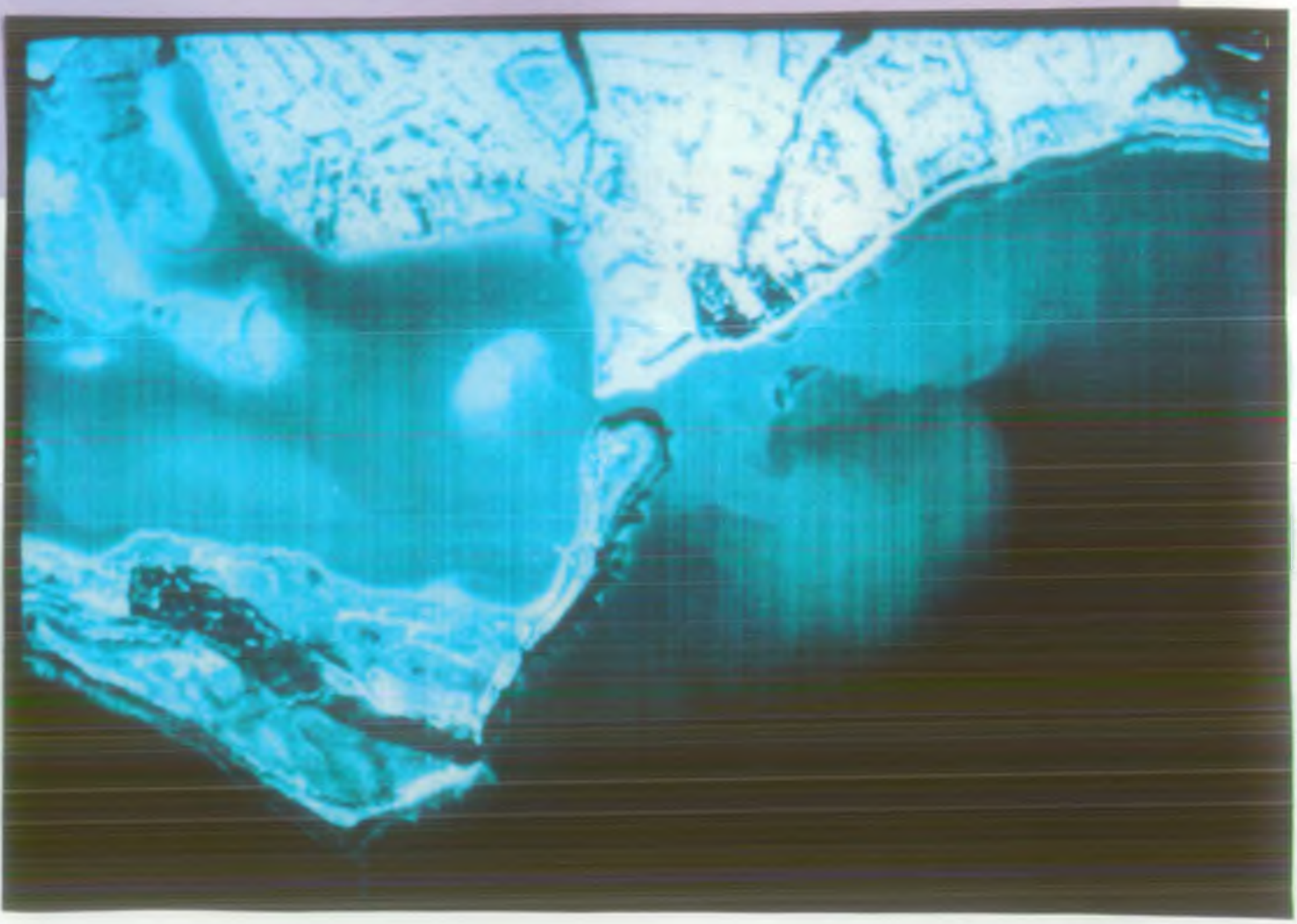


A SURVEY REPORT
REMOTE SENSING AND BASELINE MONITORING OF THE COASTAL WATERS OF ENGLAND AND WALES
1992 - 1993

NRA

National Rivers Authority

A SURVEY REPORT

REMOTE SENSING AND BASELINE MONITORING

OF THE COASTAL WATERS OF

ENGLAND & WALES

1992 - 1993

THE REMOTE SENSING AND BASELINE MONITORING OF THE COASTAL WATERS OF ENGLAND AND WALES 1992 - 1993

CONTENTS:-

i. EXECUTIVE SUMMARY

General

The project was instituted as the most likely and practicable means of fulfilling the Authority's duty under the Water Resources Act 1991 to monitor controlled coastal waters and its responsibility to the UK Government as the competent body under various EC directives. This latter includes the identification of areas of controlled waters which are or might become subject to eutrophication.

A series of 4 surveys were carried out around the coast of England and Wales. The Authority's 4 coastal survey vessels took samples at 15 km intervals for laboratory analysis and carried out on-board monitoring and analysis. This work was coordinated with the use of a compact aerial spectrographic imager (CASI) and an infra red (thermal) imager, both producing digital data. A colour video recorder was also included in the "package" of instruments flown over the coast.

Results

Samples analysed in the laboratories produced information on metals, organic pollutants, nutrients, suspended solids and chlorophyll-A.

Areas of the coast around the Tees estuary, south of the Humber, north of the Thames, in the Solent and in the northern Irish Sea contained chlorophyll-A in excess of that defined as "normal" for the purposes of the relevant Directives.

Other areas, notably the Severn and Thames estuaries, were below this level despite having high concentrations of nutrients. It is likely that high concentrations of suspended solids in these areas suppressed algal growth.

Continuous monitoring equipment on the vessels produced information between the survey sampling points and enabled some changes between water bodies to be identified.

In addition to the laboratory samples, near-continuous information on nutrient concentrations was obtained from the Thames to Milford Haven.

Fluorimeters were used to measure chlorophyll continuously around the coast. This latter information was also used to calibrate images obtained from the aircraft-mounted CASI scanner/imager.

Images were produced from the CASI data in which the density of colour was inversely proportional to the fluorescence line height recorded by the instrument. A grey scale was produced for each image by reference to readings from the continuously monitoring fluorimeter on the survey vessel and this can be used to estimate the chlorophyll-A concentration anywhere in the image.

Images developed from the CASI data showed features not easily identifiable by other methods including some discharges, water bodies, currents and vegetation.

The IR (thermal) imager can be used to provide information not readily available by other techniques on the extent of mixing zones and the dispersion

of discharges and areas subject to riverine influence.

Recommendations

It is recommended that the survey should continue in a modified form to maximise the information from the aerial survey in the spring and summer when algal productivity is at a maximum. This would have the additional benefit that weather conditions in this period should be less likely to be adverse. Aircraft lease and CASI lease are estimated to cost £105k and £97k respectively.

Experience has shown that hiring the CASI instrument from abroad significantly reduces the flexibility to operate when conditions are most favourable or at periods of particular interest. It is therefore recommended that the NRA purchases its own CASI scanner/imager. The budget price for the purchase of a suitable instrument is £275k. Purchase would reduce the annual cost of the combined survey by at least £75k.

Shipboard surveys should be carried out in February, May, July and September each year to provide the required winter nutrient concentrations, maximum data during the period of peak algal activity and to coordinate with the aerial remote sensing.

Total annual cost of the proposals above is £517k reducing to £429k if the NRA purchases its own CASI.

Arrangements should be made to ensure that all 4 coastal survey vessels are equipped to carry out continuous monitoring while under way, including chlorophyll-A and the monitoring of vertical profiles when stationary.

The vessels should also all be equipped to carry out near-continuous analysis of nutrients while under way.

1. THE NEED, AIMS AND OBJECTIVES

1.1 General

Under Section 84(2) of the Water Resources Act 1991, the NRA is placed under a duty to monitor the extent of pollution in controlled waters .

These are defined under Section 104 of the Act such that they include territorial waters which extend seawards for 3 nautical miles (5 km) from baselines defined around the coast of England and Wales. The total area amounts to about 20,700 square kilometres (8,000 square miles), by far the biggest area of water for which the NRA has the responsibility for water quality.

The need for, and requirements of, the monitoring of these waters in addition to the general duty in the Water Resources Act, are set out in various Directives of the European Community.

The Directives on Dangerous Substances, Bathing Waters and Shellfish require the monitoring of certain specific areas in detail but the Directives on Urban Waste Water Treatment (UWWTD) (91/271/EC) and Nitrates (91/676/EC) impose an additional requirement to identify and keep under review areas which are "sensitive" to eutrophication and those which are less vulnerable due to their dispersion characteristics.

1.2 Monitoring Requirements

The DoE has defined the criteria which regulatory authorities should use to define eutrophication for the purposes of these Directives.

The main elements of these criteria, in the context of marine monitoring, include monitoring the winter nutrient concentration, which will give an indication of the propensity for algal blooms, and the monitoring of the occurrences of any subsequent blooms. The occurrence of such blooms is, however, also dependant upon available light , and thus inversely related to the amount of sediment in suspension.

Other UK commitments relate to the need to monitor the state of coastal waters under the North Sea Inter-ministerial Conferences and the Paris & Oslo Commissions.

1.3 Monitoring Methods

In anticipation of these requirements, the NRA commissioned 2 projects in its R & D programme to examine the feasibility of monitoring coastal waters by both remote sensing by satellite and a combination of aerial and shipboard surveillance.

These studies indicated that the only reasonable option was the shipboard sampling and analysis for dangerous substances and both nutrient and algal content combined with aerial imagery to integrate the algal information spatially across the 3 mile zone.

2. WORK CARRIED OUT

2.1 General

Four separate surveys of the quality of water around the coast of England and Wales were undertaken in November 1992, February 1993, May 1993 and August 1993 with the intention of gathering data during all 4 seasons of the year.

The surveys were each carried out using 3 different basic methods which were coordinated and carried out simultaneously.

These methods were the baseline sampling survey, on-board monitoring carried out by the Authority's 4 coastal survey vessels, and remote sensing from an aircraft using a compact aerial spectrographic imager ('CASI") and thermal imager.

The 3 methods together form a hierarchical system. They vary from great certainty about water quality but no information on distribution or extent (samples for laboratory analysis) to a much lower degree of certainty about water quality but considerable information on distribution and the extent of water bodies (aerial remote sensing).

Given perfect conditions for flying and remote sensing, it would be theoretically possible to carry out the aerial survey around the entire coast of England and Wales in about a week. However, as such conditions cannot be relied upon in the UK and the boat survey will necessarily take considerably longer, it was considered that 4 weeks were necessary to allow for adverse weather conditions and other delays.

2.2 Samples Taken For Laboratory Analysis

A network of 186 survey sites at about 15 km intervals was set up around the coast after consultation with staff from the relevant regions. These sites are shown in Appendix 1 and the areas covered by individual vessels in Appendix 2. Subject to tidal and navigational difficulties, sampling was repeated at these sites on all four surveys. Samples were analysed for nutrients and dissolved metals at all sites and for organic compounds at one third of the sites.

2.3 Shipboard Continuous Monitoring & Analysis

The 4 coastal survey vessels all use continuous monitoring equipment which measures such parameters as dissolved oxygen, conductivity, temperature, depth, salinity and transmission. They also operate fluorimeters to measure chlorophyll. These data are logged together with time and position on the Qubit navigational system. The general arrangement is shown in Appendix 3.

Analysis for nutrients is carried out on 3 vessels using Skalar auto-analysers either automatically at 3 minute intervals or under manual control on spot samples taken at the identified sites.

2.3 Aerial Remote Sensing Survey

A compact airborne spectrographic imager (CASI), a thermal scanner and a colour video camera were flown in a leased aircraft over 189 flight lines around the coast of England and Wales.

The swath covered by each flight line is 5 km wide at 3050 m.(10,000 ft) using a lens with a field of view of 80 degrees and the lengths vary from less than 10 to more than 50 km.

Despite bad weather with low cloud, almost all the coastline was overflown and scanned on each of the 4 surveys. Maps showing the areas covered in winter 1992, spring 1993 and summer 1993 are shown in Appendices 4 a, b & c respectively. The adverse weather caused great difficulty in achieving coincidence between the boats and the aircraft except in the August survey.

The thermal scanner was successful in recording various discharges, showing distribution, surface mixing zones and riverine influences, thus providing information which is required to ensure that sampling points are positioned correctly.
(Appendices 5 - 7)

Data from the CASI is converted by merger with data from the navigational system and corrections for the pitch and roll of the aircraft at Bridgwater. The resulting files are held on optical discs from which data can be obtained by reference to survey number and position or by time and date.

Data from the first 3 surveys has, by the end of August, been converted, merged and processed onto the optical discs. Images have successfully been produced of some areas of the coastal zone as examples and the data for the entire 4 surveys are now available for the production of images as required.

3. RESULTS AND INTERPRETATION

3.1 Shipboard Survey - Laboratory Samples

3.1.1 General

Chlorophyll-A values were found in February (Appendix 8a) and May 1993 (Appendix 8b) surveys to be low around most of the coast but areas with values greater than the 10 ug/l "norm" were identified in the May survey. These areas were around the Tees estuary, south of the Humber, north of the Thames and in the Solent.

High concentrations of nutrients were, however, present in other areas, notably in the Thames and Severn estuaries (Appendices 9a & b). It is likely that the amount of suspended solids present in the sea water in these areas reduces the amount of algal activity and hence chlorophyll-A production. Seasonal variation in weather such as a calm sunny summer could, therefore, result in a significant increase in algal productivity in these waters. Appendix 14 demonstrates the ability of the CASI to identify chlorophyll in the turbid water off Weston super Mare.

3.1.2 Nutrients and Chlorophyll

Chlorophyll-A concentrations increased in all areas between February 1993 and May 1993, as would be expected (Appendix 8c). The biggest increases were found in the North Sea near the Tees and south of the Humber to the south of the Thames estuary. There was also a significant increase in the Irish Sea north of the Mersey estuary. The decrease in nutrients associated with an increase in chlorophyll can be seen by comparing Appendices 9a & b and also 10a & b.

3.1.3 Suspended Solids

The water in some areas was shown to contain high concentrations of nutrients but not to sustain excessive algal growth.

The highest concentrations of nutrients were found in the Severn estuary followed by those in the Thames estuary. However, neither the greatest concentration nor the greatest increase in chlorophyll-A concentration was found in either of these areas. Reference to the distribution of suspended solids found shows very high concentrations in the Severn estuary (300 - 500 mg/l) and levels in both the southern North Sea and Thames area (50 - 100 mg/l) were significantly above those in the northern North Sea, English Channel and Irish Sea areas (5 - 20 mg/l). (Appendices 11 a & b)

These higher concentrations of suspended solids are likely to reduce the production of chlorophyll-A by significantly decreasing the depth to which sunlight penetrates into the sea water and, therefore, algal productivity.

3.1.4 Dissolved Metals

Most of the metals are found only in low concentration, well below EQS values. There are however, examples of two well-separated samples in which both copper and zinc exceed EQS. (Appendices 12 a & b)

There is also a pattern showing areas of generally increased metal's concentration, notably around the major estuaries.

3.1.5 Organic Solvents and Biocides
Almost all samples analysed for organic compounds were found to be at or below the limits of detection though these varied between laboratories.

Two samples in Caernarfon Bay had concentrations of HCB of 0.09 and 0.2 ug/l (cf EQS of 0.03)

3.2 Shipboard Continuous Monitoring and Analysis

All 4 survey vessels can monitor basic determinands such as temperature, salinity and dissolved oxygen on a continuous basis as well as chlorophyll. Data are stored together with positional information on the Qubit Trac V navigational loggers. Examples of Qubit-derived track data from the Solent area are shown as Appendices 13 a & b. The example shown in Appendix 13 c shows the change from coastal to estuarine water in the Severn estuary off the Somerset/Devon coast.

Results of nutrient analysis at 3 minute intervals from the Skalar auto-analyser are available between the Thames estuary and Milford Haven.

3.3 Aerial Survey

3.3.1 Thermal Imaging
Examples are attached as Appendices 5 - 7 showing clearly :

- riverine discharges to coastal waters;
- a discharge at St.Austell Bay;
- boat tracks demonstrating the presence of a cooler underlying stratified layer; &
- discharges from Hinkley Point and Wylfa nuclear power stations.

These images clearly show that the technique can be used to define, simply and successfully, mixing zones, current flow and the likely areas of influence of discharges.

As with any other technique, imaging under different tidal conditions would be required to show distribution and mixing zones under different conditions.

The technique provides a demonstrable and practical solution to the problem of assessing mixing zones and avoids both the sampling and float tracking involved in the calibration of models and the uncertainty of their output.

3.3.2 CASI Scans

The principles of hierarchical calibration of remotely sensed images using continuous on-board measurements which are in turn calibrated from laboratory samples as set out above in Section 2.1 can be employed.

Calibration of Fluorescence Line Height (FLH) imagery from the CASI with ground truth data, has been demonstrated using data from in situ fluorimetry obtained by the survey vessels. This was achieved by matching the range of FLH values in an image with the in situ fluorescence values for a corresponding section of boat track, thereby giving a grey scale with which to calibrate the black and white FLH image.(Appendices 14 a - c)

The cross calibration of the fluorimetry results with the results of laboratory analysis was hampered by differences in the methods of analysis. This matter should be addressed via the Laboratory Managers.

Appendix 15 shows a comparison between laboratory and continuous track data for chlorophyll along the south coast and Severn estuary. The scales have been altered to bring the 2 sets of results to a similar position on the graph.

In addition to the spatial distribution of chlorophyll, data from CASI scans can be processed to provide other information.

Appendix 16 shows a discharge not visible to the eye. It may be clear relative to the surrounding water and therefore shows dark in the enhanced image.

Appendix 17 shows inter-tidal vegetation. Further processing can differentiate between types of vegetation.

Appendix 18 shows a discharge from a vessel off Worms Head. The plume was not visible in either the infra red (thermal) or colour video records.

4. DISCUSSION

4.1 Survey Planning & Operation

The CASI and associated roll and pitch correction equipment were obtained on lease from Borstad and Associates, a Canadian company. Only one other company, the manufacturers (also Canadian) have a fully operational instrument to our specification available for hire.

Precise periods when the equipment was available in this country for NRA use had to be agreed well in advance and, because of the company's other commitments, were inflexible once agreed. The NRA was, therefore, committed to carrying out the marine and aerial surveys within those periods despite poor weather conditions, breakdown of a survey vessel or any other adverse circumstances which might occur.

For the same reasons, when the CASI is out of the country, it would be difficult to quickly make arrangements to take advantage of particularly favourable conditions or to investigate individual events such as an algal bloom or discharge.

Regions with coastal survey vessels operate to a programme of work in order to optimise their use. Each national baseline survey requires the vessels to travel from one end of the coast of the region to the other or along the coast of neighbouring regions. Small overlaps, both temporal and spatial, with neighbouring vessels are desirable to ensure continuity of data. The national baseline surveys are therefore important factors in the programming of regional and other work. Any re-timing of the national baseline survey to accommodate circumstances inside or outside the region will be likely to impact on the regional work. While every effort is made to avoid significant change to the baseline programme once agreed, the support of the relevant regional management teams may be required on occasions to give priority to the national baseline survey should changes be necessary.

These limitations of availability were found to cause difficulties with the coordination of the ship-board and aerial surveys which is necessary to ensure coincidence of data from both the survey vessels and the CASI.

Poor weather with low cloud and a series of Atlantic low pressure areas in the periods of the autumn and winter surveys made it difficult to achieve the desired synchrony. Special calibration flights were therefore carried out during the summer (August) survey to ensure that sufficient coincident data was available.

Other than in calm, clear summer weather usually found in spring and summer, the conditions which favour the operation of the survey vessels are likely to be those which are unfavourable to the successful operation of the scanner and vice versa.

For instance, the boat crews report that calm sea conditions in autumn and winter which favour boat operations are likely to be accompanied by low cloud, mist or rain. In contrast, the clear skies or high cloud required for the optimum performance of the scanner are reported to accompany moderate or high winds.

The results obtained during the survey demonstrate that, as would be expected, chlorophyll-A concentration in waters around the entire coast are at a minimum during the winter and that these minimum levels are very low. Algal activity increases in spring, summer and early autumn. Blooms may occur singly or in succession at any time in this period.

During the winter, cloud cover, the angle of incidence of sunlight, the intensity of light and the increase in solids in suspension combine to limit the effective operation of aerial remote survey. However, the amount of nutrient in the water in late winter is an important factor in the propensity of the water to support large scale algal activity in the following spring and summer.

5. CONCLUSIONS

The surveys demonstrate that, by means of coordinating the use of the four NRA coastal survey vessels and an aircraft operating a CASI scanner together with infra red and colour video recorders it is possible to acquire data which can be processed to provide the monitoring information required in Section 1 above plus other information.

Aerial remote sensing can be used to provide information not otherwise practically obtainable on the spatial distribution of chlorophyll, mixing zones of discharges and areas of riverine influence.

6. FINANCIAL

6.1 Project Budget

The budget for the project in 1992-93 excluding staff costs is set out below:-

	Budget £k
* Aircraft (Leased)	155
* CASI (Leased)	110
* Survey vessels	75
* Laboratory analysis	95
* Consultancy & hire costs	44
* Computer hardware and software	100
* Total	579

6.2 Proposals for 1993-94

6.2.1 Surveys

The recommended change in the number of surveys will have financial implications.

Reduction in the number of aerial remote sensing surveys from 4 to 3 will reduce aircraft and CASI leasing costs in comparison with carrying out 4 surveys in the previous project.

However, the cost of hiring a CASI can be expected to increase by at least 15% due to the change in the rate of exchange of the pound sterling against the dollar since the negotiation of the previous contract.

The costs of laboratory analysis below has been amended to include all the 186 baseline sites.

6.2.2 Cost Estimates

* Aircraft leasing costs.

Approx. 30 days covering 115 flying hours per survey @ £400 per day and £200 per flying hour	£35k per survey

* CASI leasing costs

Pro rata 1992-93 survey	£28k per survey
(Probable increase as in 6.2.1 +15%	£32k per survey)

* Thermal (I.R.) lease	£12k per survey

* Survey vessels

Running costs (incl. salaries) 26 boat days @ £800		£21k per survey
Laboratory analysis (1992-93 unit cost)		
186 sites of which		
1/3 include total metals @ £157.3	£10k per survey	
2/3 exclude total metals @ £123.3	£15k per survey	
Total for laboratory analysis		£25k per survey

* I.T. and data handling costs — £15k per survey

* Consultancy and hire costs — £35k

6.2.3 Cost estimate summary

Item	per survey £k	per annum £k
* Aircraft (lease)	35	105
* CASI (lease)	28	84
including +15%	(32)	(97)
* Thermal (I.R.)	12	36
* Survey vessels running cost	21	84
* Laboratory analysis	25	100
* IT & data handling	15	60
* Consultancy & hire charges	35	35
Total	171	504
including 15% exchange rate change	(175)	(517)

6.2.4 CASI purchase

Although September 1993 prices for CASI and associated equipment have been obtained, exact details of the equipment specification have not yet been agreed. Therefore, it is only possible to include a budget price of £275k in these estimates.

Purchase of a CASI would reduce the per annum estimates in 6.2.3 by at least £75k allowing for £10k per annum for servicing and repairs. The annual cost would reduce to £429k.

7. RECOMMENDATIONS

7.1 Aerial Remote Survey

The aerial surveys should mainly be concentrated into the spring and summer months when algal growth is at its maximum. However, it is possible that conditions in the winter of 1992/93 were atypical. Therefore surveys should be carried out in the winter either over selected areas of coastal water or the entire coast during one year in three.

Overflights in May, July and September would provide more useful information and at lower cost than 4 seasonal surveys each year.

This change would have the additional benefit of improved weather conditions for aerial remote sensing.

7.2 Aircraft Leasing

The CASI and associated instruments were carried in a chartered aircraft for all the surveys. The aircraft was modified as necessary to accommodate the equipment and any Civil Aviation Authority approvals obtained by the charter company. Similarly, arrangements to enter restricted airspace were, where necessary, obtained by the company. The arrangements were very satisfactory and enabled NRA staff to concentrate on the requirements of the survey. It is therefore recommended that an appropriate aircraft be chartered for future surveys.

7.3 Purchase of CASI

As mentioned in Section 4, the leasing of a CASI from abroad limited the flexibility to amend the timing and extent of surveys. As a result, parts of some surveys were carried out in conditions which adversely affected the outcome to some extent.

The leasing arrangements also make it difficult to obtain the CASI at short notice to scan particular events such as blooms.

In addition to its uses to locate discharges, identify mixing zones and establish the spatial distribution of chlorophyll, the CASI has been used elsewhere to locate and identify inter-tidal vegetation and land use.

It is therefore recommended that the NRA purchases a CASI, thermal imager and video system.

7.4 Shipboard Survey

The coordination of the 4 NRA coastal survey vessels to carry out the marine baseline survey can provide both a series of discrete water quality measurements, near continuous measurement of nutrients and continuous instrumental monitoring of certain determinands around the coast.

The surveys should be carried out in February, May, July and September. The first to meet the requirement for the winter measurement of nutrients as an indicator of the propensity for the production of algal blooms and the others to coincide with the aerial remote sensing.

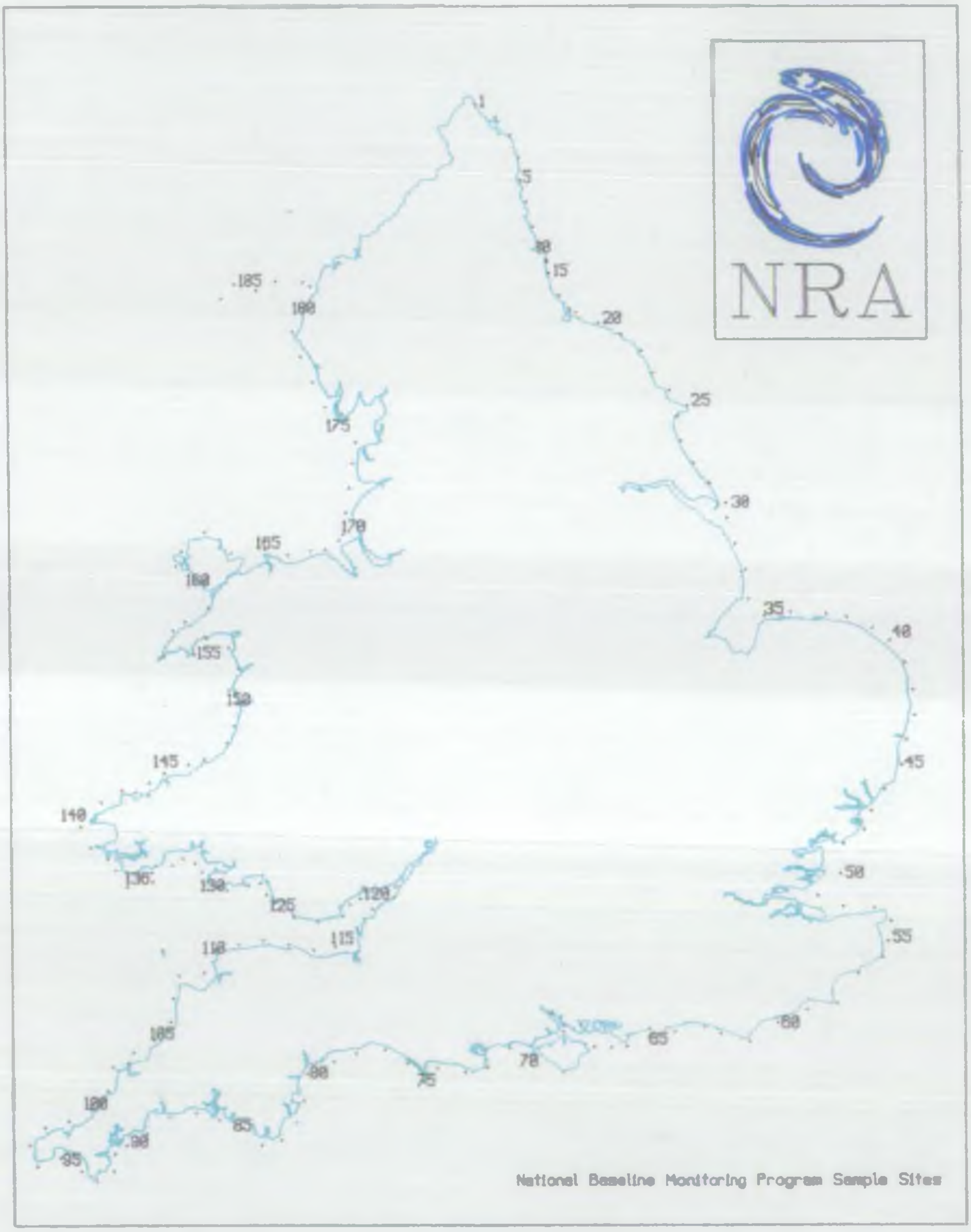
7.5 Samples For Laboratory Analysis

Discussions should be held with the National Laboratory Manager to rationalise the arrangements for the analysis of samples taken as part of the national marine baseline survey in order to optimise performance, costs and work load.

7.6 On-board Monitoring and Analysis

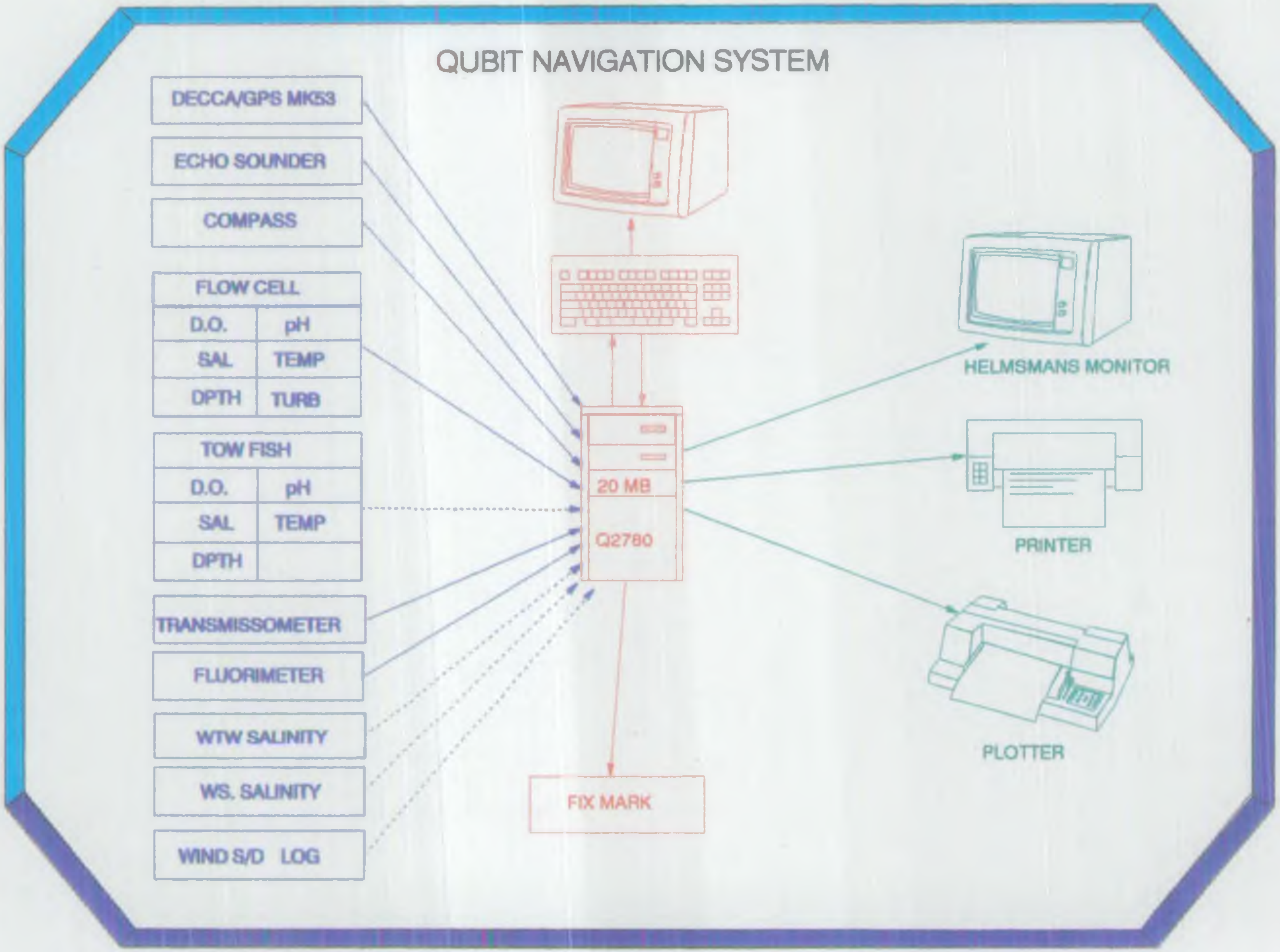
The single survey vessel without the capability for nutrient analysis should be equipped to do so. If a "Skalar" auto-analyser is not available as a result of the rationalisation of the NRA chemical laboratories, then £50,000 (budget price) should be allowed for this and the conversion of 2 auto-analysers to automatic sample feed to permit near-continuous nutrient analysis.

APPENDIX 1



National Baseline Monitoring Program Sample Sites

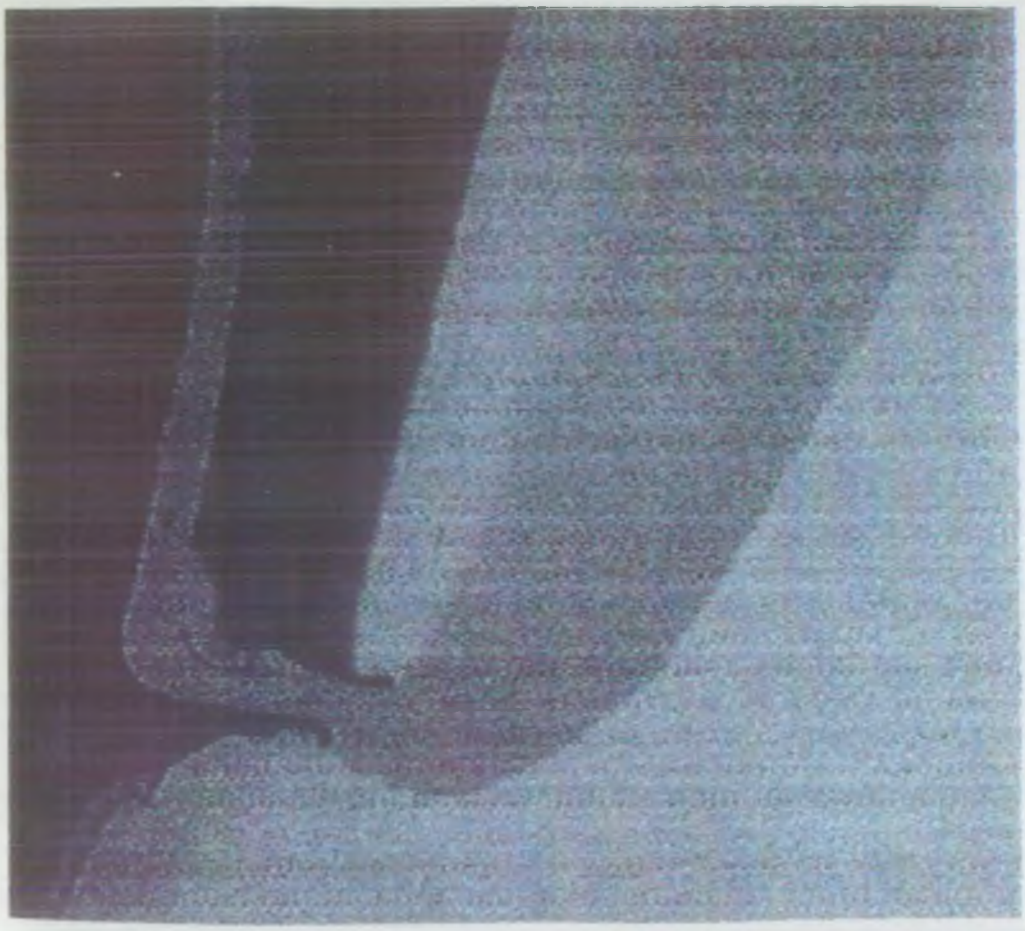

COASTAL BASELINE SURVEY
COASTAL AREA TO BE COVERED BY INDIVIDUAL N.R.A. VESSELS.
R.V. WATER GUARDIAN
R.V. GUARDIAN
R.V. SEA VIGIL
R.V. VIGILANCE

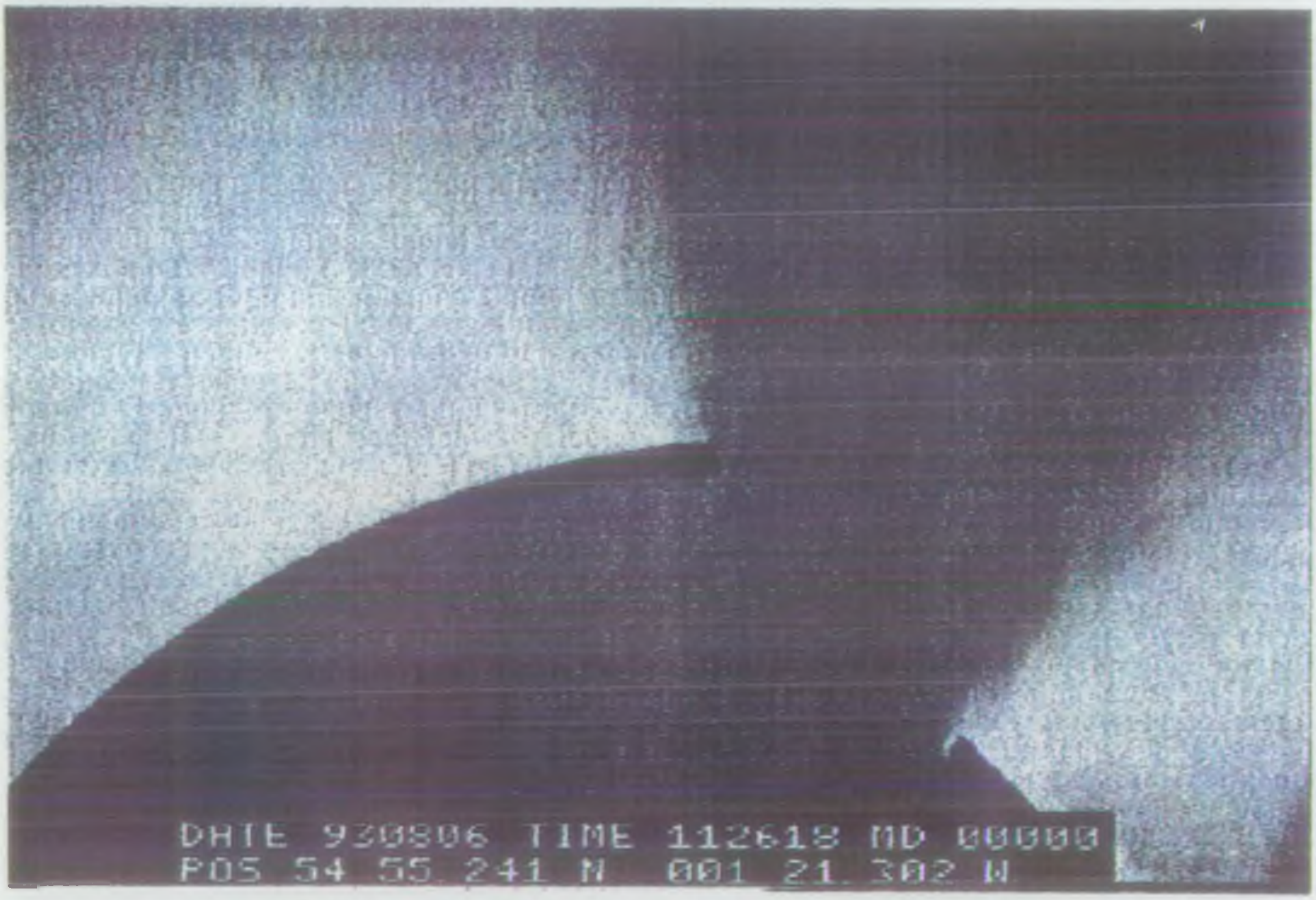

QUBIT NAVIGATION SYSTEM
DECCA/GPS MK53
ECHO SOUNDER
COMPASS
FLOW CELL
D.O.
pH
SAL
TEMP
DPTH
TURB
TOW FISH
D.O.
pH
SAL
TEMP
DPTH
TRANSMISSOMETER
FLUORIMETER
WTW SALINITY
WS. SALINITY
WIND S/D LOG
20 MB
Q2780
FIX MARK
HELMSMANS MONITOR
PRINTER
PLOTTER

APPENDIX 4a

APPENDIX 4b

APPENDIX 4c

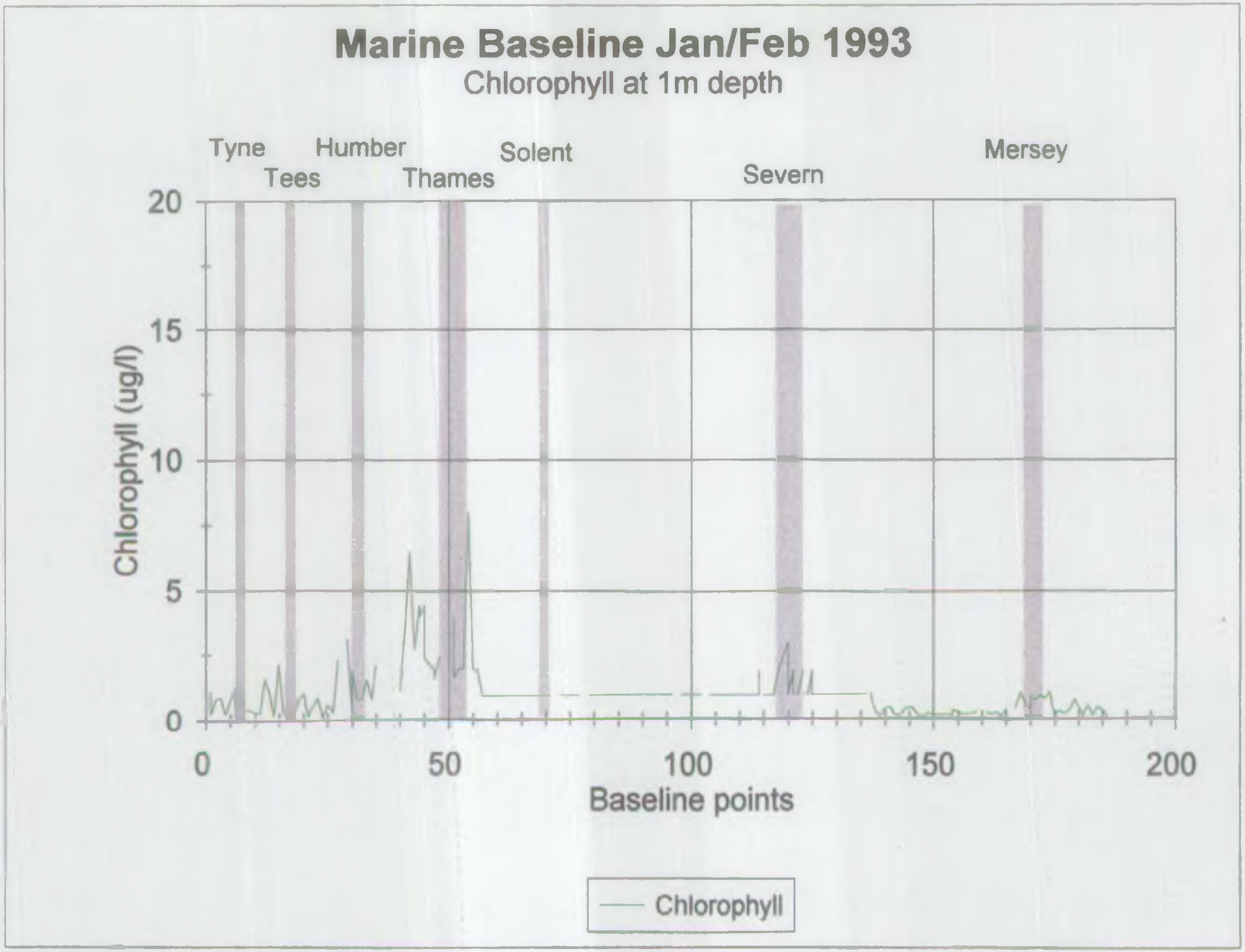


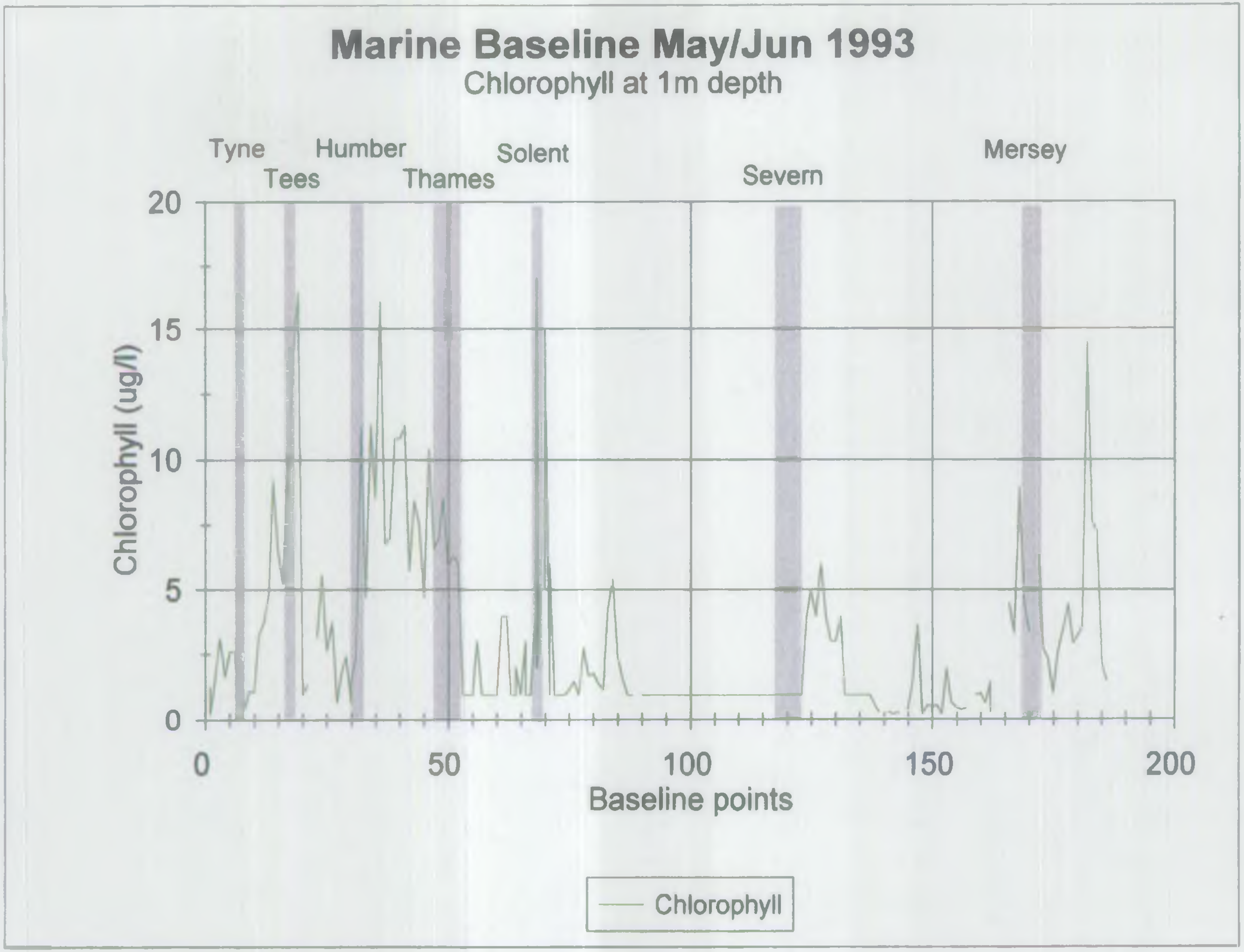


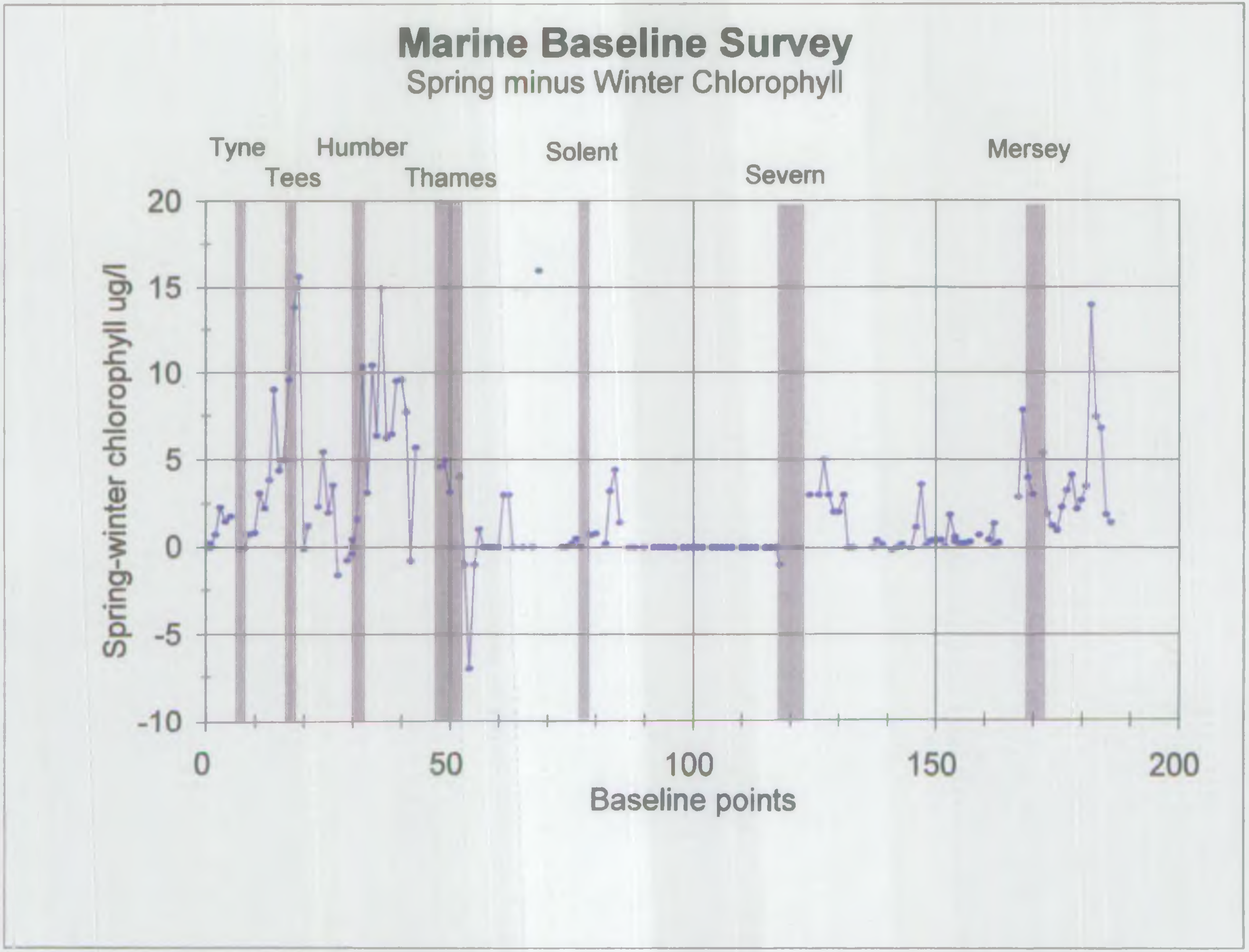
Appendix 5: Riverine discharges to coastal waters at Gorleston-on-Sea and the River Wear.

Appendix 6: A discharge at St. Austell Bay.
Boat tracks demonstrating the presence of a cooler underlying stratified layer.

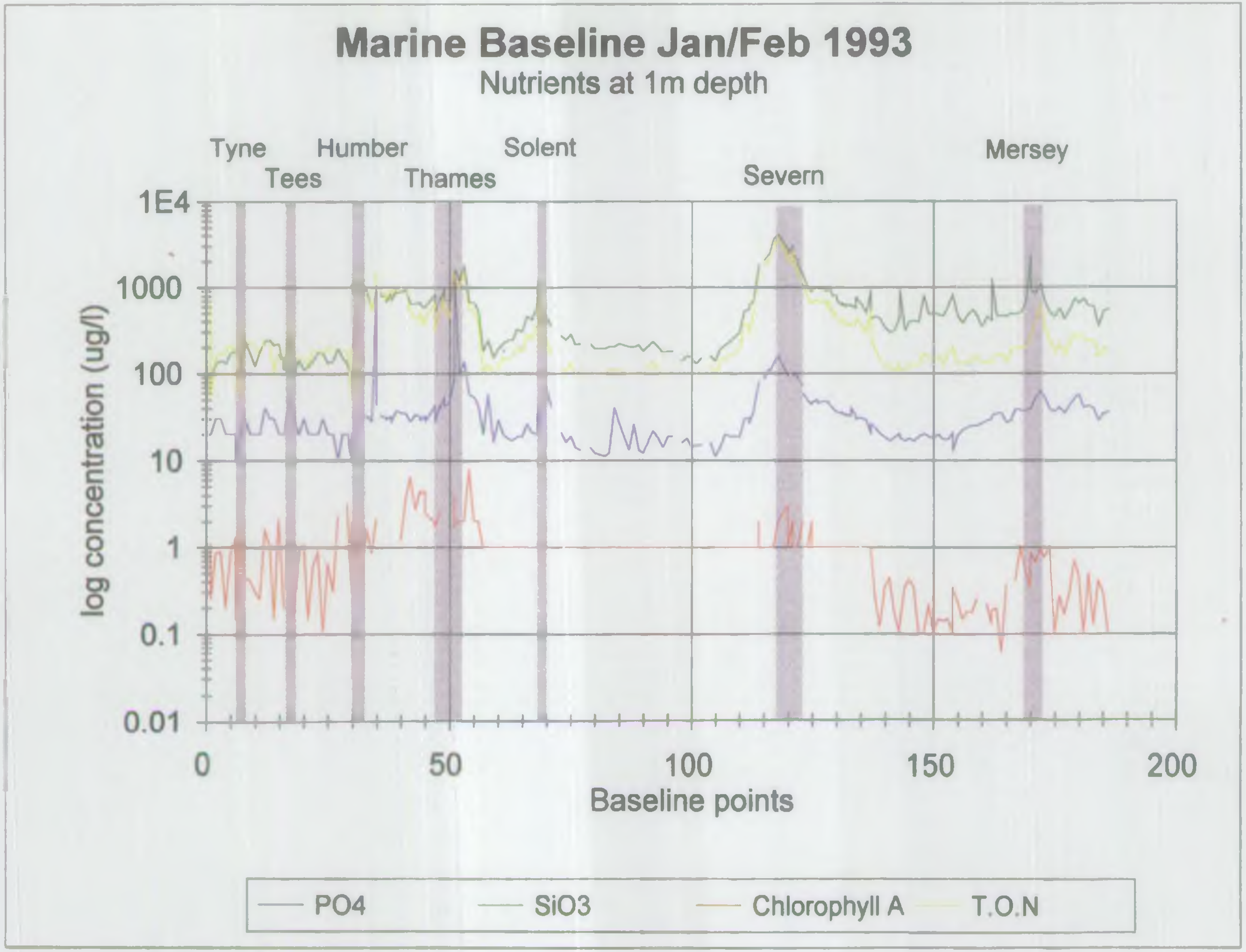
Appendix 7: A discharge from Hinkley Point and Wylfa nuclear power stations


Marine Baseline Jan/Feb 1993
Chlorophyll at 1m depth
Tyne
Tees
Humber
Thames
Solent
Severn
Mersey
Chlorophyll (ug/l)
0
5
10
15
20
0
50
100
150
200
Baseline points
Chlorophyll

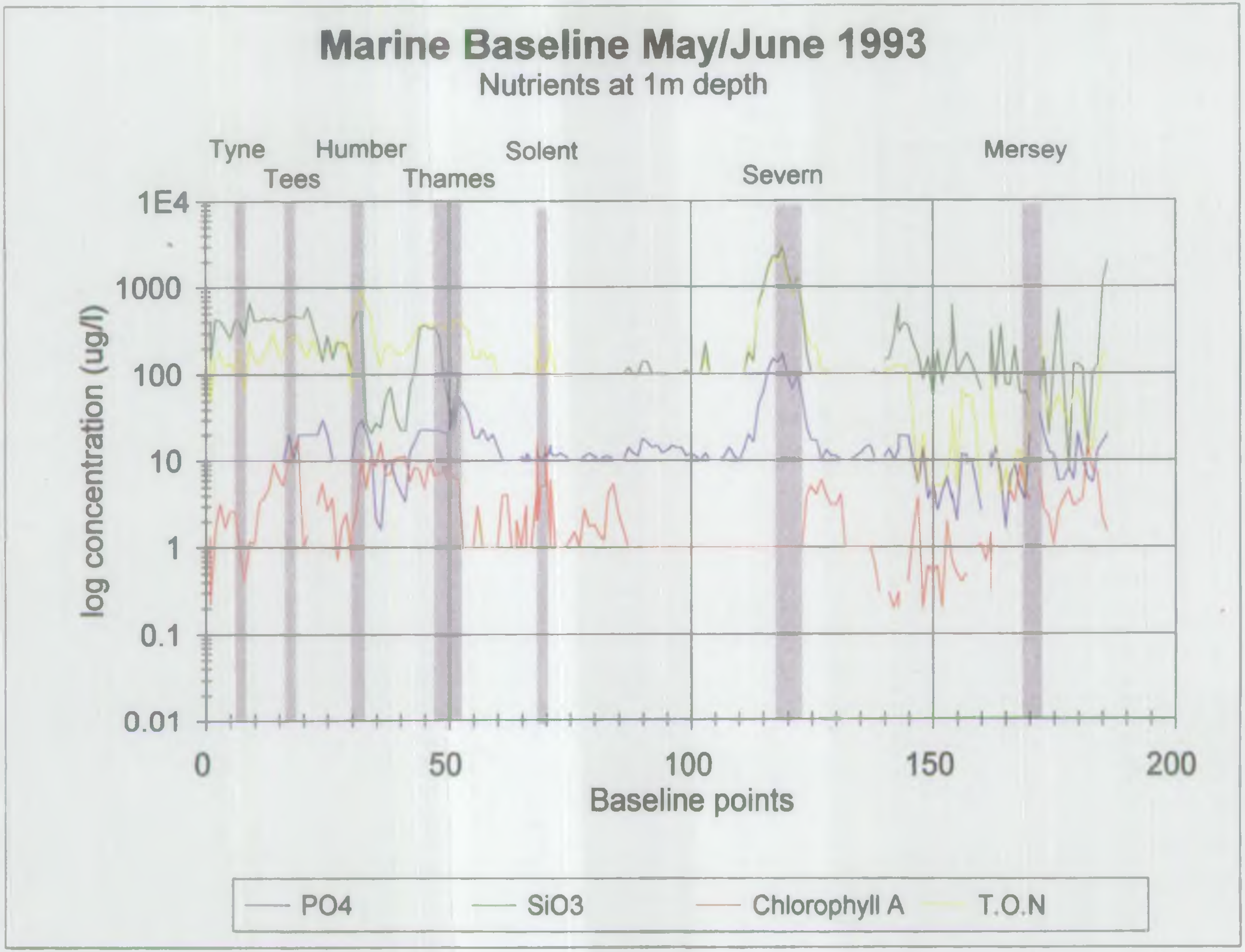

Marine Baseline May/Jun 1993
Chlorophyll at 1m depth
Tyne
Tees
Humber
Thames
Solent
Severn
Mersey
Chlorophyll (ug/l)
20
15
10
5
0
0
50
100
150
200
Baseline points
Chlorophyll


Marine Baseline Survey
Spring minus Winter Chlorophyll
Tyne
Tees
Humber
Thames
Solent
Severn
Mersey
Spring-winter chlorophyll ug/l
20
15
10
5
0
-5
-10
0
50
100
150
200
Baseline points

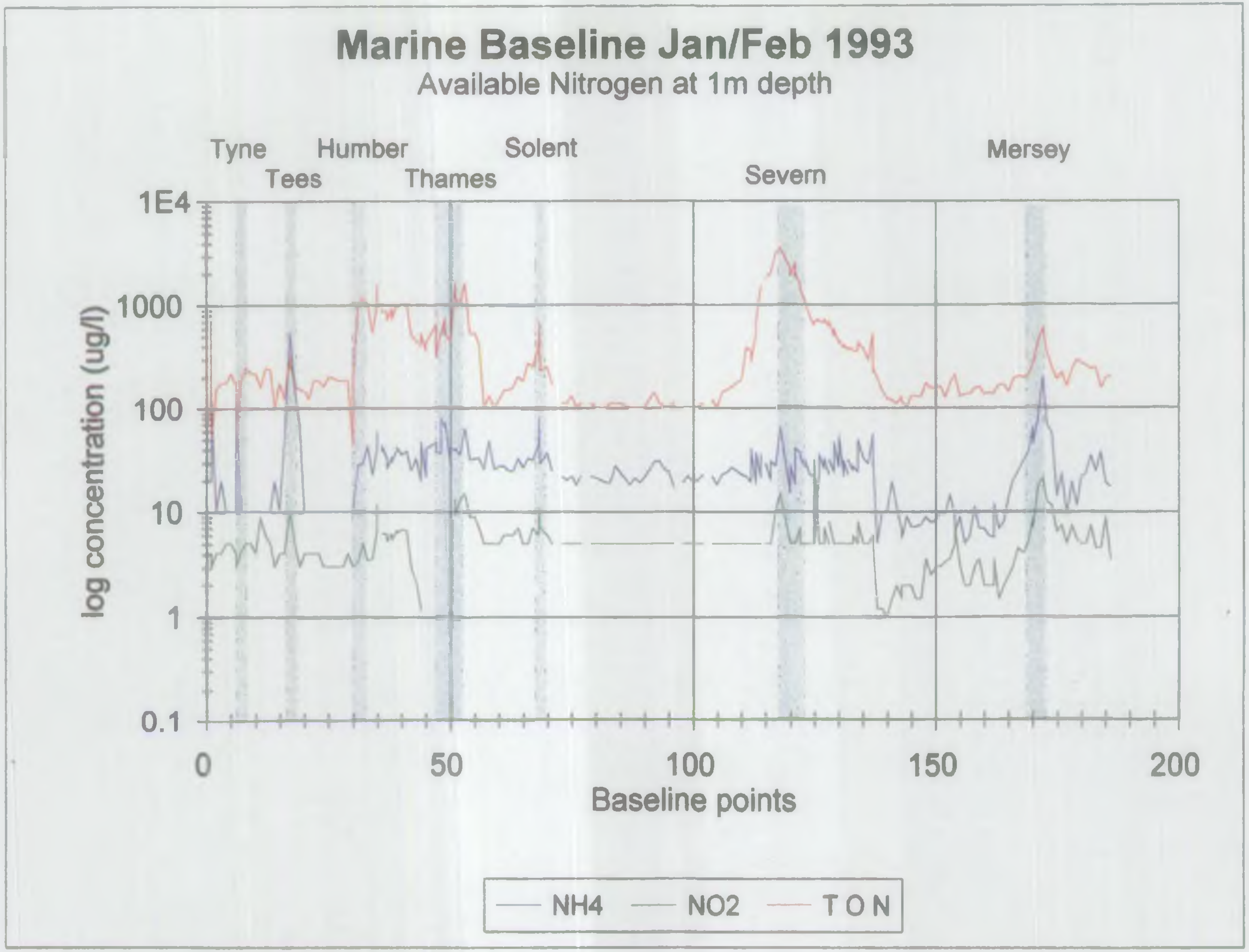
APPENDIX 8c

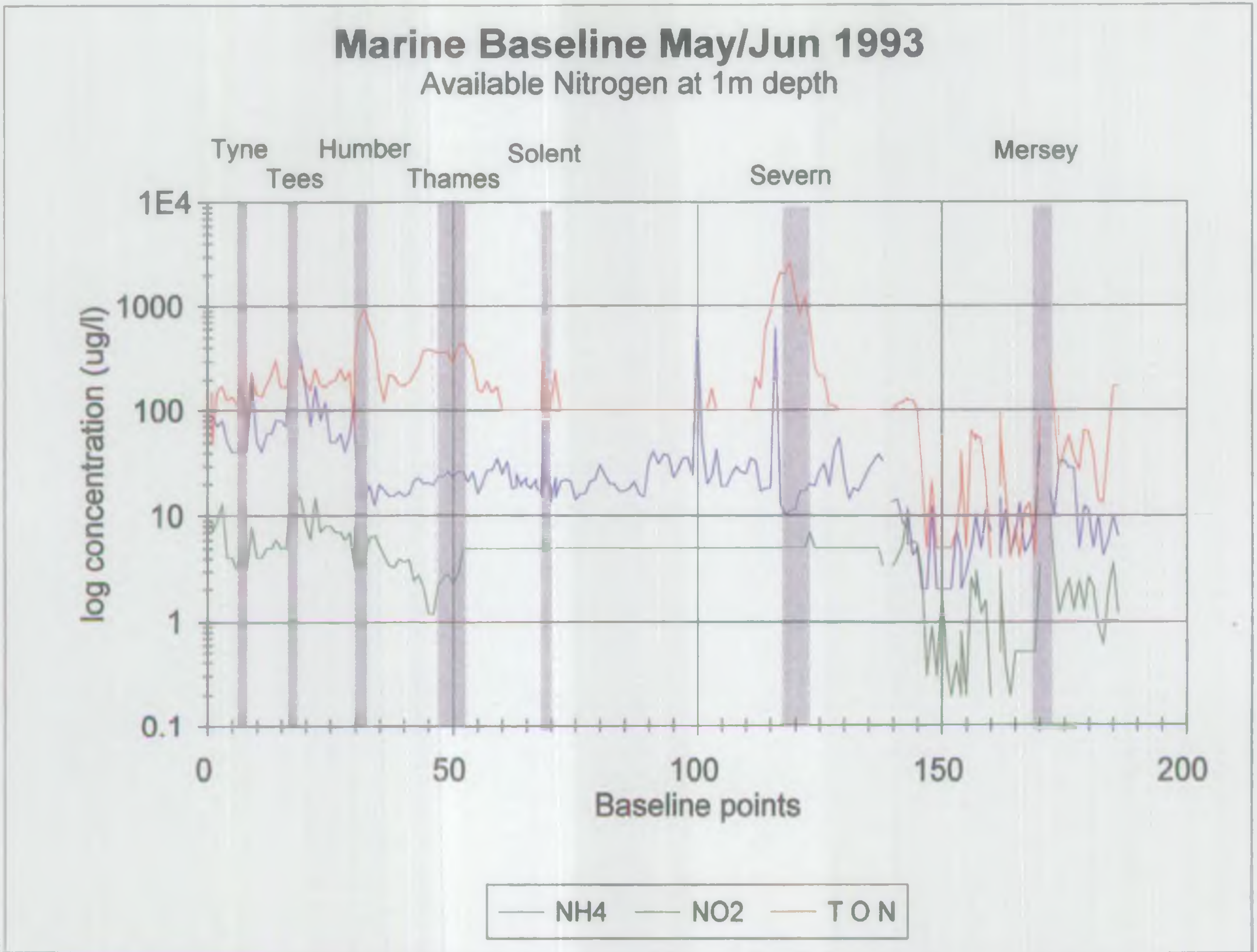


Marine Baseline Jan/Feb 1993
Nutrients at 1m depth
Tyne
Tees
Humber
Thames
Solent
Severn
Mersey
log concentration (ug/l)
1E4
1000
100
10
1
0.1
0.01
0
50
100
150
200
Baseline points
PO4
SiO3
Chlorophyll A
T.O.N

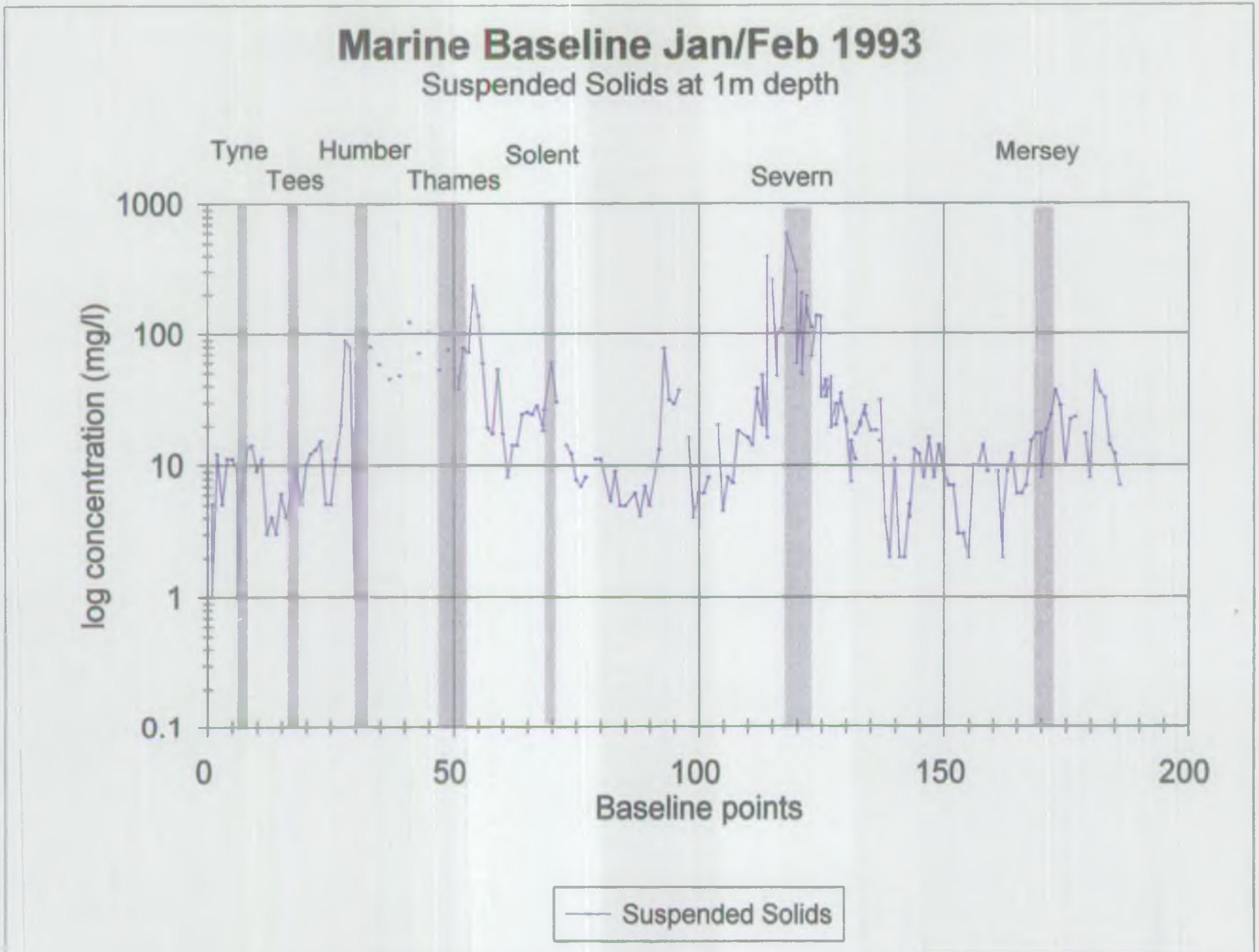

Marine Baseline May/June 1993
Nutrients at 1m depth
Tyne
Tees
Humber
Thames
Solent
Severn
Mersey
1E4
1000
100
10
1
0.1
0.01
log concentration (ug/l)
0
50
100
150
200
Baseline points
PO4
SiO3
Chlorophyll A
T.O.N

APPENDIX 9b

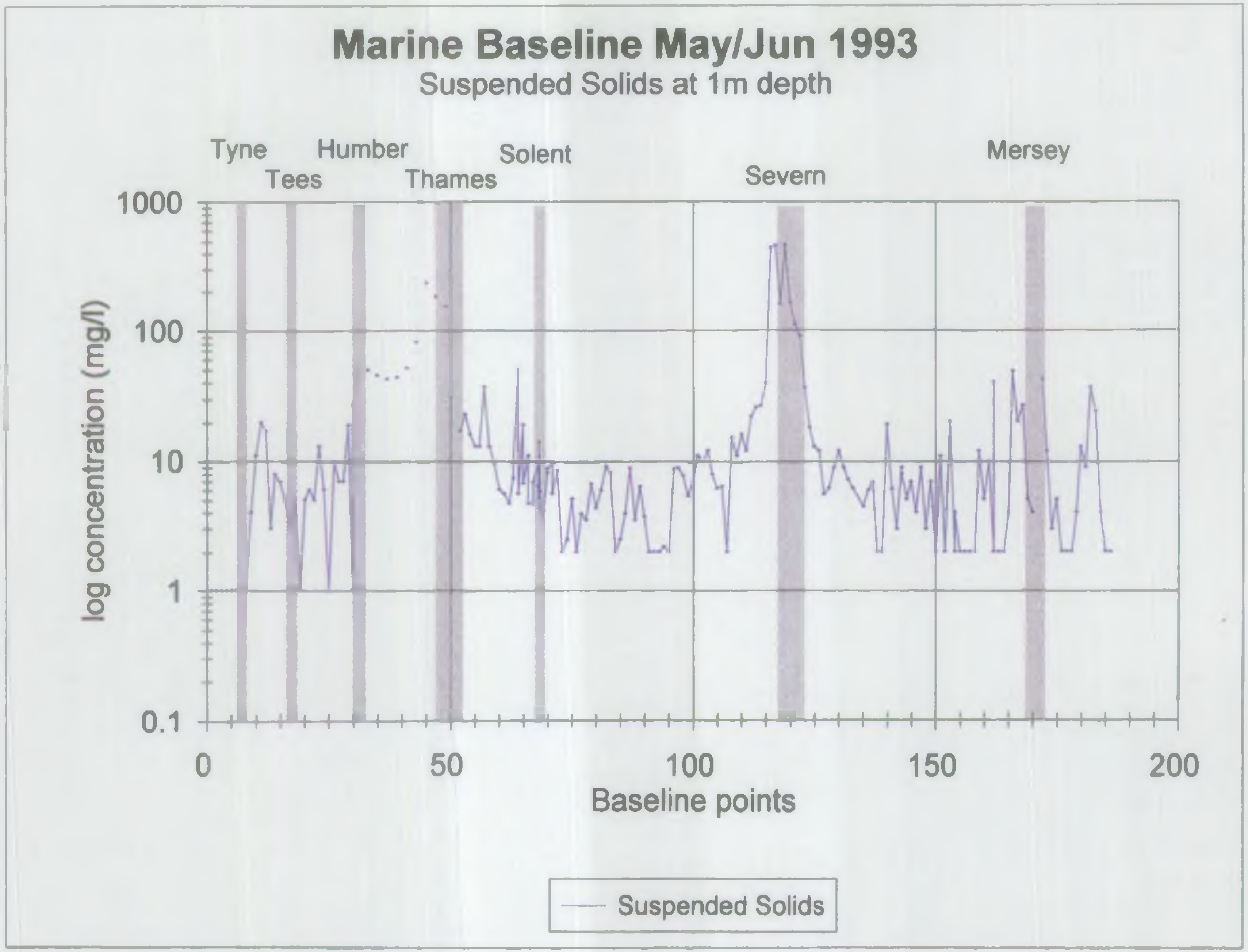

Marine Baseline Jan/Feb 1993
Available Nitrogen at 1m depth
Tyne
Tees
Humber
Thames
Solent
Severn
Mersey
1E4
1000
100
10
1
0.1
log concentration (ug/l)
0
50
100
150
200
Baseline points
NH4
NO2
T O N

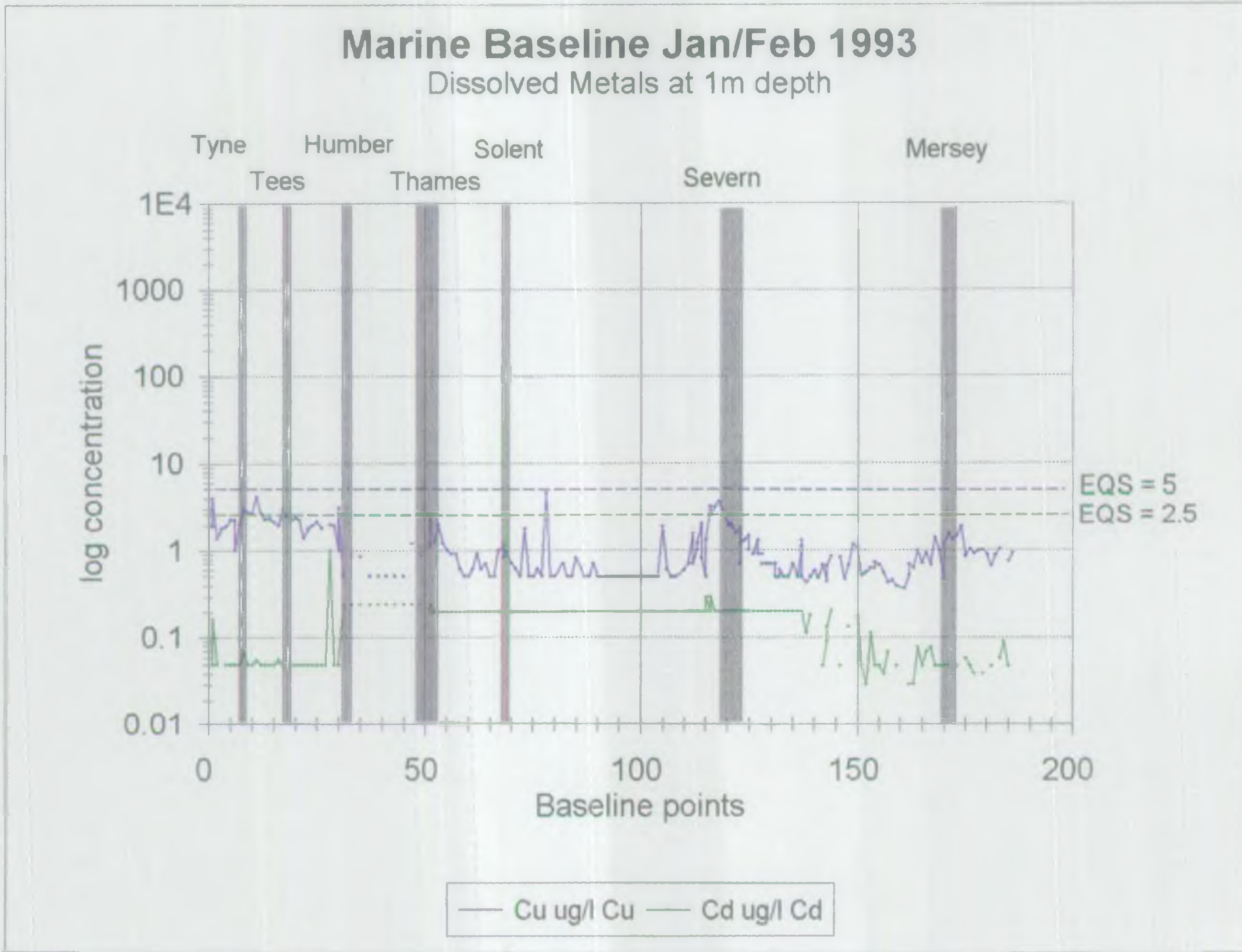


APPENDIX 10b

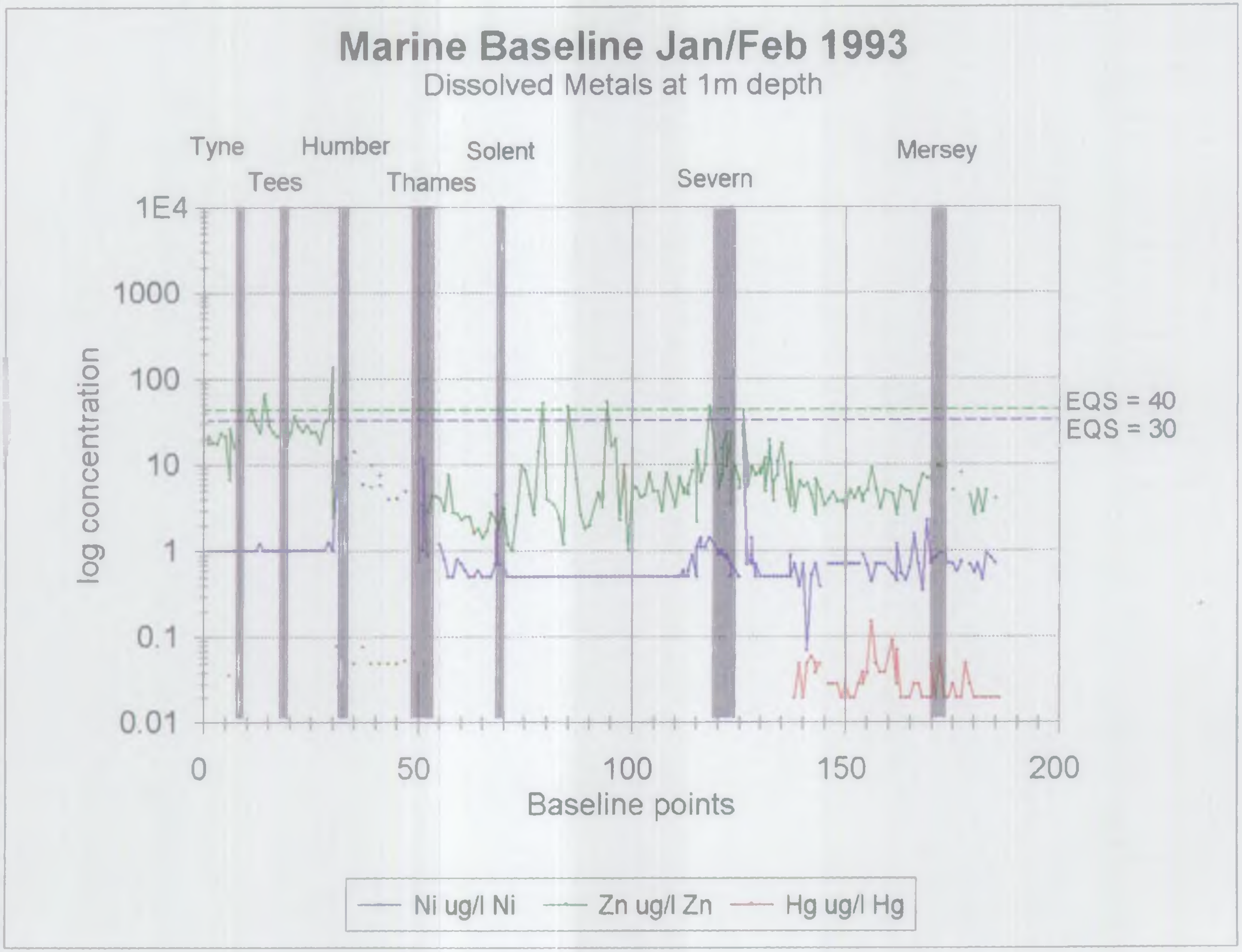


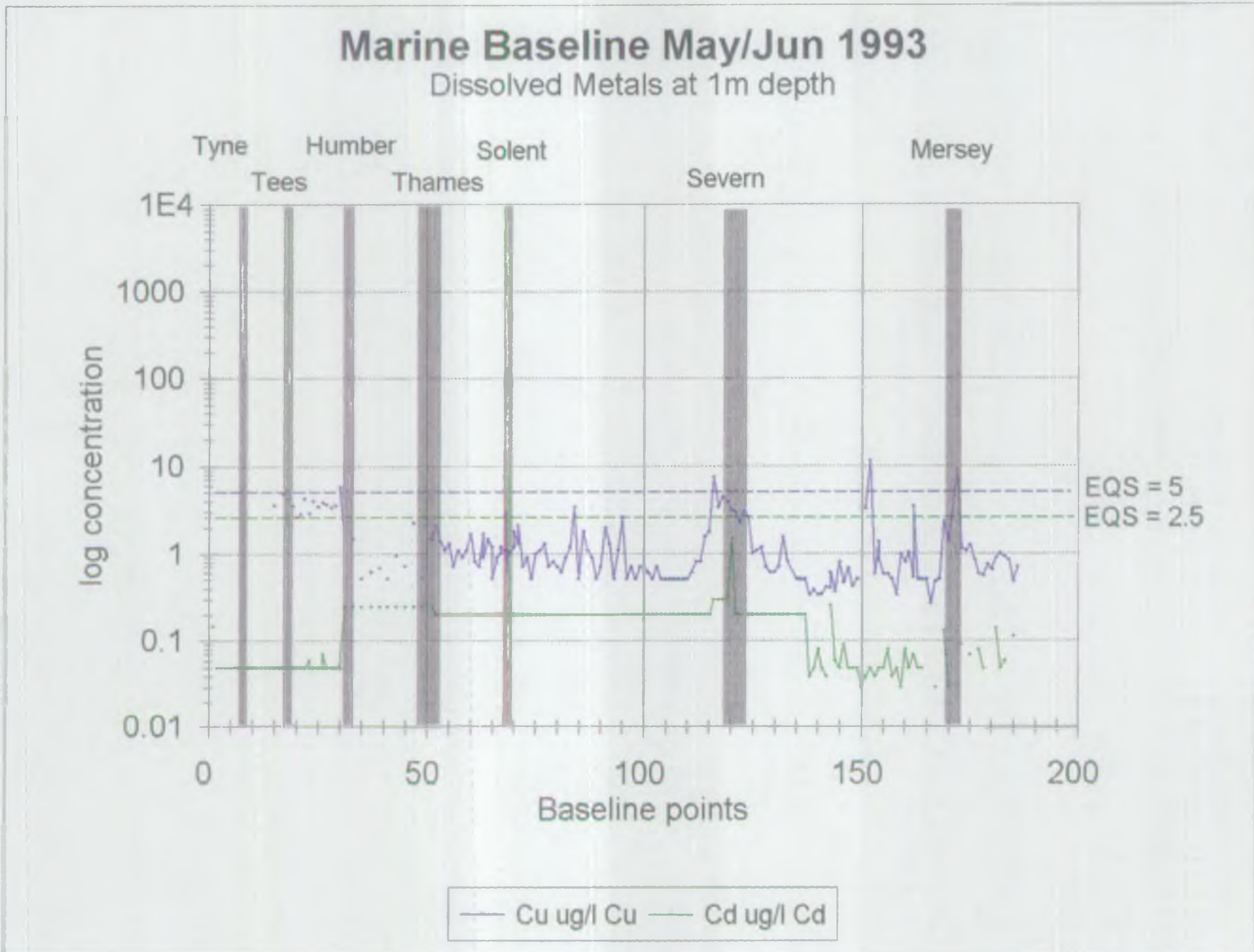
APPENDIX 11a


Marine Baseline May/Jun 1993
Suspended Solids at 1m depth
Tyne
Tees
Humber
Thames
Solent
Severn
Mersey
1000
100
10
1
0.1
log concentration (mg/l)
0
50
100
150
200
Baseline points
Suspended Solids

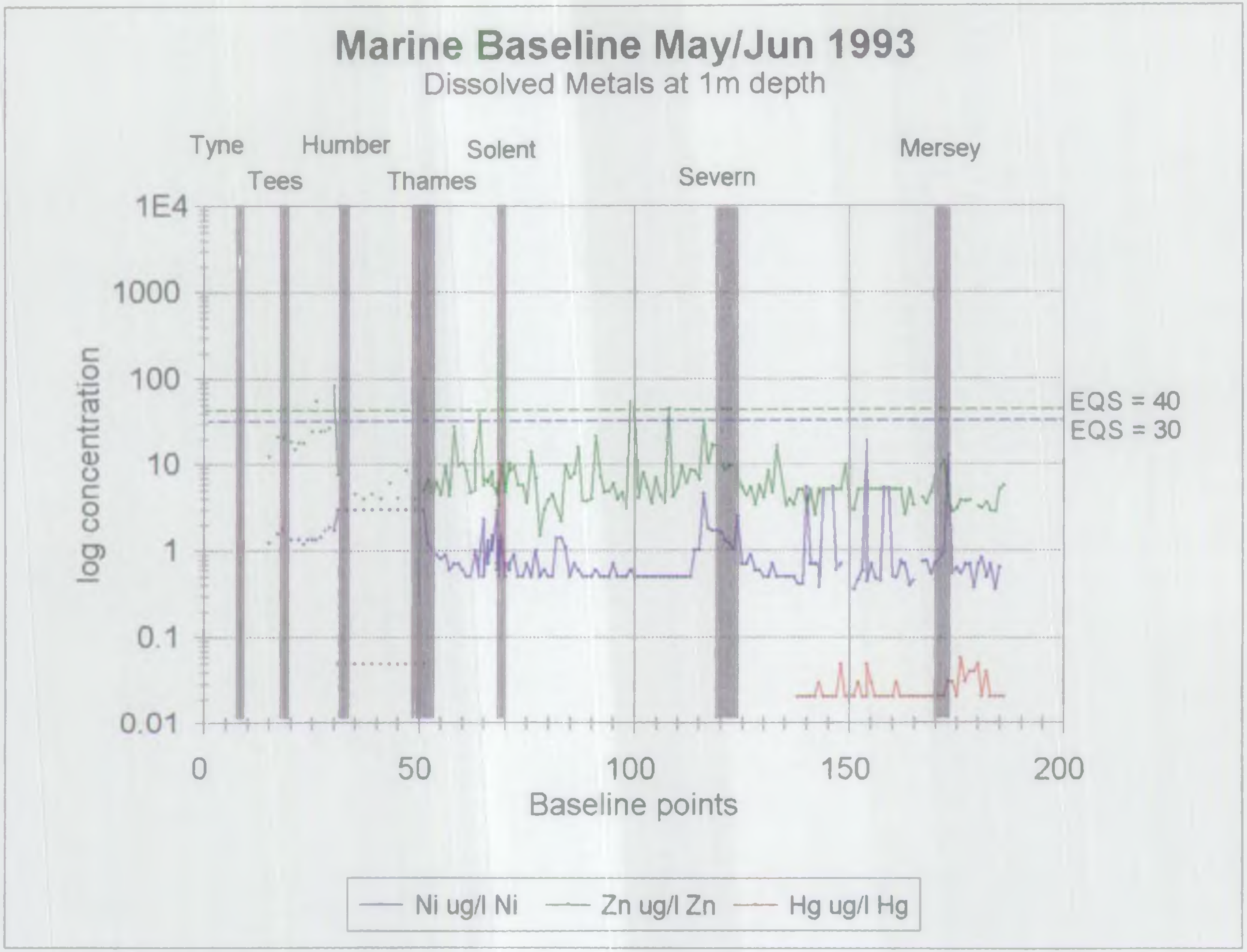


Appendix 12A


Marine Baseline Jan/Feb 1993
Dissolved Metals at 1m depth
Tyne
Tees
Humber
Thames
Solent
Severn
Mersey
1E4
1000
100
10
1
0.1
0.01
log concentration
EQS = 40
EQS = 30
0
50
100
150
200
Baseline points
Ni ug/l Ni
Zn ug/l Zn
Hg ug/l Hg



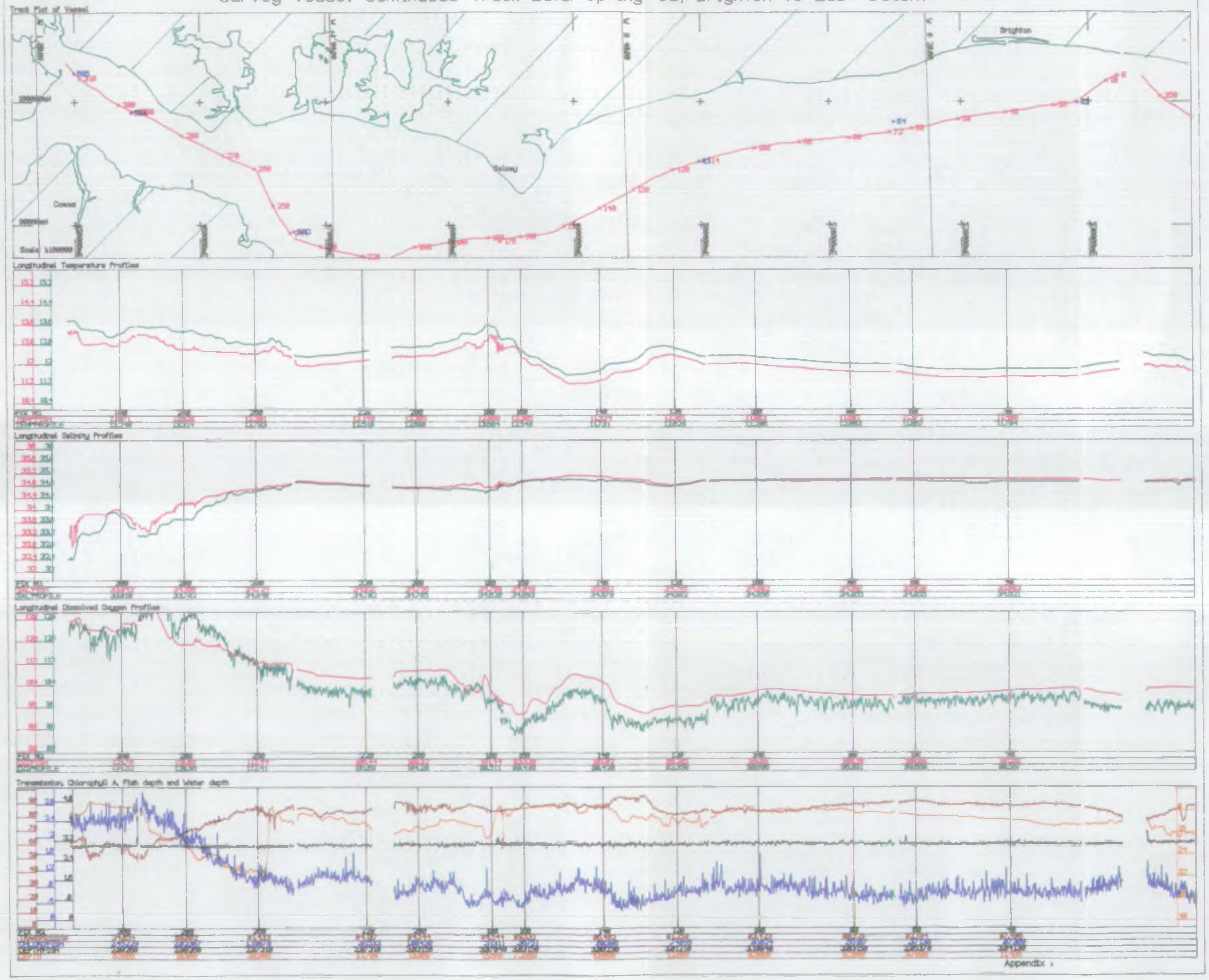
Appendix 12B



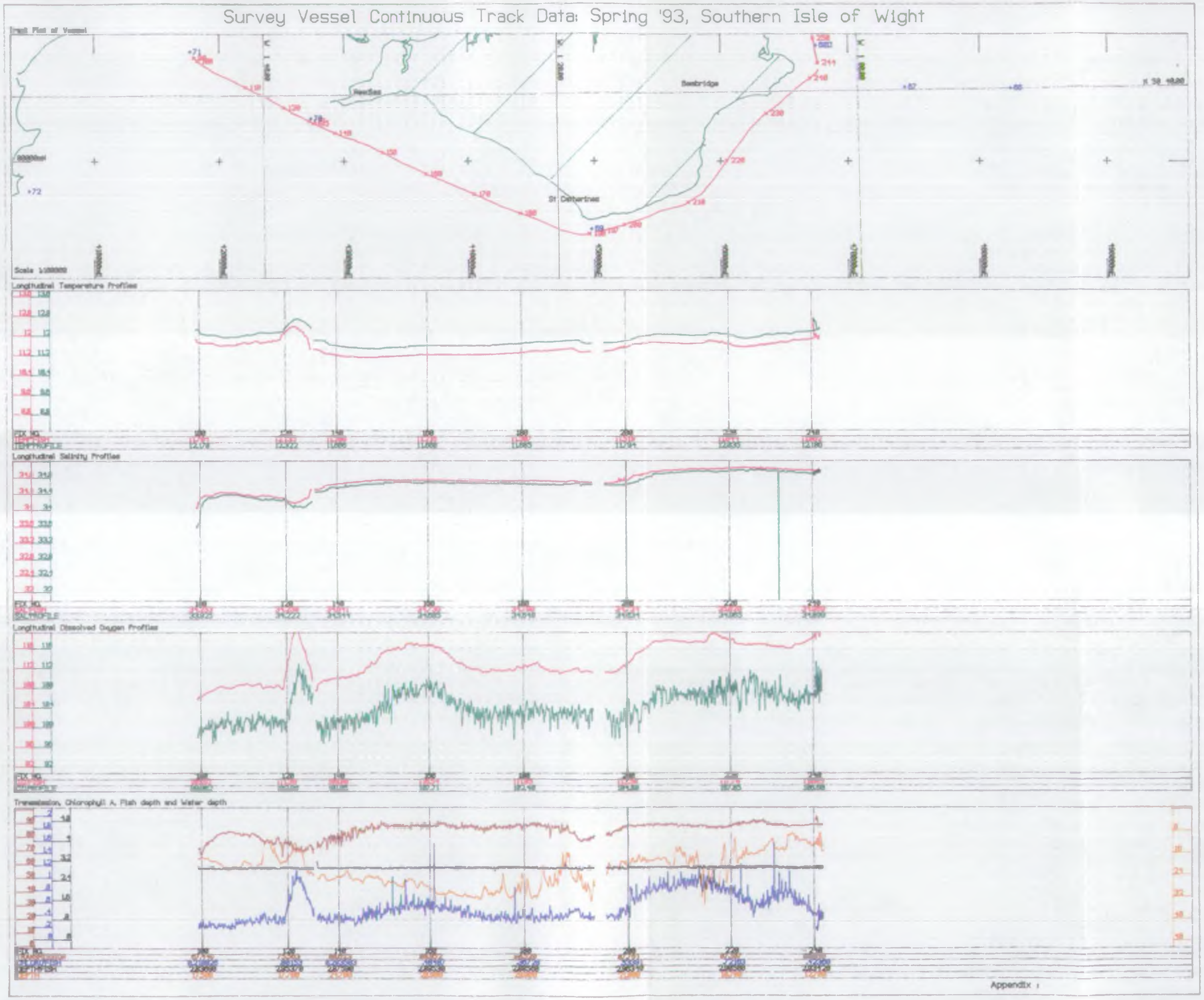
Appendix 12B

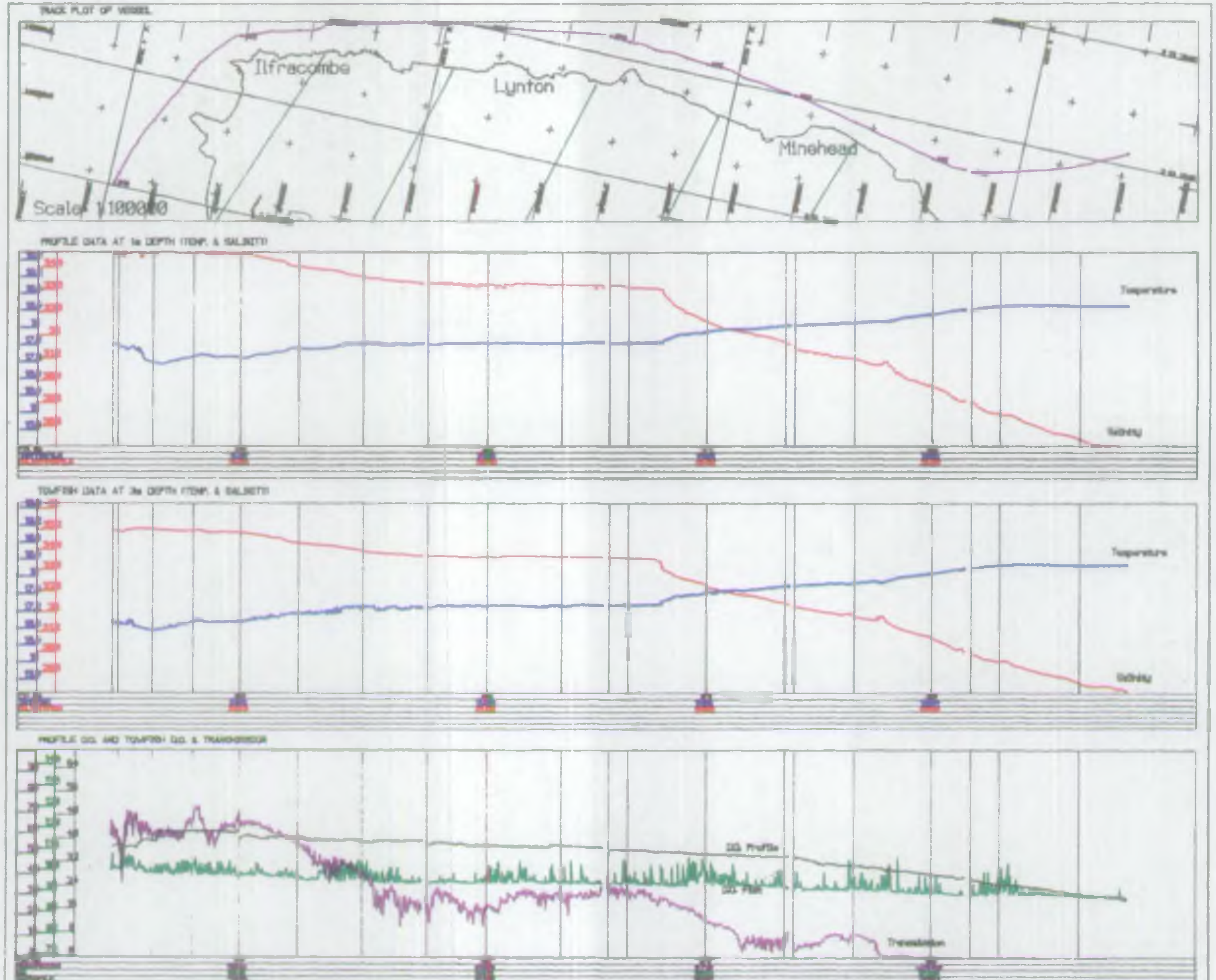
APPENDIX 13a

Survey Vessel Continuous Track Data: Spring '93, Brighton to East Solent

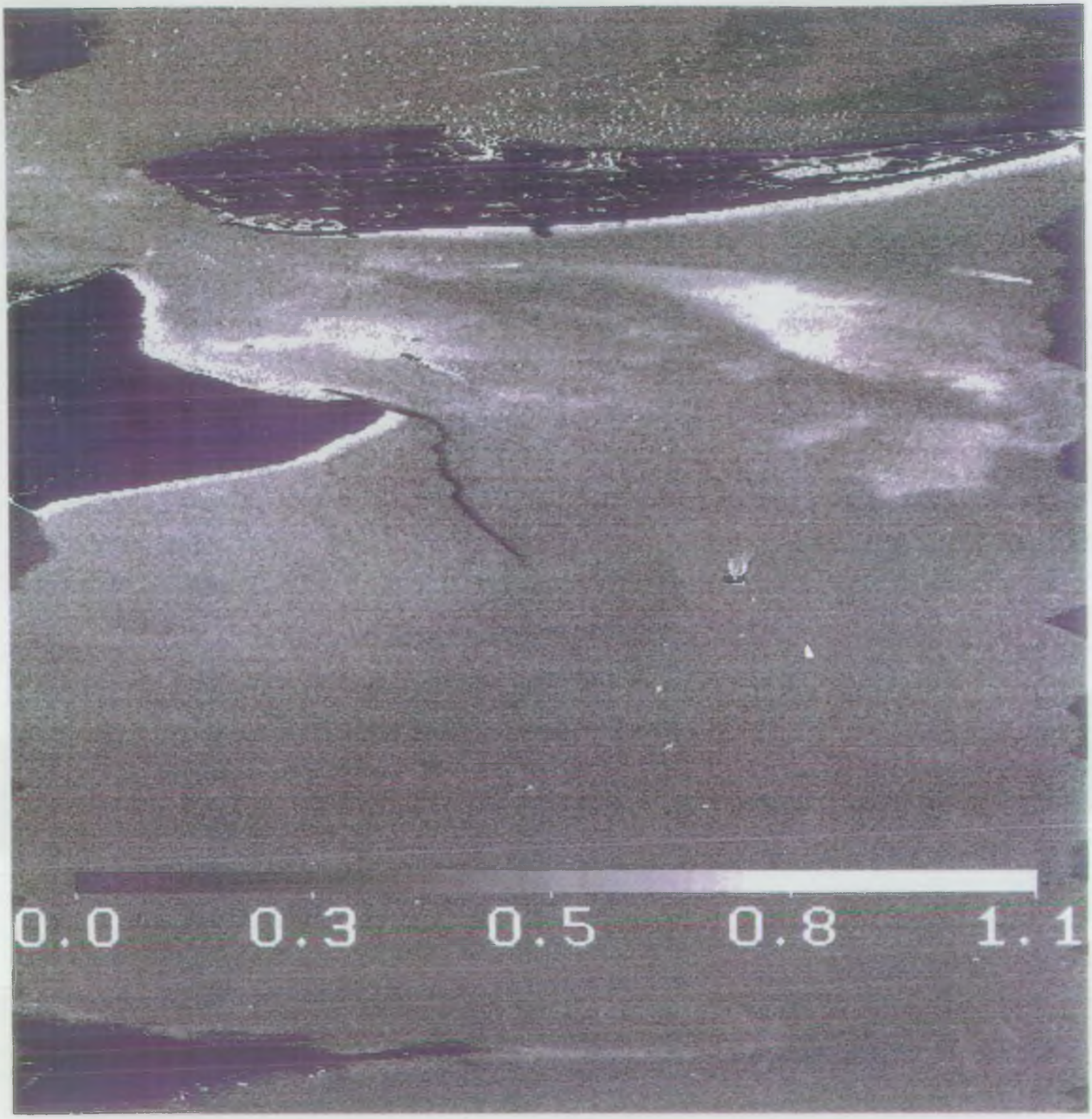


APPENDIX 13b

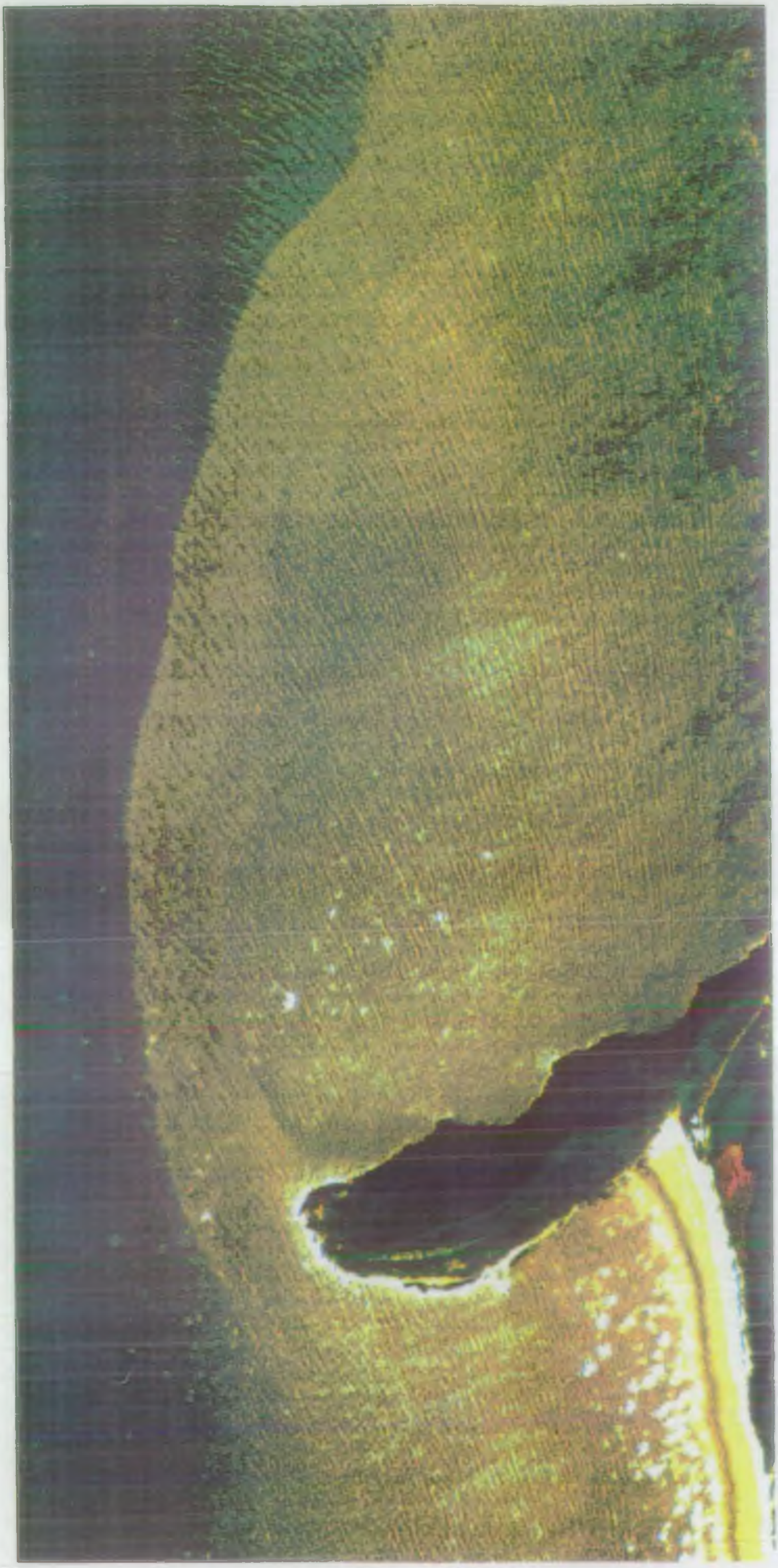




Summer '92 Baseline : Longitudinal Profile

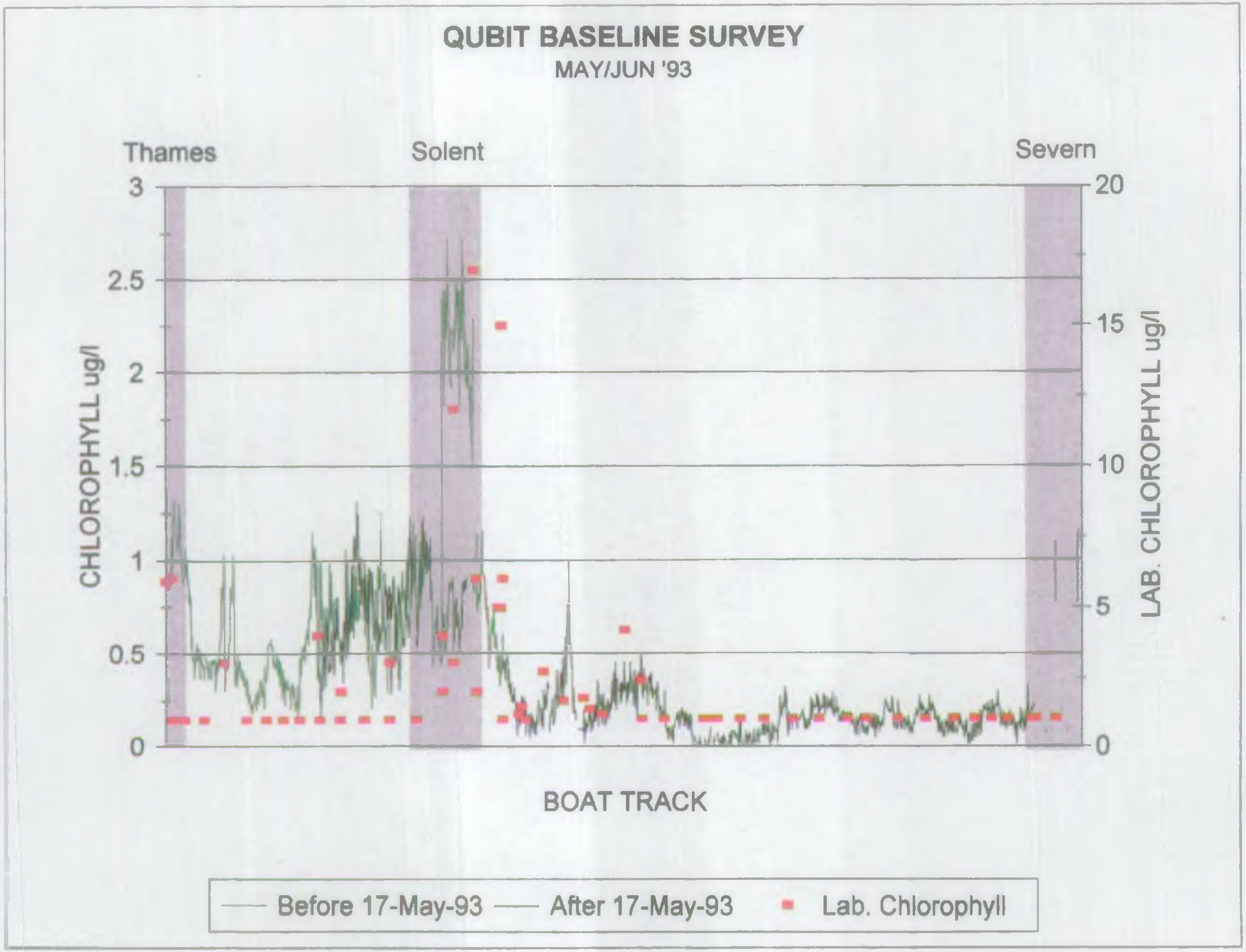


Appendix 14a: Variation in chlorophyll spatially around the entrance of Poole Harbour, Dorset (27/08/93).



Appendix 14b: True Colour Composite around Brean Down, Weston-Super-Mare (15/05/93).

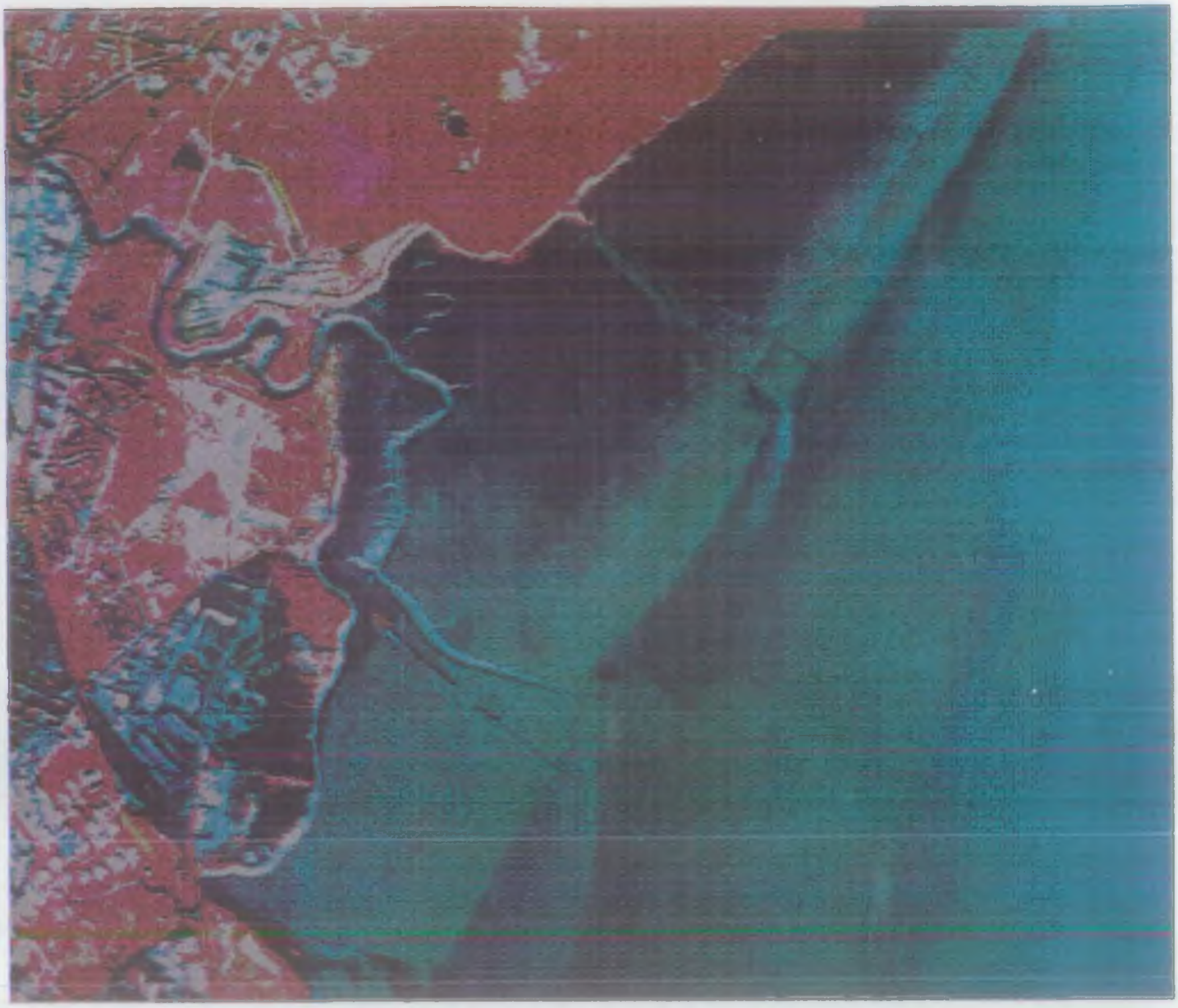
Appendix 14c: Variation in chlorophyll spatially around Brean Down, Weston-Super-Mare (15/05/93). Boat track data (black line) has been used to standardise it.


QUBIT BASELINE SURVEY
MAY/JUN '93
Thames
Solent
Severn
CHLOROPHYLL ug/l
LAB. CHLOROPHYLL ug/l
3
2.5
2
1.5
1
0.5
0
20
15
10
5
0
BOAT TRACK
Before 17-May-93
After 17-May-93
Lab. Chlorophyll

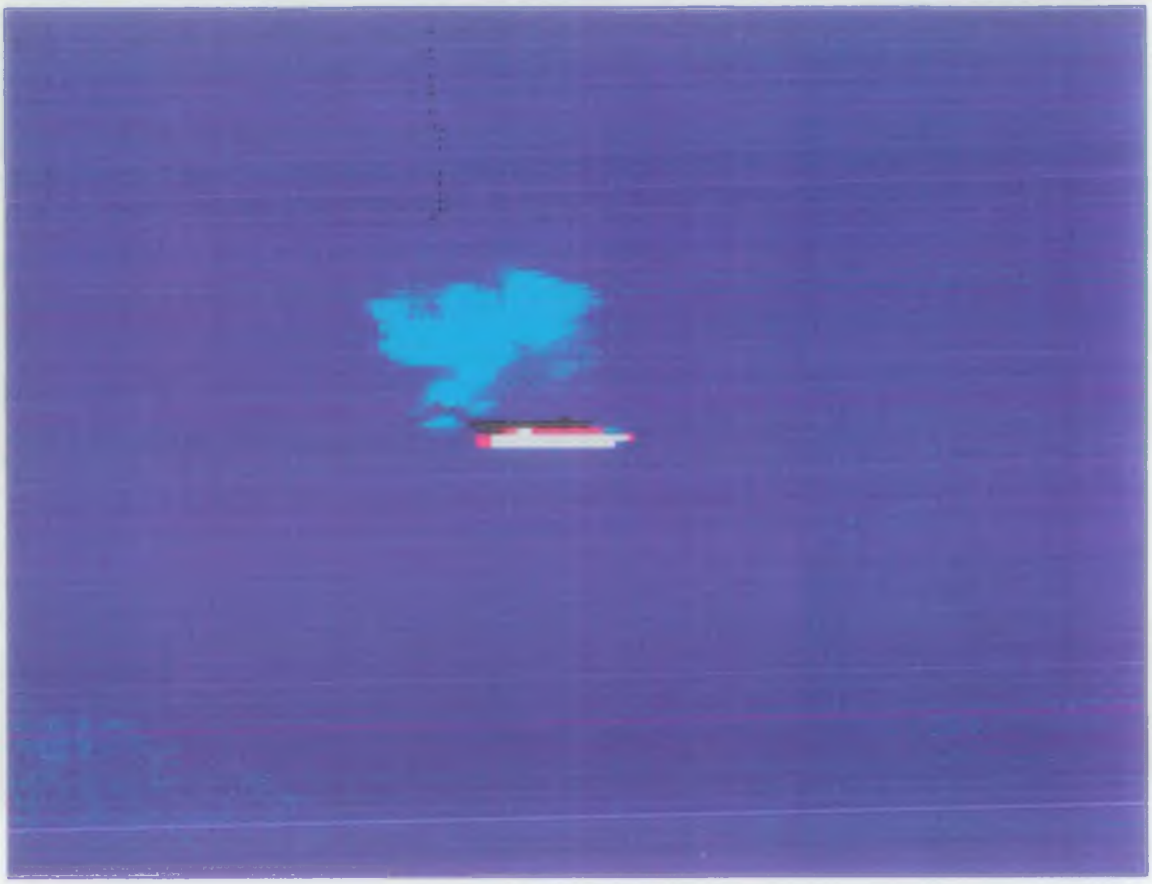
APPENDIX 15

APPENDIX 16

. A near-true-colour image from CASI bands 7 (red), 4 (green), and 2 (blue), showing an outfall near Port Talbot, southern Wales. This is CZMP swath 127/68 and was acquired in February 1993. Linear contrast enhancement shows an extremely dark outfall and its proximity to a beach. Docks are visible in the lower left.



A false-colour enhanced image from CASI bands 12 (infrared), 7 (red) , and 4 (green) highlighting intertidal vegetation and outfalls in Cardiff Bay, Wales. This is CZMP swath 122/63 and was acquired in February 1993. Plumes at the seaward end of cross-beach drainage channels are visible, and disperse outwards as they drift toward the top of the image.



An enhanced near-true-colour image from CASI bands 7 (red) , 4 (green), and 2 (blue), showing discharge from a ship near Worms Head, on the north side of Bristol Channel. This plume was invisible in the infrared, indicating that it was submerged and would not be detected using radar. Detection of this plume from conventional colour video would also be unlikely. This is CZMP swath 130/71 and was acquired in February 1993. Linear contrast enhancement, histogram enhancement, and density slicing were used to accentuate the discharge.