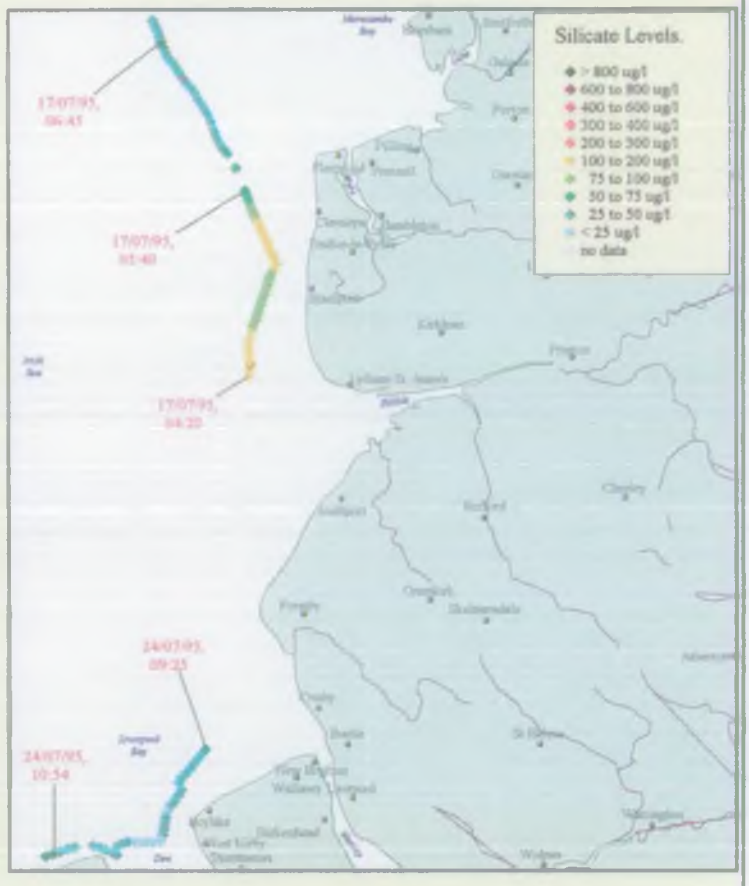
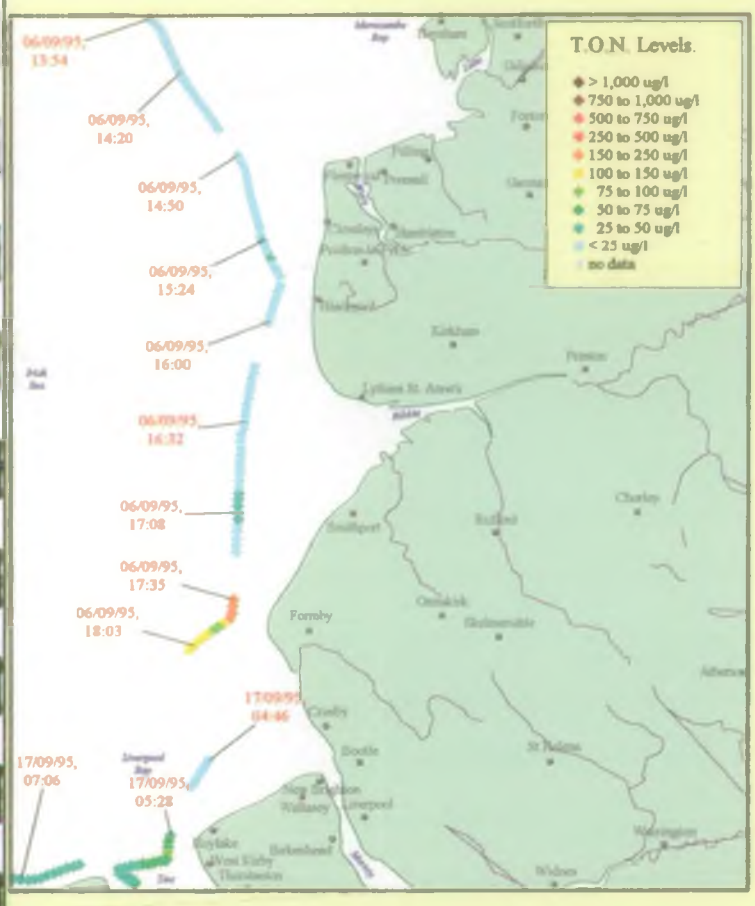
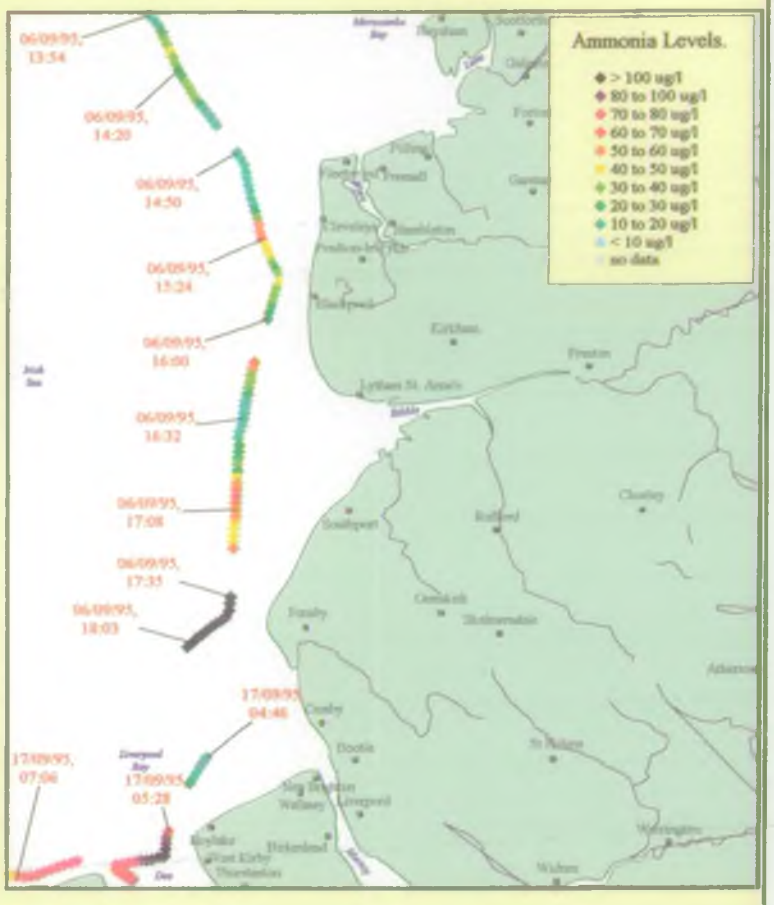
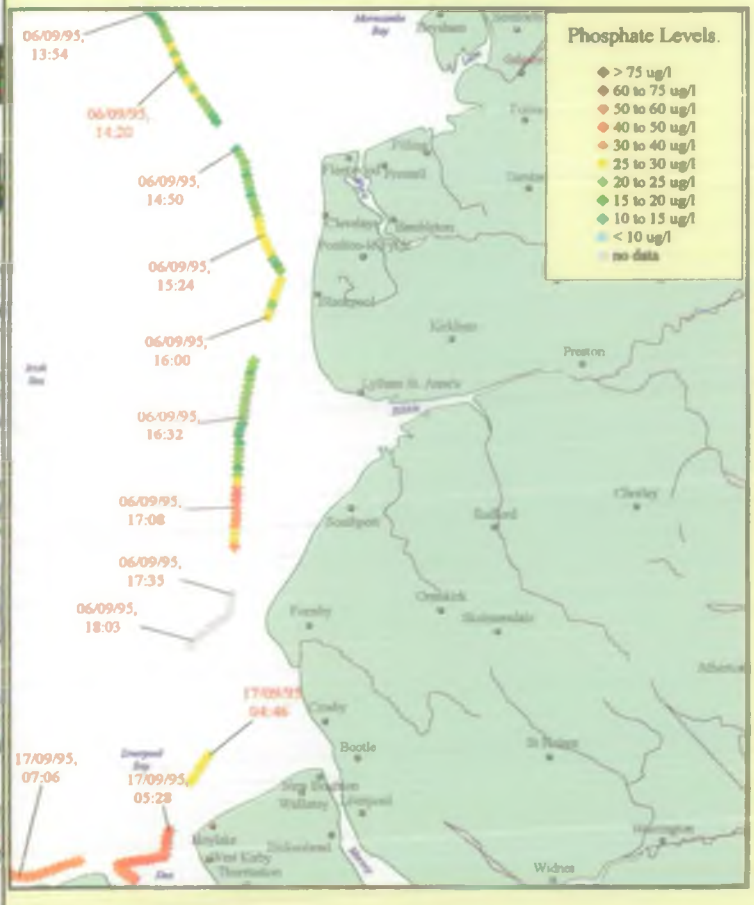


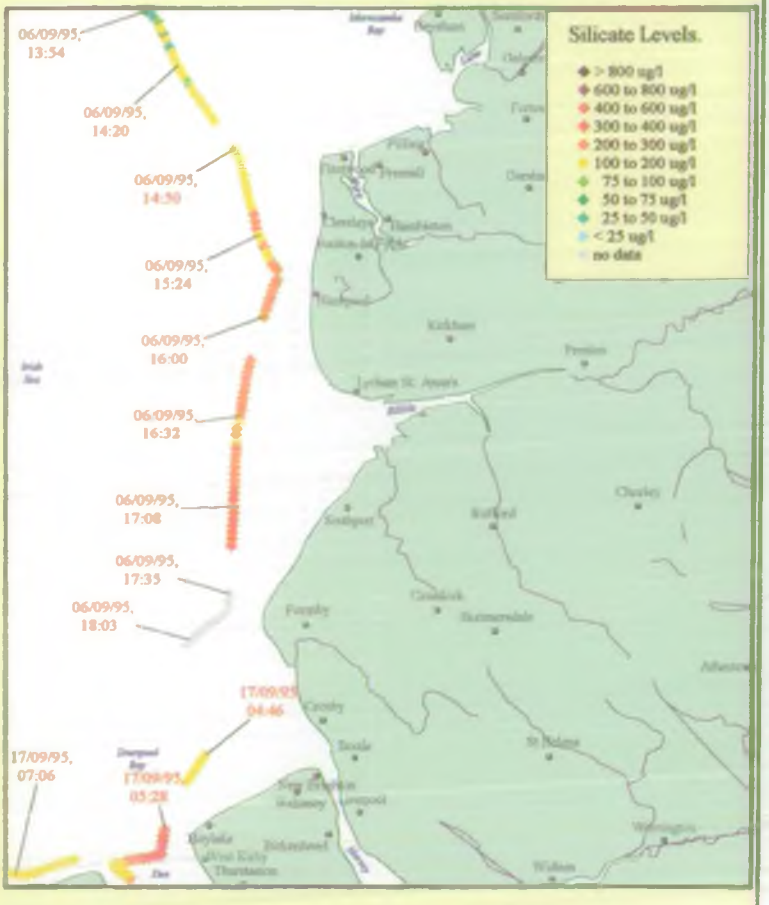
Figure 6.

Skalar Nutrient Data from The Dee Estuary to Morecambe Bay , Autumn 1995.









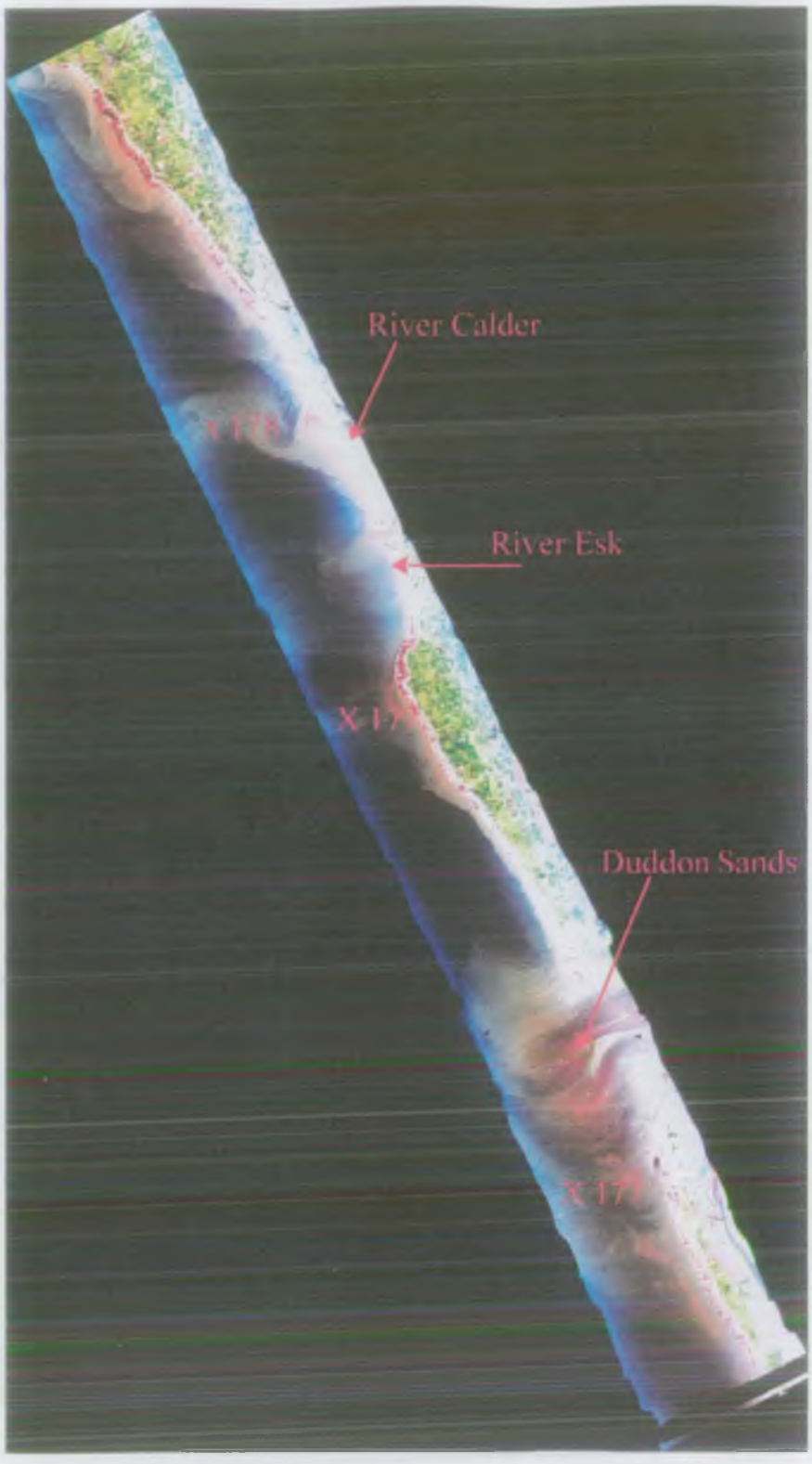
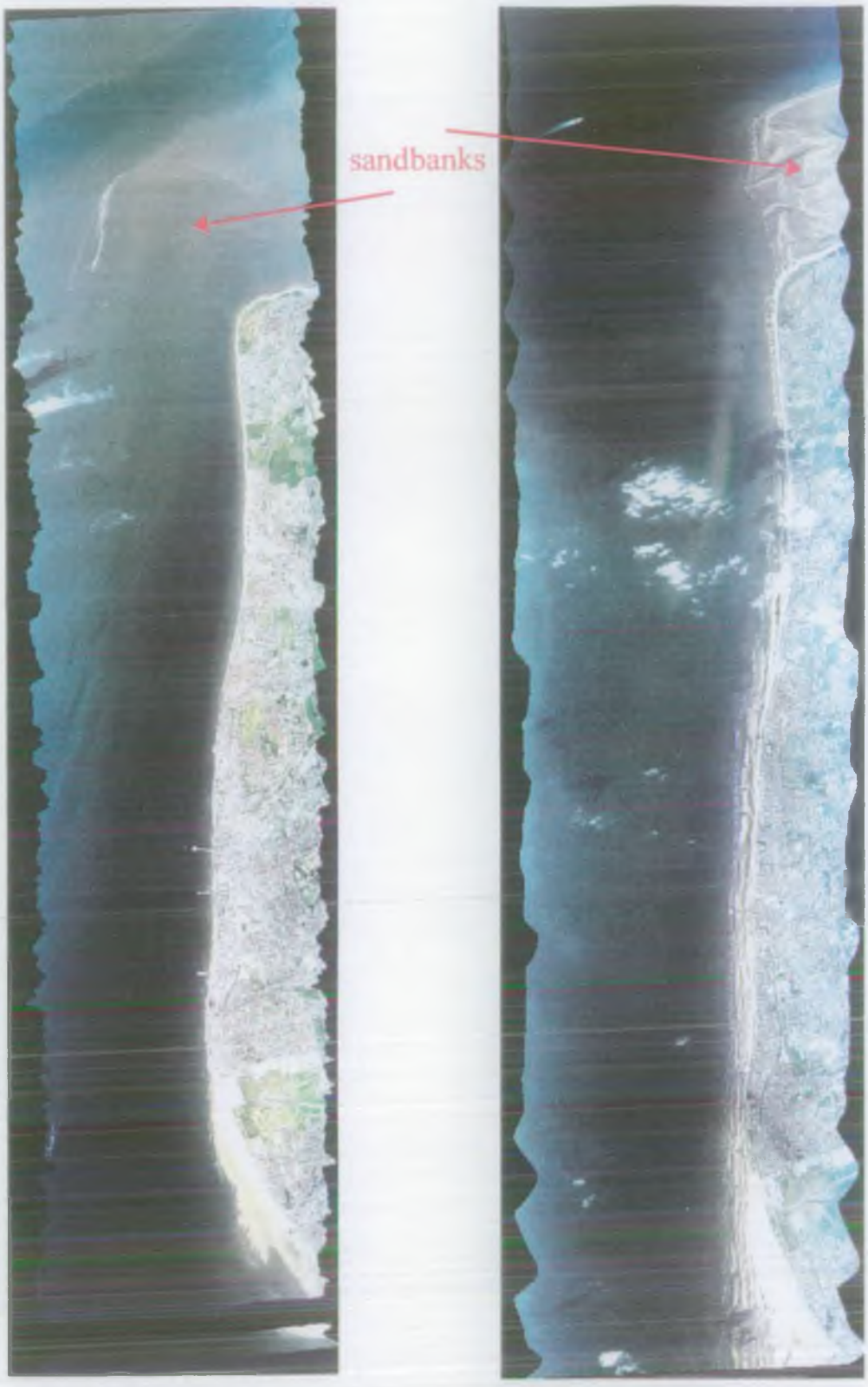


Plate 1: The Cumbrian Coast
CASI enhanced true colour composite image
15th September 1995, 12:16 GMT
Baseline sampling sites are marked as red crosses



(i) 29th July 1995
10:44 GMT

(ii) 20th September 1995
16:18 GMT

Plate 2: Blackpool
CASI enhanced true colour composite images

Plate 3: Heysham power station
CASI enhanced true colour composite image
9th July 1995, 15:28 GMT

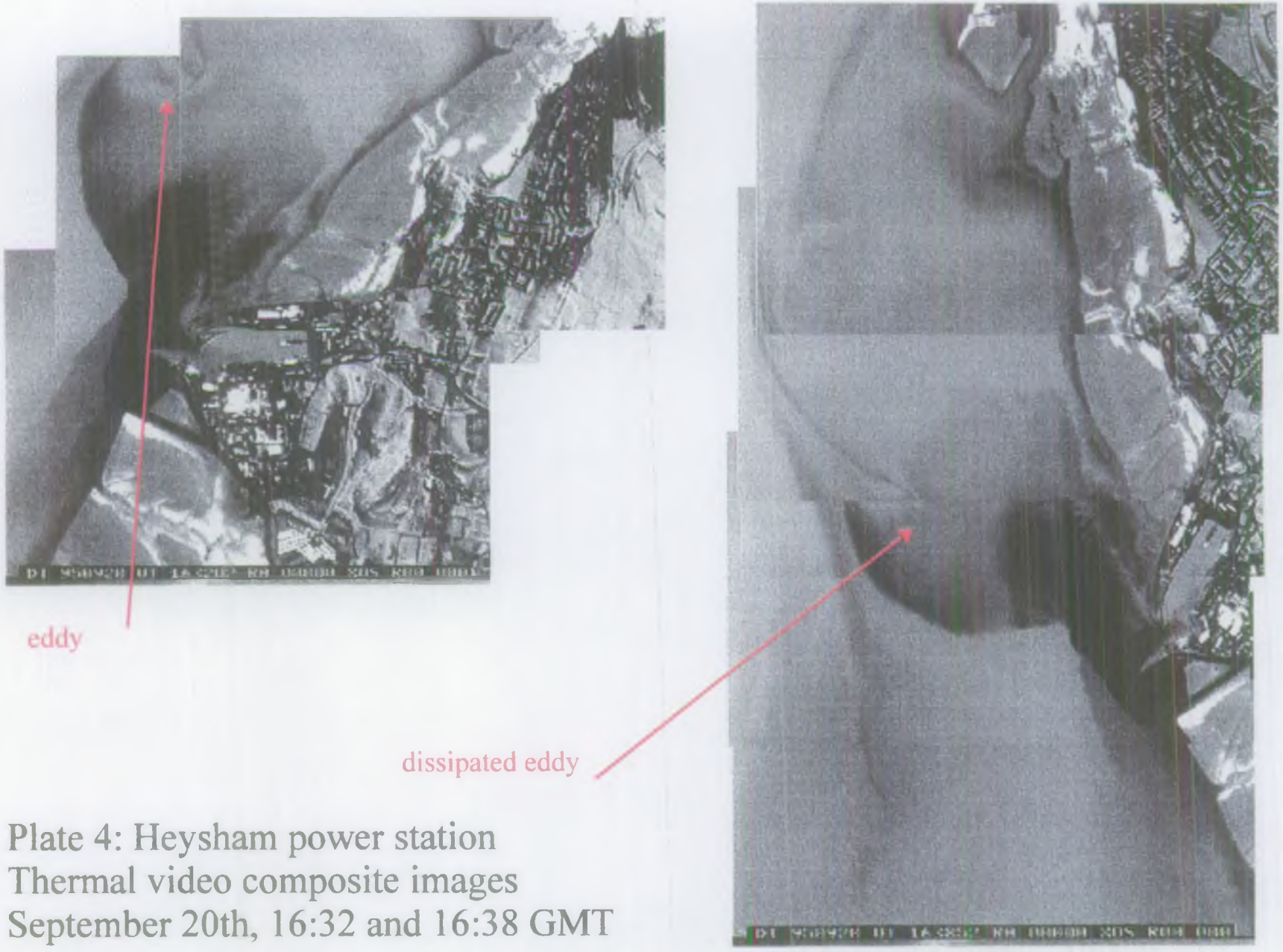


Plate 4: Heysham power station
Thermal video composite images
September 20th, 16:32 and 16:38 GMT

Plate 5: Grange-over-Sands
CASI enhanced true colour composite
9th July 1995, 15:18 GMT

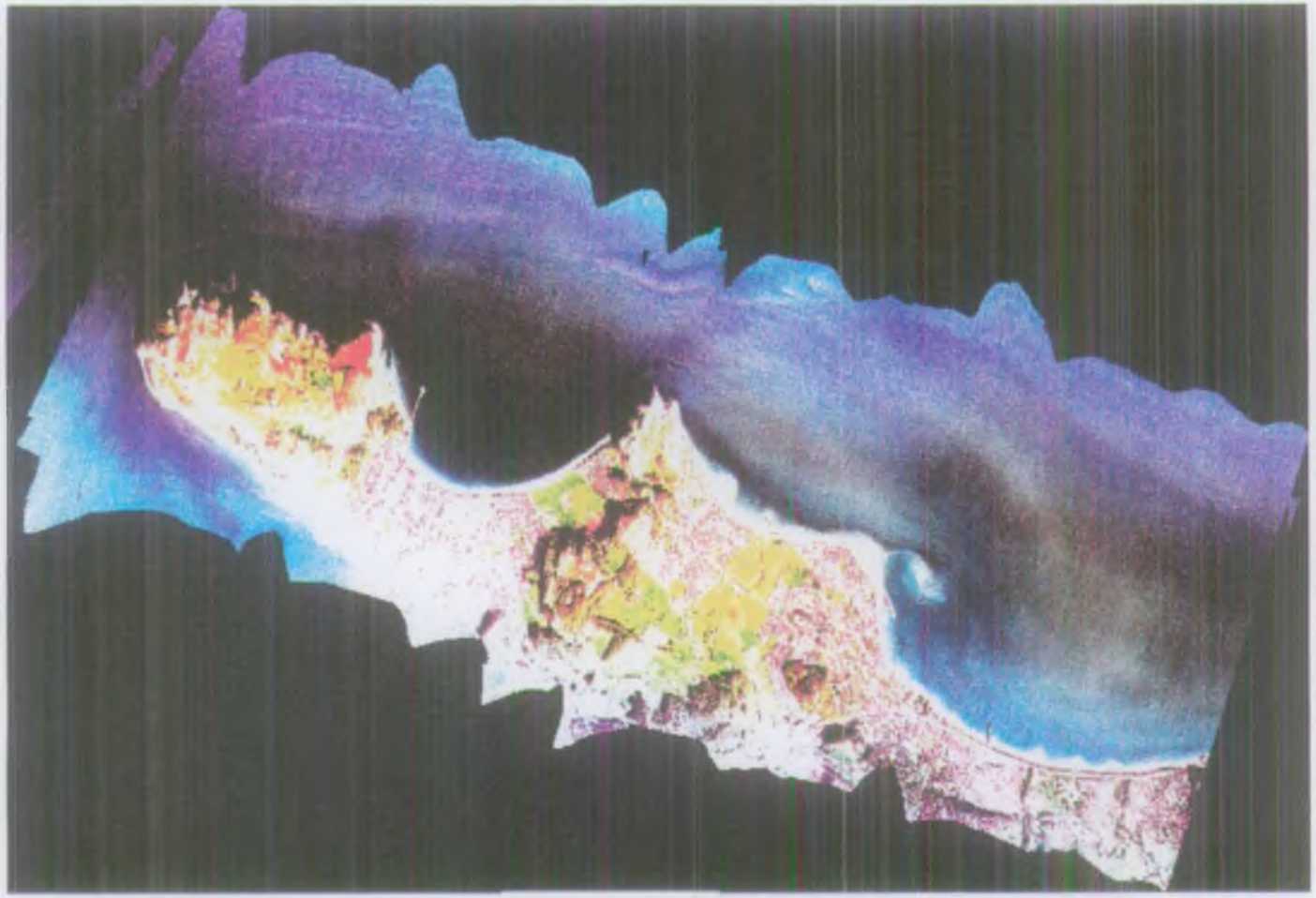


Plate 6: Llandudno Bay
CASI enhanced true colour composite image
10th October 1995, 09:14 GMT