NRA - Water Quality 52

PROJECT RECORD FOR THE REVIEW AND STATISTICAL ANALYSIS OF THE BASELINE COASTAL WATERS SURVEY

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EXECUTIVE SUMMARY

Introduction

The NRA has undertaken national baseline coastal surveillance surveys in 1993 and 1994 with the objective of measuring background levels of contaminants to provide a baseline of water quality in the coastal zone. These surveys have taken the form of simultaneous boat and airborne surveys in Spring, Summer and Autumn, and a boat survey in Winter (when weather conditions render aerial surveillance difficult), around the coast of England and Wales. During these surveys the following data were obtained:

- *Spot measurements*: samples were collected at 186 sites, at 15km intervals, and analysed at the NRA laboratories for nutrients, chlorophyll-*a*, suspended solids, metals and organics.

- *Profile measurements*: profile data (dissolved oxygen concentrations, temperature and salinity) were recorded at set depths at the baseline sites.

- *Continuous sampling*: dissolved oxygen, conductivity, pH, temperature, depth, salinity, transmission and chlorophyll-a were measured at 10 second intervals using a 'tow-fish'. Nutrient data (phosphorus, ammonia, nitrite, silicate and TON) were collected at 2 minute intervals using an on-board Skalar autoanalyser.

- *Remote sensing*: image data from the CASI (Compact Airborne Spectral Imager) instrument which has the potential to provide quantitative information on chlorophyll-a and SPM (suspended particulate matter) concentrations as well providing information on the location and extent of other phenomena affecting water colour.

- *Remote sensing*: thermal data from an infra red (thermal) imager which was used to provide information on the location and extent of thermal anomalies.

The objectives of this phase of the study are to review the existing baseline coastal water surveillance surveys, carry out a statistical analysis of the data described above so as to determine what has been achieved and recommend the future format of the surveys taking into consideration all the NRA water quality monitoring requirements in marine waters.

To fulfil these objectives, the work has been divided into three phases:

i) *Identification of the NRA's needs*: an information gathering phase aimed at establishing the various Statutory, Surveillance and Regional Operational monitoring requirements of the NRA (and the new Environment Agency).

ii) *Data appraisal and analysis*: review of the data collected to date during the baseline coastal water surveys, namely the spot samples, continuous ship-based measurements and airborne CASI and thermal data.

iii) *Survey review*: the third phase is to compare the requirements of the NRA (ie the results of phase i) with the information that can be extracted from the survey data (ie the results of phase ii) in order to identify any shortfalls or exceedencies in the format of the present surveys and make recommendations as to how the surveys can be beneficially modified.

The key findings of the study are summarised below.

Key findings

The combined use of remote sensing (CASI, thermal imager) and conventional *in-situ* data gathering techniques constitute the optimum practicable approach to operational data collection in support of the NRA's business needs. The ship-based measurements provide detailed information concerning determinand concentrations in specific locations whereas airborne instruments provide synoptic measurements from which the extent and location of spatial features, eg HNDAs, chlorophyll-rich patches, mixing zones, thermal anomalies, discharge footprints and sediment transport, can be identified. The complementary capabilities of the two techniques can be exploited so as to ensure maximum use of NRA resources and funds. For example, the airborne data can be used to identify the most appropriate location (eg inside a plume) for *in-situ* sampling. Furthermore, the *in-situ* chlorophyll measurements can be used to calibrate the airborne measurements, thus enabling conversion of the qualitative CASI information into quantitative chlorophyll concentrations, which in turn can be used to grade coastal waters into chlorophyll concentration bands. Such a grading scheme has obvious application in classifying waters according to their susceptibility to eutrophication. Use of airborne sensors constitutes the most practical and cost-effective method for the wide area data collection required in generating such a grading scheme.

The baseline coastal waters surveillance survey constitutes an effective means of meeting many of the business needs of the NRA in the areas of statutory and surveillance monitoring, regional operational activities, flood defence and conservation, as discussed in section 2. Given a number of modifications to its sampling site coverage, the baseline survey would provide a rationalised approach to data collection in support of EC legislation. In particular:

- the baseline survey and the UK National Monitoring Plan should be combined in the case of estuarine sampling, such that those determinands common to both activities are measured during the baseline surveys;
- some of the measurements required by the Quality of Shellfish Directive may be undertaken at the same time as the baseline surveys, depending on site accessibility;
- measurements of chlorophyll and nutrient concentration made during the baseline surveys can be used in support of the Urban Waste Water Directive.

In addition to providing a means for *monitoring* the quality of coastal waters, the baseline surveys yield a dataset of great importance in environmental *surveillance*, an activity which will be given increased emphasis in EnvAge. This dataset is of interest not only to the NRA but also to commercial organisations and the R&D community. Regular aerial and ship-based surveys provide a mechanism for establishing seasonal and yearly trends and variations, as well as longer term effects resulting from climate change. Furthermore, the expertise that has been accrued by the NRA in analysis of the airborne data, will prepare the way for operational use of data from a new generation of satellite based coastal zone imaging instruments (eg SeaWiFs, MERIS, OCTS), which are similar in concept to the CASI instrument and are well suited to environmental surveillance.

In reviewing the data collected during the past eight baseline surveys, it has become apparent that there are very many missing data, which necessarily reduce the scientific value of the dataset. This lack of data has arisen because of problems in performing the measurements and in the storage and transit of the samples, although principally because of variations in the limits of detection of the laboratories performing the analyses. A number of recommendations have been made and are summarised below as to how these problems could be reduced or overcome. In particular, it is considered extremely important that all laboratories should operate to the same level of detection, which should be the lowest possible level achievable. This will ensure that many data previously lost will be recorded. Finally, attention is drawn to the clear distinction between the terms *detection* limit and *reporting* limit. The detection limit is governed by the capability of the analysis procedures and the associated instrumentation; the reporting limit is a level chosen such that any values above this limit are noted and reported. Review of the data suggests that some confusion has arisen over these two terms.

Survey strategy

Chlorophyll: it is recommended that the current strategy of measuring chlorophyll concentrations during surveys in Spring, Summer, Autumn and Winter continue. The optimum spatial sampling frequency for chlorophyll-*a* is dependent on season and shows no similarity between 1993 and 1994. It is therefore difficult to recommend an improved spatial sampling interval and the continued sampling at 15km intervals is recommended.

Results of the data analysis have indicated that hot spot concentrations of 30μg/l have been recorded. The occurrence of such high values, which may well not represent the peak concentration, suggest that in such hot spots (eg North coast of Wales) fixed moorings with *in-situ* sensors for measuring chlorophyll should be used.

SPM: the sampling frequency for SPM should remain at 15km at present. However, it is recommended that SPM calibration runs are performed during which measurements are required more frequently. These may be used for the calibration of the CASI imagery using ratio algorithms to estimate surface suspended sediment concentration.

Metals: the baseline values for metal concentrations have been established in coastal areas away form estuaries and hot spots. It is recommended that:

- ❑ Seasonal surveying continues to be performed with increased spatial frequency in hot spots and appropriate estuaries. It is suggested that a sampling strategy be considered for estuarine locations based on that used in the National Marine Plan, in which sampling locations are representative of the 0-10ppt, 10-20 and 20-30ppt salinity ranges.

- ❑ Sampling in other coastal areas is reduced such that surveys are conducted once per 5 years with the spatial sampling being reduced to every other or third baseline site.

- ❑ Once it has been established that there is a downward trend in metal concentration in a particular hot spot or estuary, the reduced sampling procedure summarised above can be implemented.

Nutrients: the natural seasonal variability of nutrients means that to follow effectively the impact of man made inputs of nutrients (rivers, discharge from sewage plants etc) seasonal monitoring is mandatory, as is currently undertaken by the NRA coastal vessels. It is recommended that:

- ❑ the possibility of measuring the nitrate:phosphate:silicate ratio be considered as it is important in determining the composition of bloom forming algae;

- ❑ other nutrients such as urea and dissolved organic nitrogen should also be measured once operational measurement systems are available.

Organic contaminants: it has been difficult to draw any conclusions concerning the optimum sampling strategy for organics because of the limited number of measurements that are above the limit of detection. In order to make meaningful measurements, the detection limits need reducing. If possible the limits of detection should be improved and then the current practice of making measurements in Spring, Summer, Autumn and Winter (boat only) should be continued for at least a year, or until it is possible to establish a baseline for the organic contaminants. If no seasonal variability is seen to exist and after appropriate baseline values have been determined, the monitoring could then be reduced to once per year and in due course follow the pattern recommended for metals. If any hot spots are detected then it is recommended that these should continue to be monitored on a seasonal basis.

The measurement of organics should be reviewed annually as more information becomes available on the acceptable levels of these compounds. It is recommended that the Marine Pollution Monitoring Management Group be consulted over this matter.

General recommendations

Rec 1 Staff briefings/manual

Rec 1.1 It is recommended that the NRA laboratory scientists are provided with an overview of how the samples are taken and how the results of their work are used.

Rec 1.2 It is also recommended that the NRA vessel scientists are collectively briefed on the various methods they should be using for data collection, instrument calibration etc, with the objective of ensuring standardisation of measurements and procedures between the various boats.

Rec 1.3 A comprehensive manual should be produced which details sampling and laboratory procedures (and associated Quality Control) to be applied to all aspects of data collection, analysis and reporting.

Rec 2 Limits of detection

Rec 2.1 It is recommended that all data above the limit of detection be recorded.

Rec 2.2 All laboratories should operate to the same lowest achievable limit of detection.

Rec 3 Sample storage

Rec 3.1 Concern exists over the storage and transport of some samples and it is recommended that these procedures be reviewed and clarified.

Rec 4 Ancillary data requirements

Rec 4.1 It is recommended that ancillary data be recorded at the time of the baseline surveys, including meteorological data (also required during the month prior to the survey) and tidal data.

Rec 5 General sampling procedures

Rec 5.1 Triplication of spot samples should be undertaken so as to improve confidence in the data.

Rec 5.2 The measurement of total metals should be abandoned and replaced by triplication of dissolved samples.

Rec 5.3 Steps should be taken so as to ensure that no metallic or potentially contaminating components are in contact with, or near the water sample used for metal analyses.

Rec 5.4 The water sample size taken for use in suspended sediment analysis should be selected according to the transmissometer reading. It is suggested that the following working estimate be used as an interim measure and modified in the light of further campaigns:

- for areas greater than ~80% transmission, a 5 litre sample should be used;
- for areas with greater than ~ 90% transmission, a 10 litre sample should be used;
- otherwise a 1 litre sample should be used.

Rec 5.5 Filtration of the SPM sample should take place on the boat and the sample should be well shaken. Prewashed, oven dried, preweighed filter papers should be used and place in labelled Petri dishes. Samples should be fixed with magnesium carbonate.

Rec 5.6 Should there be a future requirement for nutrients to be sampled at both surface and deeper water, the use of a lever action, or equivalent messenger activated Niskin bottle, is recommended. This bottle is also suitable for sampling a range of determinands , including metals, nutrients and some organics.

Rec 5.7 The profiler probes should be monitored continuously rather than at set depths and the data subsequently screened to remove any unwanted data.

Rec 5.8 The possibility of using towed undulating systems to give underway profiling should be considered.

Rec 5.9 It is recommended that total, organic and inorganic values of SPM be recorded.

Rec 6 Instrumentation

Rec 6.1 The Towfish fluorometer should be calibrated during the surveys rather than relying solely on the makers' calibration. It is recommended that this calibration be performed at the beginning and end of each daily survey. At each time, the Towfish should be brought in when coming on to the sampling station so as to allow a near surface measurement to be made whilst simultaneously taking a water sample for chlorophyll analysis at the laboratory. If an improvement in the correlation between the fluorometer and laboratory measured chlorophyll-*a* is achieved, a decrease in the use of water samples would be appropriate.

Rec 6.2 If it is not already the case, it is recommended that the Skalar autoanalyser be automatically calibrated so as to ensure any drifts in the response of the instrument are identified.

Rec 6.3 The CASI instrument provides high quality ocean and land colour data. It is recommended that the CASI bandsets are reviewed to ensure that the optimum bands are being used for monitoring chlorophyll, SPM and vegetation.

Rec 6.4 The thermal video system currently in use has demonstrated the benefits to the NRA of flying a thermal sensor. However, to enable further scientific use of the thermal data requires that the system measures absolute temperature. Firstly using the present system, a procedure could be adopted which requires the alteration in offset and gain to be recorded. This could then be used in conjunction with coincident ship truth data to calibrate the image. Alternatively, the thermal video currently used could be replaced with a calibrated thermal scanning system. To improve data handling, it is recommended that the thermal video data be spatially integrated with the CASI data and displayed simultaneously with the corresponding CASI image.

Rec 7 Calibration runs

Rec 7.1 It is recommended that measures are taken to improve the calibration of CASI imagery using the Fluorescence Line Height technique. In particular, calibration runs should take place perpendicular to the coastline as this will ensure a larger range of chlorophyll concentration is encountered and will guarantee the presence of land in the imagery.

Rec 7.2 Ideally, the NRA vessels should be organised so as to ensure some overlap in coverage (and thus sampling) occurs between 'neighbouring' vessels during each of the baseline surveys. However, it is recognised that in practice this may be difficult to achieve. To overcome this, it is recommended that a boat inter-calibration exercise be performed each year so as to maximise the quality assurance of the measurements made by the two vessels.

Rec 8 Data storage systems

Rec 8.1 All nutrient data, previously stored separately, should be stored in Qubit files. The data collected should be automatically referenced to Easting/Northing and time whilst on the boat.

Way ahead

In addition to these modifications to the survey format, it is proposed that the following suggestions be considered:

- ❑ it would be desirable for the airborne system's hire period to be extended at the time of each of the baseline surveys in order to allow flights to be made in response to regional requests;
- ❑ there is a need to assess the extent to which the CASI/thermal system can identify effluent plumes using the existing archive of data;
- ❑ on occasions the crews of the NRA vessels are having to work extremely long hours in order to complete their data collection activities, which has obvious implications for data quality. It is recommended that the number of scientific crew be increased (eg 4 per vessel), as this would allow a reduction in the working hours of the individual crew members, whilst still performing the same workload;
- ❑ in order to increase the usefulness of the basline survey data to the Regions, it is recommended that the National Centre for Instrumention and Marine Surveillance consider providing a standard set of regional value-added products (eg regional maps showing chlorophyll concentrations, surface SPM concentrations, discharge footprint etc) on a routine basis (eg after every survey);
- ❑ in order to obtain maximum usage of and benefit from the data collected during the baseline surveys, the employment of a dedicated image analyst/oceanographer should be considered;
- ❑ a large amount of data has been collected during the past baseline surveys. Consideration should be given to the data storage, manipulation and distribution mechanisms so as to ensure that a data processing capability exists able to cope with the ever increasing data volumes and associated demand.

Conclusions

During this study it has become apparent that the NRA has developed a considerable expertise in performing baseline coastal waters surveillance surveys, which places them among the leaders in Europe in conducting such operational monitoring campaigns.

The basline surveys performed to date have allowed the NRA to modify and develop its procedures for data collection and analysis such that the current system constitutes a well-rounded approach to operational monitoring and demonstrates the feasibility of conducting such surveys. Review of the baseline survey dataset has enabled the survey procedures now in place to be critically assessed. The conclusion of this review is that the expertise developed in performing the basline coastal waters surveys to date should be built on so as to provide a smooth running and efficient coastal monitoring service for EnvAge.

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1 INTRODUCTION

1.1 General

This report has been prepared by Smith System Engineering Limited and University of Southampton under the contract entitled "Review and statistical analysis of the baseline coastal waters survey" for the NRA. It constitutes the Project Record for the contract.

1.2 Context

The NRA has undertaken national baseline coastal surveillance surveys in 1993 and 1994 with the objective of collecting background levels of contaminants to provide a baseline of water quality in the coastal zone. These surveys have taken the form of simultaneous boat and airborne surveys in Spring, Summer and Autumn, and a boat survey in Winter (when weather conditions render aerial surveillance difficult), around the coast of England and Wales. The four NRA coastal survey vessels (Water Guardian, Sea Vigil, Vigilance and Coastal Guardian) were used to perform the boat work and a chartered light aircraft was used for the aerial surveillance work.

The boat-based surveying has included:

- Spot data:
  - samples were collected at 186 sites, at 15km intervals, and analysed at the NRA laboratories for nutrients, chlorophyll-*a*, suspended solids, metals and organics. The data are collected at a nominal depth of 0.5m. Appendix A lists the determinands measured. Appendix B shows the locations of the baseline sites, the coastal areas covered by the individual NRA vessels and identifies at which laboratory the samples are analysed;
  - in addition to the spot sample data, profile data (dissolved oxygen concentrations, temperature and salinity) were recorded at set depths at the baseline sites.
- Continuous data: underway sampling was performed, such that:
  - dissolved oxygen, conductivity, pH, temperature, depth, salinity, transmission and chlorophyll-a were measured at 10 second intervals using a 'tow-fish';
  - nutrient data (phosphorus, ammonia, nitrite, silicate and TON) were collected at 2 minute intervals using an on-board Skalar autoanalyser.

The airborne surveys have provided continuously acquired data in the form of:

- image data from the CASI (Compact Airborne Spectral Imager) instrument which has the potential to provide quantitative information on chlorophyll-a and SPM (suspended particulate matter) concentrations as well providing information on the location and extent of other phenomena affecting water colour;

- thermal data from an infra red (thermal) imager which was used to provide information on the location and extent of thermal anomalies.

It is the data collected during these surveys as well as the overall conduct of the surveys that forms the subject matter of this study.

1.3 Study objectives

The overall objective of the study is to:

- review and describe the existing data collected in the 1993 and 1994 baseline coastal waters surveillance surveys;

- carry out a statistical analysis of the survey data with a view to establishing the statistical validity and quality assurance of the measurements, the optimum sampling strategy within a survey and the most appropriate timings for conduct of the surveys;

- consider the monitoring requirements associated with the business needs of the NRA and based on these requirements develop options for the design of future coastal surveys.

To fulfil these objectives, the work has been divided into three phases:

i) Identification of the NRA's needs: an information gathering phase aimed at establishing the various Statutory, Surveillance and Regional Operational monitoring requirements of the NRA (and the new Environment Agency).

ii) Data appraisal and analysis: review of the data collected to date during the baseline coastal water surveys, namely the spot samples, continuous ship-based measurements and airborne CASI and thermal data.

iii) Survey review: the third phase is to compare the requirements of the NRA (ie the results of phase i) with the information that can be extracted from the survey data (ie the results of phase ii) in order to identify any shortfalls or exceedencies in the format of the present surveys and make recommendations as to how the surveys can be beneficially modified.

The results of the study are presented in two documents, namely:

- a report in NRA's water quality series format which contains a summary of the data analysis, highlighting the principal findings and focusing on the most important results and conclusions;

- this project record, which comprises a complete record of the work undertaken, the results, conclusions and recommendations.

1.4 Contents

In section 2.1 to 2.4, the current and future business needs of the NRA in terms of monitoring coastal waters are detailed and the potential of ship-based and airborne measurements to help fulfil these business needs are identified. Sections 2.5 and 2.6 address the business needs of the NRA in the categories of flood defence and conservation and consider how these needs could benefit from the data and information collected during boat and airborne surveys. Section 2.7 considers the likely remit of the new Environment Agency. Section 2.8 summarises the findings of this section.

Section 3 presents an appraisal of the various data collected to date, including the spot sample measurements (section 3.2), the continuous ship-based measurements (section 3.3) and airborne CASI and thermal data (section 3.4). The findings of this appraisal are summarised in section 3.5.

Section 4 provides an overview of the analyses performed on the spot sample and continuous data, summarises the results of the statistical analyses and presents the key findings. Detailed analysis results are presented in Appendices C and D.

A review of the CASI and thermal imager data and of the associated calibration exercises is included in section 5. Detailed image statistics are presented in Appendix F.

Section 6 considers how well the present survey format meets the various needs of the NRA and discusses possible modifications to the existing surveys so as to ensure that the NRA's needs are met in the most cost-effective manner.

In section 7 the conclusions and way ahead are discussed.

2 SURVEY CAPABILITIES AND NRA'S BUSINESS NEEDS

2.1 Introduction

The NRA was established by the 1989 Water Act as a Non-Departmental Public Body. It has statutory responsibilities for water resources, pollution control, flood defence, fisheries, conservation, recreation and navigation in England and Wales. In 1996, the NRA is due to be subsumed into the Environment Agency (EnvAge), whose overall remit is likely to be somewhat different to that of the current NRA.

The Water Resources Act (1989 and revised in 1991) places a duty on the NRA 'to monitor the extent of pollution in controlled waters'. For the marine environment 'controlled waters' covers estuarine and coastal water to the 3 nautical mile limit. Marine monitoring undertaken in support of the Water Resources Act, as well as various EC Directives and other international agreements can be subdivided into three categories: Statutory, Surveillance and Regional Operational Requirements. The business needs of the NRA in each of the Statutory, Surveillance and Regional Operational Requirements categories are reviewed in sections 2.2, 2.3 and 2.4 respectively, and the potential of ship-based and airborne measurements to help fulfil these business needs is identified.

In addition to its duties with respect to water quality, the NRA is involved in a wide range of other environmental activities covering water resources, flood defence, fisheries, conservation, recreation and navigation across England and Wales. There is potential for data and information collected during boat and airborne surveys (similar to the baseline coastal waters surveys) to enhance the capability of the NRA in the areas of flood defence and conservation. Sections 2.5 and 2.6 review this potential in these two categories, respectively.

Section 2.7 considers the likely remit of EnvAge and considers how boat and aerial surveys can help the Agency to fulfil this remit.

In section 2.8 a summary of the findings is presented.

2.2 Statutory monitoring

Statutory monitoring covers the requirements of EC Directives and other national and international commitments. The activities of the NRA in support of various legislation and international agreements are discussed below as is the potential contribution of ship-based and airborne data.

The Bathing Water Quality Directive requires the NRA to monitor and sample identified bathing waters during the bathing season and at a point at which the daily average density of bathers is highest. Current policy is that to fulfil the bathing water quality directive, twenty samples must be taken and analysed during the bathing season at a depth of 30cm below the surface (except in the case of samples used for testing for mineral oils). Determinands measured are summarised in table 2.1 below.

Potential contribution of survey data: aerial surveys provide spatial information on the colour and temperature differences of the water and thus are useful in identifying the location, extent and movement of any phenomena which lead to a change in water colour or temperature. For example, effluent from an outfall may affect the baseline water colour; sediment transported in a moving body of water may affect the colour of body of water thereby providing a means of monitoring the movement of water mass; an effluent mixing zone may have a temperature different to the baseline water temperature.

Consequently, image data from the CASI and thermal data can be used to identify the locations, extent and movement of water masses (including effluent plumes) and thus has application in support of regional investigations into bathing water quality problems. Through the wide area spatial data they provide, aerial surveys could be used to help identify the source of the problem and also in identifying the most appropriate sampling locations (eg inside and outside the effluent mixing zone) for supporting data collection.

Table 2.1:Bathing Water Quality Directive requirements and the potential contribution of ship-based and aerial survey data

Bathing Water Quality Directive SI 1991/1597 Bathing Waters (Classification) Regulations 1991 (arising from 76/160/EEC on Bathing Water Quality)		
Mandatory determinands to be measured	**Sampling location**	**Sampling frequency**
Total Coliforms - Confirmed. Faecal Coliforms -Confirmed Salmonella., Enteroviruses, pH, Colour, Mineral Oils, Surface Active Substances reacting with Methylene Blue. Total Phenols (Phenol, 2 methyl phenol, 3 methyl phenol, 2 chloro phenol, 2,5 dichlorophenol, 2,4,6 trichlorophenol, 2,5 dimethyl phenol). Transparency. Faecal Streptococci	Identified bathing waters at a point at which the daily average density of bathers is highest	Minimum of fortnightly between 1 May and 30 September (20 samples to be taken throughout season)
Survey potential contributions		
Boat	**Aerial**	**Comments**
Data potentially of use in support of WQ failure investigations	Provide wide area spatial information in support of WQ failure investigations - mixing zones - effluent zones - coastal processes	In-situ sampling best undertaken by regions since samples are shore-based

In summary, given the specific requirements in terms of sampling frequency and location, the activities in support of the bathing water quality directive are best undertaken by the regions (given that the determinands and parameters currently measured during the ship-based surveys do not match those requiring measurement in support of this directive and that European legislation requires sample to be taken from the shore) and would not obviously form part of the national baseline survey. However, the data collected during the baseline surveys (including ship-based and aerial data) has obvious potential in supporting the various regional activities, as discussed above.

The Quality of Shellfish Waters Directive requires sampling of the water column above designated shellfish sites. Parameters measured and sampling details are summarised in table 2.2.

Table 2.2: Quality of Shellfish Waters Directive requirements and the potential contribution of ship-based and aerial survey data

Quality of Shellfish Waters Directive 79/923/EEC Quality Required for Shellfish Waters		
Mandatory determinands to be measured	**Sampling location**	**Sampling frequency**
a) Salinity, Dissolved Oxygen Saturation b) pH, Colouration (after filtration) Suspended Solids, Petroleum Hydrocarbons c) Organohalogenated Substances (DDT, Lindane, Parathion and Dieldrin), Silver, Arsenic, Cadmium, Chromium, Copper, Mercury, Nickel, Lead, Zinc d) Substances affecting the taste of shellfish	Designated shellfish waters	a) Monthly b) Quarterly c) Once every six months d) Where presence is presumed
Survey potential contributions		
Boat	**Aerial**	**Comments**
Some of the determinands listed above are measured during the ship-based coastal surveys	Provide wide area spatial information on potentially harmful phenomena, eg, movement of effluent	In-situ sampling best undertaken by the regions

Potential contribution of survey data: aerial survey data could provide information on the movement of water masses and sediment which is of potential use to the shellfish 'community'. For example, the location, extent and movement of a polluted body of water could be detected via the associated water colour and temperature changes and data collected during a number of consecutive surveys would permit any trends in the movement of this poor quality water in relation to the location of the shellfish site. The movement of sediment in relation to the shellfish location could also be monitored because of the associated colour changes of sediment loaded water. In particular the survey data could be used to alert NRA to changing conditions which may affect the quality of the shellfish waters.

In summary, given the specific requirements in terms of sampling frequency, location and parameters to be measured, the activities in support of this directive are best suited to performance by the competent authority and would not obviously form part of the national baseline survey. However, the aerial data collected during the baseline surveys has obvious application in supporting the various competent authorities' activities, as discussed above. Furthermore, given that some determinands requiring measurement in support of this Directive are also measured during the ship-based baseline surveys, such data may also be of use to the competent authorities.

The Dangerous Substances Directive requires the monitoring of all waters receiving identified discharges for certain dangerous substances. In addition, for certain substances (for which standstill applies) there is a requirement to monitor levels in sediments/molluscs/shellfish/fish. Substances to be measured and sampling details in support of this Directive are summarised in table 2.3.

Potential contribution of survey data: the Directive requires that the monitoring point should be sufficiently close to the discharge point to be representative of the aquatic environment in the area affected by the discharges. This in itself does not provide a definitive guide to the required sampling locations given that what is considered to be 'representative of the aquatic environment' is subjective. In practical terms, the monitoring requirement translates into a requirement for the location and extent of an effluent mixing zone to be known. Aerial surveys provide information on the thermal and colour properties of the water, and thus in most cases permit identification of the location and extent of effluent plumes and mixing zones. Consequently, the national coastal surveys have direct application in identifying the most appropriate sampling locations (eg inside and outside a plume) and/or areas requiring further in-situ investigation. Notwithstanding the fact that the airborne data is only valid for the given tidal conditions, the CASI and thermal instruments provide a valuable spatial perspective, not otherwise available.

Given the overlap in determinands measured in support of the Dangerous Substances Directive and those measured during the ship-based coastal waters surveys, there is potential for these ship-based measurements to fulfill this Directive for appropriately located discharges.

Monitoring in support of the standstill provision is undertaken in locations displaying stable sedimentation characteristics. Identification of such sediment monitoring sites is currently based on local knowledge of local deposition and re-suspension characteristics. Since suspended particulate matter (SPM) affects water colour, the CASI instrument can be used to provide information on surface SPM concentrations and movements of sediment. Thus CASI can be used to help identify standstill areas in a more objective manner than that based on local knowledge.

Table 2.3: Dangerous Substances Directive requirements and the potential contribution of ship-based and aerial survey data

Dangerous Substance Directive i) SI 1989/2286 Surface Waters (Dangerous Substances) (Classification) Regulations 1989 and Direction to the NRA of January 1990 ii) (Incorporating the requirements of Directives 76/464/EEC, 82/176/EEC, 84/156/EEC, 83/513/EEC, 84/491/EEC, 86/280/EEC, 88/347/EEC) iii) SI 1992/337 Surface Waters (Dangerous Substances) (Classification) Regulations 1992 incorporating the requirements of Directive 90/415/EEC iv) List II Substances; as set out in DoE Circular 7/89		
Mandatory determinands to be measured	**Sampling location**	**Sampling frequency**
At National Network sites all determinands from the list below should be monitored. At sites down-stream of known discharges only determinands specific to the discharges should be monitored. i) Aldrin, Dieldrin, Endrin, Isodrin., Cadmium and its Compounds, Carbon Tetrachloride, Chloroform, DDT (all isomers), para-para DDT, Hexachlorobenzene, Hexachlorobutadiene, Hexachlorocyclohexane (all isomers). Mercury and its Compounds, Pentachlorophenol and its Compounds	Waters downstream of discharges; sediment and/or shellfish and/or fish in affected areas; waters at National Network sites	Monthly for water samples; annually for sediments/shell-fish/fish; quarterly for National Network sites
ii) 1, 2 Dichloroethane, Trichloroethylene, Perchloroethylene, Trichlorobenzene	+as above	+as above
From the list below only determinands specific to the relevant discharge(s) should be monitored. Lead, Chromium, Zinc, Copper, Nickel, Arsenic, Iron, pH, Boron, Vanadium, Tributyltin, Triphenyltin, Mothproofing Agents (PCSDs, Cyfluthrin, Sulcofuron and Permethrin)	Waters downstream of discharges	Monthly
Survey potential contributions		
Boat	**Aerial**	**Comments**
Some overlap between baseline survey determinands and those listed above. The potential to measure these during surveys exists for some discharge locations.	Permit identification of location and extent of effluent plumes and mixing zones and thus the most appropriate sampling locations. Sediment related information potentially useful in identifying standstill areas	Potential for rationalising baseline surveys and some Dangerous Substances Directive sampling

The Titanium Dioxide Directives require that the quality of the waters receiving titanium dioxide waste be measured. Samples are required to be taken in the immediate vicinity of the discharge point and in a neighbouring zone deemed to be unaffected by the discharge. Parameters measured and sampling details are summarised in table 2.4.

Potential contribution of survey data: the sampling strategy requires that the effluent mixing zone be known so that samples can be taken inside and outside the zone. As was discussed in the case of the Dangerous Substances Directive, aerial surveys provide information on the thermal and colour properties of the water, and thus in most cases permit identification of the location and extent of effluent plumes and mixing zones. This being the case, it is worth noting that at present only three relevant factories exist and a key factor in assessing the overall contribution of aerial data is where the factory is located in relation to the coverage of the coastal zones surveys.

Table 2.4: Titanium Dioxide Directive requirements and the potential contribution of ship-based and aerial survey data

Titanium Dioxide Directive 78/176/EEC Waste from the Titanium Dioxide Industry 82/883/EEC Procedures for Surveillance and Monitoring of Environments Concerned by Waste from the Titanium Dioxide Industry		
Mandatory determinands to be measured	**Sampling location**	**Sampling frequency**
Water: Iron (total dissolved, hydrated oxides and hydroxides) Sediment: Titanium, Iron (total hydrated oxides and hydroxides) Living organisms: Titanium, Chromium, Iron, Nickel, Zinc, Lead Diversity and relative abundance of benthic fauna: presence of morbid anatomical lesions in fish	At the same location and depth and under the same conditions each time. One near the discharge and another in a neighbouring area deemed to be unaffected by the discharge	Once every 4 months for water samples; annually for sediments and biota
Survey potential contributions		
Boat	**Aerial**	**Comments**
-	Wide area spatial data permit identification of sampling points inside and outside the discharge plume	Only three relevant factories currently exist

The Urban Waste Water Treatment Directive concerns the consenting and monitoring of discharges from urban waste water treatment plants and the concomitant identification of Sensitive Areas (eutrophic) and High Natural Dispersion Areas (HNDAs). Parameters measured and sampling details are summarised in table 2.5.

Table 2.5: Urban Waste Water Directive requirements and the potential contribution of ship-based and aerial survey data

Urban Waste Water Treatment Directive 91/71/EEC Concerning Urban Waste Water Treatment		
Mandatory determinands to be measured	**Sampling location**	**Sampling frequency**
Winter nutrients: including TON, NH', NO². Data of use in assessment of eutrophication. Percentage cover of algal growth (for areas > 10 hectares), chlorophyll-a concentration, cell counts, summer nutrients.	Sampling to be undertaken at existing points, notably those for bathing waters and shellfish waters	In general weekly between May and September. Winter nutrients: three times between December and February. Algal growth: June-August
Survey potential contributions		
Boat	**Aerial**	**Comments**
Provide chlorophyll calibration data	Permit identification of location and extent of HNDA's and sensitive areas. Permit chlorophyll concentrations to be measured (and banded, if appropriate)	Very cost effective solution. The development of a database of sensitive areas (eg based on a chlorophyll banding approach) is desirable.

Potential contribution of survey data: the Urban Waste Water Directive requires that costly secondary treatment be applied to any discharges into sensitive areas, whereas primary treatment will suffice for discharges into HNDAs. The costs associated with applying secondary treatment to a discharge, assuming that primary treatment has already been applied, are <u>typically</u> £31k, £200k, £1.3M and £8.8M for populations of 100, 1000, 10,000 and 100,000 respectively[1]. A precautionary approach might be to apply secondary treatment to all discharges although this approach would have severe cost implications. Obviously a more cost effective approach would be to only apply secondary treatment to discharges into sensitive areas, but this requires that the location and extent of such sensitive areas be known. Areas susceptible to eutrophication can be both spatially and temporally variable and thus it is unrealistic to expect a survey vessel to locate all such areas. The CASI instrument offers a unique means of identifying the location and extent of eutrophic areas. Quantitative information on chlorophyll concentrations can also be obtained through calibration of the airborne imagery with *in-situ* ship-based measurements. Data collected during successive surveys would ideally be collated into a database of sensitive area locations (eg based on a chlorophyll concentration banding system), from which information concerning, for example, the temporal fluctuations of sensitive areas could be derived. Given that the costs associated with performing an airborne survey of coastal waters is typically £80k - £100k[2], the use of CASI to identify eutrophic areas could easily be a cost effective solution to the problem.

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[1]private communication with Mr Martin Day, Water Research Council

[2]private communications with Mr Nick Holden, National Marine Centre for Instrumentation and Marine Surveillance

Other monitoring duties: in addition to the above Directives, the NRA also has statutory monitoring duties under the UK National (Marine) Monitoring Plan (NMP). This plan was developed in a bid to rationalise existing activities and to provide better co-ordination of the monitoring requirements arising from international commitments, including the Joint Monitoring Programme of OSPARCOM and the North Sea Task Force Monitoring Master Plan. The UK NMP (now likely to be superseded by JAMP) is primarily aimed at producing a coordinated and reliable dataset on nationally significant contaminants in inshore and coastal waters.

The NMP specifies a network of sites along with details of the proposed physical, chemical and biological parameters to be measured. Some of these sites are located in estuarine and coastal areas within the 3nm limit and thus the monitoring of these sites is an NRA responsibility. Determinands measured and sampling details are summarised in table 2.6.

Potential contribution of survey data: as can be seen by comparison of table 2.6, appendix A and section 1.2, there is overlap in the parameters/determinands measured during the baseline surveys and the NMP activities. Comparison of the coastal baseline spot sampling sites and the NMP sampling stations[3] reveals that there is overlap in the coverage of the baseline surveys in some of the estuarine and intermediate NMP sampling sites. Consequently there is potential for the measurements made during the baseline surveys (in particular the ship-based measurements) to be used in satisfying some of the monitoring requirements of the NMP.

Within the NMP, three monitoring sites are chosen in each estuary so as to provide a good geographic coverage of the estuary and to represent the upper, middle and lower reaches. Sites must be located within the main channel for water quality monitoring, whereas for biological and sediment sampling it is possible to sample outside this channel in order to obtain a representative sample (because of local factors such as dredging operations or to avoid the mixing zone of a known input). The NMP also states that once a sampling site has been chosen, and if necessary adjusted as a result of the initial spatial survey, all future sampling should be as near as possible to the same sampling location. As was the case for the various Directives discussed above, aerial surveys provide information on the thermal and colour properties of the water, and thus in most cases permit identification of the location and extent of effluent plumes, mixing zones and areas of sediment laden water (arising from dredging operations). Such information would be of benefit in assessing whether or not a given estuarine sampling site remains at the most appropriate location given the passage of time, in identifying a more appropriate location and in supporting investigations into unexpected measurement results.

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[3]MPMMG National (Marine) Monitoring Plan, Appendix 1, March 1994

Table 2.6: The National (Marine) Monitoring Plan and the potential contribution of ship-based and aerial survey data

UK National (Marine) Monitoring Plan Marine Pollution Monitoring Management Group (MPMMG) - UK National Monitoring Plan		
Mandatory determinands to be measured	**Sampling location**	**Sampling frequency**
Unfiltered Water: γ and α- Hexachlorocyclohexane, *β-Hexachlorocyclohexane. *Dieldrin, *Aldrin, *Endrin, *Isodrin, Hexachlorobenzene, *Hexachlorobutadiene, Pentachlorophenol, *DDT (op DDT), *Priority Hazardous Substances (Carbon Tetrachloride, Chloroform, Trifluralin, Endosulfan, Simazine, Atrazine, Azinphos-ethyl, Azinphos-methyl, Dichlorvos, Fenitrothion, Fenthion, Malathion, Parathion, Parathion-methyl, Trichloroethylene, Tetrachloroethylene, Trichlorobenzene, 1,2-Dichloroethane, Trichloroethane) Dissolved Oxygen, Suspended Solids, Chlorophyll a, Secchi-depth, Salinity, Temperature, Oyster Embryo Bioassay Filtered Water Sample: Mercury, Cadmium, Copper, Lead, Nickel, Zinc, Chromium, Ammoniacal Nitrogen, Nitrate as N, Nitrite as N, Orthophosphate as P, Silicate as Si Total Surficial Sediment: Aluminium, Mercury, Cadmium, Copper, Lead, Nickel, Zinc, Arsenic, Chromium, Tributyl Tin, Polychlorinated Biphenyls, *Dieldrin, *Aldrin, *Endrin, Hexachlorobenzene, DDT (pp TDE, pp DDE, pp DDT), Oyster Embryo Bioassay Shellfish: Mercury, Cadmium, Lead, Zinc, Tributyl Tin. Polychlorinated Biphenyls, γ and α-Hexachlorocyclohexane, *Dieldrin, *Aldrin, *Endrin, Hexachlorobenzene, Pentachlorophenol, DDT (pp TDE, pp DDE, pp DDT), *Hexachlorobutadiene Fish Muscle: Mercury, Arsenic Fish Liver: Cadmium Lead, Polychlorinated Biphenyls, *Dieldrin, *Aldrin, *Endrin, DDT (pp TDE pp DDT)	Sites in agreed estuaries representative of the 0-10 ppt, 10-20 ppt, 20-30 ppt, salinity ranges; agreed intermediate coastal water sites. To be decided for sediment, biological tissue and analysis and benthos after analysis of the spatial surveys * Estuarine sites only	Quarterly for water quality at estuarine sites; annually for water quality at intermediate sites; annually for sediment samples; twice per year (Winter and Summer) for oyster embryo bioassay at estuarine sites, once per year at intermediate sites; to be decided for sediment, biological tissue analysis and benthos after analysis of the spatial survey
Survey potential contributions		
Boat	**Aerial**	**Comments**
Potential for the ship-based baseline survey data to be used to meet some of these monitoring requirements for some estuarine and intermediate sampling sites	Wide area spatial information on effluent plumes, mixing zones and sediment transport is of use in identifying and monitoring estuarine sampling sites	Baseline survey vessels coverage may need modification to ensure the estuarine and intermediate sites are visited, so as to permit some of the NMP measurements to be taken during the baseline surveys. Combination of the two surveys requires that collection and analysis methods as well as limits of detection be rationalised.

2.3 Surveillance monitoring

Surveillance monitoring covers those activities undertaken to report on the status of the marine environment. The category of surveillance monitoring covers monitoring undertaken for national purposes whereby the NRA reports on the general status of water quality and the changes which have occurred with time. This is in accordance with the NRA Water Quality Strategy (1993) which states that the NRA will 'publish reports on all aspects of water quality on a regular basis'.

Potential contribution of survey data: the data collected during baseline coastal water surveillance surveys are particularly suited to the application of water quality surveillance. The ship-based surveys provide a cost effective means of *in-situ* data gathering from which temporal trends and variations can be monitored. The aerial surveys provide wide area quantitative information on chlorophyll concentration and surface suspended sediment concentration and qualitative information on the spatial extent of mixing zones, HNDAs, discharge footprints, sensitive areas and coastal processes and provides a context for the *in-situ* measurements. Furthermore the data can be used to estimate sediment transport and changes in geomorphology.

Through the regular conduct of ship-based and aerial surveys, a database of water quality related phenomena could be compiled, which would facilitate the identification of seasonal and yearly trends as well as any significant anomalies. Such data would aid the NRA in forming an opinion on the state of coastal waters and would be of use in identifying areas for further investigation (as well as identifying optimum sampling locations) and providing timely warning of possible water quality problems.

With the objective of providing regular reports on the general status of water quality, the NRA and its predecessor organisations have developed classification schemes for controlled waters. However, although an estuarine NWC classification scheme exists (which is shortly to be replaced by a General Quality Assessment scheme), no such scheme exists for reporting on the quality of coastal waters. Until more information is available concerning the GQA scheme for estuaries, it is not possible to consider in detail the applicability of a similar scheme to coastal waters and the potential contribution to be made by the baseline coastal surveillance survey data. However, based on the estuarine NWC classification scheme, there is potential for the ship-based data to make a significant contribution to data gathering in support of chemical quality (eg dissolved oxygen) assessments and for the aerial data to supply information in support of aesthetic (eg colour, spatial extent of discharges) quality assessments and in selecting the optimum sampling location for *in-situ* measurements.

2.4 Regional operational requirements

Regional operational requirements and activities are managed by the NRA Regions and address specific local issues. Allowable activities include:

- ❑ Discharge impact assessment and pre-consenting studies (Water Resources Act): this includes monitoring investigations related to point source discharges and the assessment of their environmental impact. The objectives of this type of survey are to assess the likely environmental impact prior to issuing an NRA consent, in order to set appropriate consent limits, and then review these consent conditions to ensure that they are protecting the aquatic environment.

Potential contribution of survey data: aerial surveys provide information on the thermal and colour properties of water and thus in most cases permit identification of the spatial extent of mixing zones and discharge plumes. Such data are of use not only in pre-consenting investigations for discharges into estuarine and coastal waters, but also in identifying suitable locations for in-situ sampling in support of post-consenting activities. As discussed above (Urban Waste Water Treatment), the CASI instrument offers a unique means of identifying the locations and extent of sensitive areas as well as providing quantitative information on chlorophyll concentrations. Such information, in addition to the data collected during boat surveys, has obvious application in pre-consenting studies since the data collected over an extended period would allow the water quality characteristics of the area, for example the susceptibility of an area to eutrophication, to be assessed.

- ❑ Development Impact Assessment: this category includes environmental impact assessments associated with large developments in estuaries or coastal waters and covers, for example, tidal barrages. The activities required of the NRA in support of these assessments are similar to those outlined in the discharge impact assessment category, above.

  Potential contribution of survey data: the potential contributions of survey data discussed in the discharge impact assessment and pre-consenting studies section above are equally applicable to the activities in support of development impact assessment studies. In addition, the CASI instrument provides spatial information, at no extra cost on the location and extent of sediment laden waters, which is of use in determining the impact of activities which affect sediment transport, eg dredging in support of construction or tidal barrages which create a barrier to sediment flow.

- ❑ Detection of trends and general water quality characterisation: this category includes investigations to determine background water quality and temporal changes in water quality. Such investigations are required to be justified in terms of solving or identifying a particular water quality issue or problem. It is anticipated that the implementation of the estuarine GQA scheme will subsume the majority of this type of monitoring.

  Potential contribution of survey data: the data collected during baseline surveys provides information valuable in establishing the year-on-year and season-on-season averages for various water quality parameters as well as providing a means to identify trends and anomalies.

- ❑ National and regional R&D: this category covers the survey work undertaken by the Regions in support of National R&D initiatives and Regional investigative or development work.

Potential contribution of survey data: the data collected during baseline surveys has the potential to provide a context for any further survey work to be undertaken (eg it permits mixing zones to be identified and can be used in assessing the optimum locations for sampling) and may, in some cases, provide enough data so that regional surveys are not required.

- Defensive studies: this covers monitoring which may be required to permit the NRA to form an opinion and respond to an issue of media interest.

  Potential contribution of survey data: the potential of survey data to contribute to defensive studies activities is obviously case specific. In broad terms, the baseline surveys provide spatial and temporal information on water quality, movement of water bodies, mixing zones, plume footprints and sediment transport, any of which may be pertinent to a particular defensive study.

- Post pollution incidents: this form of monitoring covers the sampling undertaken after an incident to monitor the recovery of the estuary or coastal waters, the extent of remedial work needed and to assist in any pollution prevention initiative to prevent future incidents.

  Potential contribution of survey data: assuming that a pollution incident causes a change in water colour, aerial surveys have the potential to monitor the pollution incident by providing spatial and temporal information on the polluted water, eg movement and extent of the polluted area. The in-situ data collected during the survey could also be of use in assessing the recovery of the waters.

- Real time water quality management: this monitoring activity is restricted to the day-to-day management of estuaries through the use of continuous monitoring instruments.

  Potential contribution of survey data: the survey data has potential application to real time water quality management since the data obtained could be used to set the context for the real time activities. For example, the data gathered through surveys over an extended period of time could be used to identify any trends or seasonal anomalies in the water quality which may affect the day-to-day management of estuarine water.

- Model development and validation: this category covers monitoring undertaken in the development and validation of water quality models which will be used to support management decisions for the protection of the marine environment. The output from models will be used to support other identified monitoring categories such as discharge impact assessment, the detection of trends and general water quality characterisation.

  Potential contribution of survey data: the ship-based and aerial data has direct relevance to regional modelling since the data could be used as input to the models (eg boundary conditions) as well as in model validation. Data obtained during surveys performed during consecutive years has obvious application in identifying temporal changes in water quality as well as providing a baseline for water quality against which anomalies and trends can be identified. Data collected using CASI can be readily incorporated in WQ models; this process is facilitated by the aircraft data being sampled on a similar grid to most currently used models. The CASI and thermal imager instrument also have the potential to provide wide area information concerning mixing zones, movement of water masses, discharge footprints, chlorophyll patches, HNDAs and sensitive areas. Such data is important in aiding interpretation of the model results.

Modelling of sediment transport is undertaken by some NRA regions in support of beach management and falls within the model development and validation category. Typical examples of this type of activity are monitoring and modelling of sediment transport in support of beach recharge schemes and in helping understand and identify coastal areas with erosion or accretion characteristics. The CASI instrument offers a unique means of obtaining wide area information on surface sediment (SPM) concentrations as well as on the composition of the sediment (ie whether quartz, clay or organic). Such data could be used in model calibration and validation as well as in setting the context for interpretation of the model and survey results. Recent R&D advances have resulted in the ability to estimate the vertical profile of sediment concentration given the surface measurement. Such data can be used in estimating sediment transport rates, by combining the profile data with a current model for example, which in turn helps develop a fuller understanding of coastal processes and sediment transport.

2.5 Flood defence

The Coast Protection Act 1949, the Land Drainage Act 1991 and the flood defence provisions of the Water Resources Act empower the relevant authorities, including NRA, to undertake flood defence and coast protection measures.

The NRA through its regional and local flood defence committees undertakes measures to reduce the risks of flooding from designated main rivers and the sea. It also exercises general supervision over all matters relating to flood defence in England and Wales.

Much of the work (including associated R&D) of the NRA in terms of coastal flood defence is linked with identifying the needs for new or improved coastal flood defence measures, assessing the environmental impact of such measures, identifying the most technically, environmentally and economically sound defence measures and monitoring their impact.

Potential contribution of survey data: aerial and ship-based survey data, as obtained in the national baseline surveys, provides a routine method for monitoring the coastal zone providing a basis from which seasonal and annual trends and variation can be derived. In addition to monitoring coastal water, the CASI data also permits monitoring of natural defences, eg sand dunes and salt marshes, whose formation, destruction and movement is of interest to the flood defence community.

Airborne sensors provide a unique means of obtaining wide area synoptic data from which some of the dynamic and mixing processes in the coastal zone can be identified or inferred, thus leading to a better understanding of coastal zone processes (and hence improved modelling capability). The data (both aerial and ship-based) collected during the coastal surveys has potential application in the calibration and validation of modelling work in support of impact assessments of coastal defences, as well as providing a means of enhancing and validating information gathered in regional surveys.

Information on sediment transport is often required in support of flood defence activities. For example, the stabilisation and development of beaches and the construction of sea defences (other than beach recharge) requires an analysis of existing and expected sediment transport rates, as well as a capability to monitor these effects. As discussed above, the CASI instrument offers a unique means of obtaining wide area information on surface sediment (SPM) concentrations as well as on the composition of the sediment (ie whether quartz, clay or organic). With recent R&D advances estimation of the sediment concentration vertical profile given the surface measurement is now possible. Such data can be used in estimating sediment transport rates, by combining the profile data with a current model (or other more complex morphodynamic models) thereby permitting the identification of areas undergoing erosion or accretion.

Finally, the CASI instrument, if flown during a flooding event, offers a way of assessing the spatial extent of flooding and providing digital information from which digital maps showing the location and extent of flooded regions could be constructed. By flying the CASI (weather permitting) over the flooded regions as the situation develops, the flooding maps can easily be updated and the temporal and spatial information so gathered used in assessing the history of the flooding event and the susceptibility of the area to flooding.

2.6 Conservation

The NRA has a duty to further conservation across all its activities as well as a duty generally to promote conservation. A detailed review of the business needs of the NRA in the area of conservation is beyond the scope of the present study. However, information collected to date indicates that land-use classification, identification and classification of mud-flat and intertidal vegetation, salt marsh monitoring and river corridor classification are areas which could benefit from data gathered using the CASI instrument. Conservation activities relating to flood defence have already been discussed above and will not be considered further here.

Potential contribution of survey data: the CASI instrument provides spatial information on the colour of the region within its field of view. Consequently, the ability of the CASI instrument to provide information of use to the conservation community, depends on the spectral signature of the feature of interest and the appropriate selection of the CASI bandset. Recent work[4] has indicated that the CASI instrument can distinguish between different types of vegetation cover (eg bare earth, deciduous wood, coniferous wood, arable, haycut, pasture, rough vegetation,

[4] Thompson AG and Fuller RM, "Some developments of airborne remote sensing techniques for the intertidal zone", Institute of Terrestrial Ecology

bare rock, heather/grass mix, heather, burnt heather, upland bog, upland grass) as well as identifying fine scale linear features such as hedges. (Unlike current satellite based sensors (eg Landsat) the spectral resolution of CASI is sufficiently fine to allow small spectral variations to be measured, thereby permitting much finer discrimination between different vegetation types.) Furthermore, it is possible to monitor changes in vegetation with time (eg changes in sand dune cover, movements of salt marshes) by appropriately timed overflights.

The NRA's 'River Habitat Survey' requires detailed information on river substrate, flows and banks. During past surveys a small number of rivers have been overflown by CASI, including the Tyne and the Tees. The CASI instrument can provide information on river flows providing the flow conditions are manifested by changes in water colour (eg white water associated with rapids, highly turbid water associated with uptake from the river bed) and on the extent of vegetation types adjoining the river.

2.7 Future needs: EnvAge

The Environment Bill (due to become an Act) specifies the duties of the new Environment Agency, EnvAge. The principal aim of the Agency in discharging its function is 'to protect or enhance the environment, taken as a whole' so as 'to make the contribution toward attaining the objective of achieving sustainable development'. In this section, the new water quality related duties of EnvAge are summarised.

The Environment Bill states that the Agency's pollution control powers shall be "exercisable for the purposes of preventing or minimising, or remedying or mitigating the effects of pollution on the environment. In addition to the monitoring activities currently undertaken by the NRA, EnvAge's remit includes compiling information relating to pollution so as to enable it 'to form an opinion of the general state of pollution of the environment'. This indicates the increased emphasis of EnvAge on environmental surveillance.

In addition the Agency will, in certain circumstances (ie at the request of Ministers) have new pollution assessment duties with respect to carrying out assessment of the effect, or likely effect, on the environment of existing or potential levels of pollution and reporting its findings.

The Agency will also be required to consider 'costs and benefits' in exercising its powers, which in turn translates into a requirement for the Agency to have greater accountability and assessment of the relative effect of different discharges (eg into estuarine and coastal waters).

Potential contribution of survey data: regular aerial and ship-based surveys constitute an ideal means of performing surveillance of coastal waters since they provide a mechanism for establishing seasonal trends and variations as well as more long term trends as a result of climate change, for example (once a number of years worth of data have been gathered). Spatial and temporal information concerning mixing zones, discharge footprints as well as coastal processes (ie those which affect water temperature and/or colour) such as along shore drift are all of use in assessing the general state of the environment and how it may change with time. As an example, the seasonal and yearly trends and variations in HNDAs could be observed. The airborne instruments also provide a unique means of identifying the location and extent of chlorophyll patches as well as providing information on chlorophyll concentration which will permit trends in chlorophyll and any seasonal or year-on-year trends or variations to be established. Furthermore, the wide area aerial data is well suited for use in identifying areas requiring more in-depth investigation and thus maximising the use of resources and funds.

The Agency's new pollution assessment duties place more emphasis on surveillance rather than monitoring activities. As discussed above, the survey data constitutes an ideal means of performing surveillance of coastal waters and of contaminants which affect the water colour (and can thus be identified using the CASI instrument).

Finally, the new 'costs and benefits' duty of EnvAge will require[5] the Agency to be in a position to assess the <u>relative</u> effect of different discharges (eg into estuarine and coastal waters). In certain cases this translates to a knowledge of the receiving waters' <u>relative</u> susceptibility to eutrophication. As has been discussed previously, the CASI instrument permits identification of chlorophyll rich patches and provides quantitative information on chlorophyll concentrations and spatial extent. Such concentration information facilitates prioritisation of areas in terms of susceptibility to eutrophication.

2.8 Summary of findings

The combined use of remote sensing (CASI, thermal imager) and conventional *in-situ* data gathering techniques has the potential to significantly enhance the effectiveness of the NRA in fulfilling its business needs, on both national and regional levels. The airborne data provides synoptic measurements from which the extent and location of spatial features, eg HNDAs, eutrophic areas, mixing zones, thermal anomalies, discharge footprints and sediment transport can be identified. Such information has application in a wide range of activities undertaken by NRA, ranging from the identification of HNDAs to providing calibration and validation information for coastal water modelling. The *in-situ* measurements provide the detailed information concerning determinand concentrations etc, as well as providing a mechanism for calibration of the airborne chlorophyll measurements, thus enabling conversion of the qualitative CASI information into quantitative chlorophyll concentrations, which in turn can be used to grade coastal waters into chlorophyll concentration bands. Each technique in itself provides valuable information for use in coastal waters monitoring, however, this information is greatly augmented by a combination of the complementary techniques. For example, the airborne data could be used to identify areas requiring further investigation using conventional in-situ techniques and to identify the optimum locations at which *in-situ* measurements could be made.

Regular aerial and ship-based surveys constitute an ideal means of performing surveillance of coastal waters since they provide a mechanism for establishing seasonal and yearly trends and variations as well as longer term trends as a result of climate change, for example. In particular, the wide area aerial survey data has application in providing warning of potential water quality problems and in identifying areas requiring more in-depth investigation. As an example, the data

[5] private communication with Dr J Pentreath, Environment Agency Advisory Committee secretariat

could be used to warn of increased chlorophyll concentrations and although it would be unrealistic and undesirable to investigate every incidence of increasing concentrations, the data could be used to help define a chlorophyll concentration hazard value.

In addition to water quality, the survey data has potential application to the flood defence activities of the NRA. The wide area airborne data provide a means of monitoring sediment transport through the associated changes in water colour. With recent R&D advances, estimation of the sediment concentration vertical profile given the surface measurement is now possible. Such data can be used in estimating sediment transport rates, by combining the profile data with a current models (or other more complex morphodynamic models) thereby permitting the identification of areas undergoing erosion or accretion. Furthermore, the CASI instrument if flown during a flooding event, offers a way forward in assessing the spatial extent of flooding and providing digital information from which digital maps showing the location and extent of flooded regions could be constructed.

In the area of conservation, the CASI instrument, with appropriately chosen bandsets, has potential application in identifying vegetation cover, eg in support of river catchment land use classification. Furthermore, it is possible to monitor changes in vegetation with time (eg changes in sand dune cover, movements of salt marshes) by appropriately timed overflights.

In conclusion, the baseline coastal water surveillance surveys provide the NRA with a unique dataset not otherwise available (even the data acquired by the NERC CASI provides coverage of less than 5% of the English/Welsh coastline). The combined ship-based and airborne surveys provide NRA (and EnvAge) with an enhanced capability to meet its business needs, both at national and regional levels.

3 SURVEY DATA APPRAISAL

3.1 Introduction

In this section the data collected during the coastal waters surveillance surveys are reviewed in terms of collection and analysis procedures. The comments made in this section are based on the results of the data analyses as well as the findings of visits to the NRA vessel Vigilance (Southampton Water, 4 April 1995) and the Llanelli laboratory (16 May 1995).

The three types of data collected during these surveys, namely spot (ie in-situ sampling), continuous (ie underway) and airborne imagery are discussed in sections 3.2, 3.3 and 3.4, respectively. Section 3.5 presents the conclusions drawn from the survey data review.

3.2 Spot measurements

3.2.1 General

Baseline samples: baseline sampling measurements (ie spot measurements) are taken at 186 sites along the coast, situated approximately 15km apart, with some additional sites at major estuaries. The positions of the baseline sampling sites are shown in Appendix B. The determinands measured fall into one of three groups. Group A determinands are measured at every baseline, and include nutrients, dissolved metals, chlorophyll-*a* and suspended solids. Group B determinands are measured at approximately every third baseline site, and correspond to measurements of total metal concentration. These values are obtained so as to provide a check of the quality of the dissolved metal measurements. Group C determinands are measurements of organics, and are recorded at sites of specific interest, usually corresponding to known inputs. Appendix A lists the various determinands measured.

The water sampling procedure is provided in document form to each NRA vessel. In summary, an acid washed three litre HDPE narrow necked bottle is used to collect a single sample which is then subdivided for each analysis (except for the organics). Water for these organic analyses is collected directly into a solvent cleaned glass bottle. For dissolved metals, a 250ml sample is filtered into a PEP bottle and submitted to the lab. For total metals, the sample is placed directly into a PET bottle, without allowing time for the solids to settle. Water samples for use in the measurements of suspended solids are transferred directly from the sampling container to a PET bottle, and samples are stored in the cool. For chlorophyll-*a* the sample is filtered and the filter paper removed and wrapped in foil. This foil package is frozen and remains frozen until lab analysis. Finally, for nutrients a 250ml sample is filtered through a syringe and the filtered sample is frozen immediately and transferred to the lab in this state.

Courier transfer of samples is used at all times. In the case of chlorophyll-*a* and nutrient samples, the samples are transferred frozen in a good quality cool box, with arrangements being made for the samples to be met at the lab to eliminate the chance of defrosting prior to analysis. In the case of the Llanelli laboratory, if the samples arrive after the end of the working day they are stored in a cool room (organic samples) or freezer (nutrients). The samples are identified by the bar coded labels provided by the laboratory to the ship and then logged into the laboratory work schedule with a separate bar coded label, which uniquely identifies the sample on the Laboratory Information and Management System (LIMS).

High quality measurements are made on samples received by the laboratory. The analytical techniques used tend to be heavily automated to increase throughput and reduce the level of person power required. Analytical quality control takes about 20% of the effort of the laboratory, and includes the use of quality control charts, certified reference materials and careful assessment of blanks. The laboratories are NAMAS accredited which means that they are regularly inspected to ensure these high standards are maintained. The lab is also involved in a range of national and international inter-calibration exercises.

Depending on the locations at which the samples are taken, they are currently analysed at either the NRA Llanelli (for samples taken by the Water Guardian, Sea Vigil and Vigilance coastal vessels) or the Nottingham (for samples taken by Coastal Guardian) laboratories. The analysis performed at each of these laboratories are summarised in Appendix E.

Profiler: in addition a further set of electronic data are collected at the baseline sites. The profiling system consists of a dissolved oxygen probe and a temperature and salinity probe, which make relevant measurements at set depths.

3.2.2 Review of procedures

Suspended particulate matter: where samples are taken, subsequently filtered and the SPM determined in the shore laboratory, the significance of biological material requires address. In the summer period phytoplankton can be an abundant part of the SPM and during storage a variety of processes including cell death or even growth may influence the SPM load, resulting in unrepresentative analysis results. (In winter months and during periods with low light levels, the lithogenic biologically inert components in the SPM are expected to dominate, and thus the problem is not so acute.) The recommended approach to overcome this problem with storage is to perform the filtration on the boat rather than in the laboratory.

Concern also exists over the size of water sample used for the SPM measurements, in that for low SPM concentrations better results would be obtained with a larger volume water sample, whereas for high SPM concentrations, a smaller sample would suffice. Current practice in other SPM monitoring surveys is to select the size of water samples based on the transmissometer reading. A recommendation concerning suitable sample sizes is deferred until section 4.2.

Nutrients: the relatively crude but effective total immersion bottle sampler used on the Vigilance should be quite adequate for collection of nutrient samples. If, however, a decision is made to sample both surface and deeper water when thermal or haline stratification is observed, this crude device will not be able to sample the deeper waters. In this case a lever action Niskin bottle (General Oceanics) or similar device, can be deployed from a hydroline (plastic or stainless steel). This sampling device is suitable for a range of determinands including metals, nutrients and some organics.

Metals: there are questions over the suitability of the sampling equipment used for metals. The same open bottle system is used as for the nutrients currently, which consists of an acid washed polyethylene bottle held within a stainless steel frame with a bottom stainless steel weight; to aid in the release of air from the bottle a perforated stainless steel tube is placed in the bottle. The bottle is lowered from the ship using a plastic rope. It is general practice in research orientated work on dissolved trace metals in sea water to ensure that no metallic or potentially contaminating components are in contact with, or near the sampled water. Clearly the requirements of the NRA with the EQSs used are different and is more a question of "are the levels greater than a prescribed value". The general trends in the metal data suggest that the approaches used are working within the limits being applied in that the hot spots identified (e.g. the Tyne, Severn) have also been identified as high concentration zones within projects with better detection limits such as the North Sea Project, and that zones with background low concentrations are reported as being less than the detection limit. However, for limited additional effort (see comments on Niskin bottle in above nutrients section) more rigorous sampling could be undertaken, which would be appropriate if more stringent EQSs were to be applied in any future legislation, and using a water bottle approach would give the capability of studying the water column under stratified conditions to pick up deep discharge inputs and trends in concentrations.

The rational for the periodic measurement of "total" metals, i.e. acidification of the unfiltered sample and then filtration and measurement as per the dissolved metal analysis, is to provide a check on the dissolved data. The total value should always be greater than the dissolved value because of metals being leached from the particles, and if this trend is not so, as has occasionally been the case, it infers a contamination problem with the dissolved metal sample. However, the magnitude of the total metal concentration will be a reflection of the amount and nature of suspended particulate matter (SPM) present in the original water sample and not the dissolved metal concentration. The only use of the total metal measurements is in providing a quality check of the dissolved data. A better approach to data validation would be to perform triplicate sampling of the dissolved metals, as is the practice in some other R&D monitoring campaigns.

Organics: the sampling device for trace pollutant organic materials is similar in concept to that used for the metals except that a glass bottle is held in a stainless steel frame. The bottle is stoppered on recovery, and returned to the laboratory for analysis. For persistent, i.e. not easily degraded, organic chemicals in the environment this approach to storage is probably adequate. However one potential problem which arises with the organics is the lack of filtration of the samples. Hydrophobic organic compounds, such as chlorinated hydrocarbons, will be found primarily in the particulate phase in the water column. The actual concentration of the organic compound in the water column on a ng/l basis then becomes a question of how much particulate matter is present, and the concentration of the organic compound in the particles. Thus zones with high water column particle loadings, such as the Severn Estuary, will have high organic loadings relative to other areas where inputs may be high, but the organics remain locked up in bottom sediments. However, there is no obvious way to overcome this problem.

Storage and transport of spot samples*:* as discussed above, storage of nutrient samples can lead to changes in concentration, particularly if there is no filtration (to reduce biota), or poisoning or freezing of samples. The sometimes very significant differences between the ship auto analyser (higher), and shore laboratory (lower) data strongly suggest that transport and storage methods are not always effective. It is strongly recommended that the question of storage artifacts be reviewed, and where transport and subsequent analysis of samples for nutrients is still necessary, that the use of mercuric chloride preservation procedures be considered; this approach has been used with success in a range of marine waters. From discussions on the Vigilance it appears that some storage experiments are already underway. Whilst there is a strong incentive to move to the use of Skalar underway analyses as the main data collection method for nutrients, AQC measurement of samples at shore laboratories (as a check of ship analyses) as well as other NRA sampling programmes (when auto-analysers are not available) are critically dependent on good storage of samples between collection and analysis.

Laboratory procedures: the detection limits aimed at by the NRA laboratories are at least ten times less than any Environmental Quality Standard (EQS) which are available. Occasionally these EQS levels cannot be attained with the existing technology. The current detection limit definition used is 4.65 times the standard deviation of the blank; this factor is due to be increased to 5.2. The detection limits achieved by separate NRA laboratories do differ and in 1994 a decision was taken to report all data to the worst common detection limit (ie the highest value). This is not a good procedure because it means that good data are effectively lost. Thus it is recommended that all data above the detection limit of the individual laboratories be reported and that the existing database be modified to include all data above detection limits for 1994, where these data have not been discarded.

An important finding of the visit to the Llanelli laboratory was that the analysts appeared to have little idea of how the samples were taken or how the data were to be used. Clearly these aspects of the work are beyond the remit of these individuals, but it is recommended that they are provided with an overview so that they can relate their work, which they do well, to data collection and use of the results.

Profiler: these data provide a vital indication of the representativeness of the baseline samples, indicating whether an area is stratified or not. At present the data are recorded at set depths. It is recommended that the probes are monitored continuously and the data collected subsequently edited to remove any unwanted data, if so desired. The continuous data so acquired could provide information important in determining vertical mixing processes and mixing zones.

3.3 Continuous measurements

3.3.1 General

Each NRA vessel has a number of sensors, including a Skalar nutrient analyser and a Towfish sensor system, which allow continuous monitoring of parameters along track.

Towfish: the Towfish system records temperature, salinity, dissolved oxygen, transmission and fluorescence every two seconds on transects between baseline sampling sites.

These data are presented in the form of plots which consist of a geographically referenced display of each parameter. The data are also stored as digital plot files. Recent developments at the National Marine Centre for Instrumentation and Marine Surveillance Centre have facilitated data access and manipulation: each digital data file has been converted from the original form, which was specific to the Qubit navigational system, to a database friendly format, with columns delimited by commas. The entire data set is then split into 60 boxes around the coastline (hereafter referred to as Qubit boxes), each containing a similar length of coastline and associated underway data. The results are cross-referenced to the position as an Easting/Northing which makes them particularly accessible to Geographical Information Systems.

Skalar nutrient analyser: the Skalar nutrient analyser system records Total Oxidised Nitrogen (TON), Nitrite, Ammonium, Silicate and Phosphate every two minutes between baseline sites. The requirement for this onboard measuring system became apparent from the reliability of the nutrient results received from the laboratory samples, with problems encountered due to the necessity to store samples.

This is a continuous flow automated analyser system, in which reagents are added to a flowing stream of sample, and after mixing, and for some analyses heating, the concentration of a nutrient present in the sample can be determined colorimetrically using a flow through cell. Such auto analyser systems have many advantages over manual systems including rapid sample throughput, good precision, a robust construction with minimal components which need manipulation, and the ability to be modified to sample flowing streams of water such as from a pumped system on a ship. The Skalar also has the capacity to compensate for refractive index interferences, which can be important in estuarine systems with varying salinities and thus changing refractive indices. These features make the Skalar system well suited to shipboard monitoring applications, such as those required by the NRA, and similar units are in service with, eg MAFF and the University of East Anglia for monitoring and research applications. The system set up on Vigilance has channels to determine nitrite, total oxidised nitrogen, ammonia, phosphate and dissolved silicon. Water is continuously brought on board through a subsurface hull intake (circa 1 m) using a peristaltic pump. This water is filtered (nominal 0.45 μm pore size) in line and fed into an overflow reservoir from which samples are drawn into the Skalar auto-analyser. Calibration is done on board using concentrated standards (which should be stable), which are diluted volumetrically to concentrations suitable for calibration of the instrument for the samples being measured. Periodic AQC samples are analysed, and consist of standards diluted in low nutrient sea water.

The Skalar results are converted to a comma delimited file, referenced to Easting and Northing which may be plotted in a GIS format. The two minute sampling allows a detailed assessment of the levels of nutrients to be made, information which is vital for the identification of potential regions of eutrophication.

3.3.2 Review of procedures

Towfish: as discussed above, the Towfish data are plotted as Qubit plot files, which consist of a geographically referenced display of each parameter and are also stored as digital plot files. Although these plots are clear to understand and interpret, they have a number of drawbacks. For example, an area of interest may lie on the edge of two plots files, which makes interpretation difficult. However, the recent development of the Qubit box system by the National Marine Centre for Instrumentation and Marine Surveillance Centre have facilitated data access and manipulation. In particular the Qubit box data files can be readily imported to existing geographical information systems (GISs), including the National Centres' GIS. Development of this GIS is ongoing, and it is the opinion of this review that steps towards GIS development should be continued. However, many NRA users will not have the facility to interpret two-dimensional data. It is important therefore, to provide the Qubit data in sorted Qubit box files, with the data stored approximately representative of along track movement.

The calibration of the fluorometer on the towed fish is periodically undertaken by the manufacturer of the instrument (Chelsea Instruments). However, it is considered critically important that a calibration be performed during the survey itself. As the fish is towed at approximately 4m, there may be problems with relating surface chlorophyll signals to this deeper measurement. This may have relevance when attempting comparisons with the CASI image data. A possible approach to overcoming this problem would be to bring in and redeploy the Towfish when coming to a baseline sampling station, whilst taking a water sample for subsequent analysis for chlorophyll. This would ensure that the fluorometer reading corresponds more closely to a surface measurement and would provide a means of calibrating the fluorometer with the in-situ sample measurement. This calibration exercise could be performed at the start and finish of each daily survey, thus ensuring that any drifts in calibration during the day are identified. Development of a fluorometer system for measurement of surface layer chlorophyll using a Turner fluorometer was underway when the Vigilance was visited, and use of this system will remove the necessity to perform such calibrations.

Skalar nutrient analyser: of the conventional nutrients in marine waters, nitrate ammonia nitrite and phosphate are particularly difficult to store without changes in concentration. Normally these changes are reductions in concentrations, which appear to be due to uptake by bacteria on walls and in solution and other biota in samples. For the nutrient ammonia, both losses (biological activity) and contamination (diffusion of gaseous ammonia into plastic containers) can be important. A variety of procedures have been recommended to store samples (e.g. freezing, poisoning with chloroform, or phenol (ammonia) or mercuric chloride, etc.) without changes in concentration, but there is still no universally accepted procedure. There are therefore very strong arguments for the determination of nutrients on board ship immediately after sampling. This is the normal procedure during modern research cruises where the accuracy and precision of data is of paramount importance (e.g. work in the World Ocean Circulation Experiment, the NERC North Sea Project). The use of the Skalar (or similar) system on the NRA boats is thus viewed as critically important given that it should ensure an important improvement in the accuracy of data obtained.

Comparison of underway data between NRA ships: as the underway nutrient data from individual ships is brought together to form a single large data base, it is essential that these individual data sets should be of comparable quality. Although in theory an inter-calibration exercise between vessels at the overlap points in the coastal survey would be a good way ahead, in practise ensuring ship schedules overlap in this way is very difficult, and even if this were possible, there would be a very limited data set to inter compare. It is recommended that in addition to the AQC measurements, the distribution of blind samples across all the fleet and analysis of these materials should be undertaken, to demonstrate consistent data is being collected. However, such an approach requires that storage issues be resolved.

3.4 Image data

3.4.1 General

Remotely sensed image data is collected from two sensors, the Compact Airborne Spectrographic Imager (CASI) and the thermal video scanning system. Coverage of the coast up to the mandatory three mile limit can be achieved through a series of 189 flightlines. However, in practice, the necessity to include coastline in the imagery has resulted in the CASI imagery sometimes only extending to approximately 2.5 miles.

Compact airborne spectrographic imager (CASI): the CASI system was designed by Itres Ltd of Calgary, Canada. A number of models of the CASI have been used throughout the seven surveys to date, but each has been modified to allow potential coverage of the three mile coastal zone within one flight line by the addition of a wide angle lens. The CASI is an imaging spectrometer, which works on the principle of a two-dimensional CCD array. Light entering the system is split spectrally to fall on one dimension of the array. In addition the system works as a pushbroom scanner, recording the signal from each pixel across the swath simultaneously on the second dimension of the array. Three data collection modes are possible. With spatial data collection, information is recorded in all spatial pixels, but only a limited number of spectral channels (up to 15). In spectral mode all the spectral information is gathered but only for a limited number of spatial pixels. The third mode may only be used in short bursts and involves the collection of all spectral channels from each spatial pixel. The mode used for the NRA baseline monitoring is the spatial mode.

The CASI image data from 1994 is displayed and interpreted at the National Centre using the PCI image processing package, which is able to read and display CASI data directly, and display the data in full 16 bit resolution. (Earlier data may be displayed using the somewhat outdated R-Chips package.) Data is stored on optical disk and is easily accessible for new or inexperienced users. Images are numbered sequentially on processing and may be cross-referenced with the aid of an image database.

Thermal video: the thermal imaging system consists of four parts: the scanning camera, the processing electronics, the control unit and monitor, and the cooling system. The system operates in the 8-13 micron spectral range. The signal received is focused by a germanium cadmium telluride detector cooled to 80 degrees K by a Joule Thompson mini cooler. The resulting signals are processed to standard video format with a dat block added for recording and viewing. The input lens is a XI single element window giving a field of view of 60° horizontal and 40° vertical.

The system is operated manually (or automatically), with the gain and offset being altered to achieve the best contrast for the area being flown. This results in an uncalibrated image, with relative temperature difference only being measured.

3.4.2 Review

The requirement for collection of thermal data in collaboration with ocean colour data was a clear recommendation of the NRA pilot study[6] which was conducted prior to the establishment of the baseline surveys.

The CASI instrument provides high quality ocean and land colour data. It is recommended that the CASI bandsets are reviewed to ensure that the optimum bands are being used for monitoring chlorophyll, SPM and vegetation.

The thermal video system currently used is generally left running for a number of flight lines, being switched off only when in transit from one part of the country to another. This leads to relatively long datasets (eg three hours). The procedure used by the National Centre to extract information of interest from these datasets is to view the complete video, note features of interest, record the time associated with the feature (included at the bottom of each frame) and then compile a hard copy index of features versus time. In order to distribute information of interest to the various NRA regions, the relevant portions of the video data are extracted and transferred to a tape which is sent to the relevant regions. In both cases, if the display of individual images is required, then frames must be grabbed.

This entire process of feature identification and indexing is necessarily extremely time consuming. Furthermore, it may be difficult for a new user to understand the thermal data since in many cases land in absent from the video imagery, due to the thermal video system having a narrower field of view than the CASI. Such problems could be minimised if the thermal and CASI data could be displayed on the same display facility by including the thermal video data in an additional band. However, this requires that the video data is spatially referenced to the CASI data. A possible way forward for the NRA would be to follow the approach taken by NERC, who spatially integrate thermal scanner and CASI data obtained from simultaneous flights of the two systems.

As discussed above, the gain and offset of the thermal video system are altered manually so as to achieve the best contrast for the area being flown, resulting in uncalibrated images, with only temperature differences being measured. Furthermore, there is potential for some features being ignored as they are not clearly visible to the operator, or conversely some features being emphasised. Although there is potential for a calibration to be performed to relate the temperature difference to an absolute temperature through the use of simultaneous in-situ temperature measurements, in practice the number of gain changes performed when an NRA boat has been coincidentally measuring temperature has rendered such calibration impossible.

Notwithstanding the discussions above, the thermal video system constitutes an inexpensive means of acquiring thermal data and provides a useful means of identifying the location and extent of frontal structures, mixing zone and discharge footprints. To enable further scientific use of the thermal data requires that the system provide absolute temperatures; this may be achieved in a number of ways. Firstly using the present system, a procedure could be adopted which requires

[6] Boxall S R, Chaddock S E, Mathews A and Holden N, "Airborne remote sensing of coastal waters", R&D Report 4, 1993

the alteration in offset and gain to be recorded. This could then be used in conjunction with coincident ship truth data to calibrate the image. Alternatively, the thermal video currently used could be replaced with a thermal scanning system (and the data displayed alongside the CASI data).

3.5 Conclusions

The baseline coastal waters surveillance surveys have been carried out on eight occasions during 1993 and 1994, corresponding to Winter, Spring, Summer and Autumn in each year. The Spring and Autumn campaigns are timed to coincide with the two main bloom events of the year, when areas of chlorophyll-*a* concentration may become eutrophic. The summer campaign provides a background figure for chlorophyll-*a* concentrations and is at a time when natural nutrient levels are low. The winter campaign is a boat only campaign due to the weather problems associated with flying at this time of year. This survey provides vital information on natural nutrient levels around the coast, which are maximum at this time of year.

In conducting this review of data collection and analysis techniques, it has become clear that the NRA has developed a considerable expertise in performing the baseline coastal waters surveillance surveys, which places them among the leaders in Europe in conducting such operational monitoring campaigns. This expertise is demonstrated throughout the data collection and analysis chain; the scientists on board the NRA vessel Vigilance appeared competent and well motivated towards doing their work well. Equally, the scientists at the NRA laboratory at Llanelli appeared competent and committed to doing the work to the best of their ability.

As will be discussed in sections 4, 5 and 6, the baseline surveys constitute a useful means of fulfilling many of the NRA business needs. In performing the past eight baseline surveys, the NRA has modified and developed its procedures for data collection and analysis, such that the current system constitutes a well-rounded approach to operational monitoring and demonstrates the feasibility of conducting such surveys. Having demonstrated this feasibility, the time has come for the survey conduct and data analysis to be optimised. It is with this objective that the findings and recommendations, summarised below, are made:

- Sampling procedures:
    - high quality measurements are currently made on the spot measurement samples. It is recommended that to ensure confidence in the data, triplication of samples is adopted;
    - the measurement of total metals is not a particularly useful measurement and should not be necessary if triplication of samples is undertaken;
    - should there be a future requirement for nutrients to be sampled at both surface and deeper water, the use of a lever action Niskin bottle, or similar device, is recommended. This sampling device is also suitable for a range of determinands including metals, nutrients and some organics.
    - steps should be taken so as to ensure that no metallic or potentially contaminating components are in contact with, or near the water sample used for metals analysis.

- in the case of samples taken for suspended sediment analysis, it is recommended that the water sample size should be chosen (via a look-up table or graph) according to the transmissometer reading.

- Sample storage: concern exists over the storage and transport of some samples and it is recommended that these procedures be reviewed. In particular it is suggested that:

    - in the case of nutrients, the use of mercuric chloride preservation be considered;
    - in the case of suspended solids, filtration should take place on the boat.

- Profiler: it is recommended that profiler probes are monitored continuously rather than at set depths and that the data are subsequently edited to remove any unwanted data.

- Towfish: to enable calibration of the fluorometer during the surveys it is recommended that at the beginning and end of each daily survey, the Towfish should be brought in when coming on to station so as to allow a near surface measurement to be taken whilst taking a water sample for subsequent chlorophyll analysis, at the same time.

- Limits of detection: the current practice of setting the detection limit at the worst level attained by the individual NRA laboratories is not good practice as it means that good data are effectively lost. It is recommended that all data above the limit of detection of an individual laboratory be reported.

- CASI: the CASI instrument provides high quality ocean and land colour data. It is recommended that the CASI bandsets are reviewed to ensure that the optimum bands are being used for monitoring chlorophyll, SPM and vegetation.

- Thermal video: the system currently in use has demonstrated the benefits to the NRA of flying a thermal sensor. However, to enable further scientific use of the thermal data requires that the system measures absolute temperature. Firstly using the present system, a procedure could be adopted which requires the alteration in offset and gain to be recorded. This could then be used in conjunction with coincident ship truth data to calibrate the image. Alternatively, the thermal video currently used could be replaced with a calibrated thermal scanning system. To improve data handling, it is recommended that the thermal video data be spatially integrated with the CASI data and displayed simultaneously with the corresponding CASI image.

4 DATA ANALYSES

4.1 Introduction

In this section the principal findings of the data analyses are discussed together with the implications these findings have in the conduct of future baseline surveys. The principal aims of performing the data analyses were to :

- ❑ compare the measurements taken using different techniques at the same location.
- ❑ determine the optimum spatial and temporal resolution for the survey measurements;
- ❑ detect any trends and anomalies in the data;
- ❑ detect any hot spots;
- ❑ review the quality assurance of the data.

The datasets on which the analyses were performed are:

- ❑ the spot sample measurements (nutrients, metals, organics, chlorophyll, suspended solids measurements);

- ❑ the continuous Towfish data (transmission and chlorophyll);

- ❑ the continuous Skalar nutrient analyser data (phosphate, ammonia, nitrite, silicate and TON).

Currently the spot measurements are analysed at the Llanelli and Nottingham laboratories. Samples taken onboard the Water Guardian, Vigilance and Sea Vigil are taken to Llanelli, those taken onboard the Coastal Guardian are taken to Nottingham. Prior to the Spring 1994 surveys, the number of NRA laboratories performing sample analysis was eight (Anglian, Northumberland, North West, Warrington, Wessex, Exeter, Llanelli and Nottingham).

In summary, three types of analyses were performed on the numerical data:

- ❑ regression of the laboratory analysed spot measurements against the ship-based measurements in order to assess any relationships between and quality assurance indicators in the two datasets. The key findings of these analyses are discussed in section 4.2. A discussion of the analyses performed and the detailed results are included in appendix C.

- ❑ determination of the spatial correlation coefficients in the laboratory analysed spot measurements of chlorophyll, SPM, nutrients, metals and organics, so as to determine an appropriate sampling interval. The key findings of these analyses are discussed in section 4.3. A discussion of the analyses performed and the detailed results are included in appendix D.

- determination of the temporal correlations in the laboratory analysed spot measurements so as to assess the most appropriate temporal sampling interval and to identify any temporal trends. The findings of these analyses are discussed in section 4.4.

4.2 Comparison of ship and laboratory data

Table 4-1 provides a summary of the datasets regressed together with an identification of the sections in Appendix C in which the results are presented.

Table 4.1: Summary of the regressions performed

continuous ship-based measurements	Laboratory analysed SPOT measurements						
	chlorophyll-a	total SPM	ammonia	TON	nitrite	phosphate	silicate
QUBIT chlorophyll-a fluorescence	(section C.3)						
QUBIT % transmission		(section C.4)					
Skalar ammonia			(section C.5)				
Skalar TON				(section C.6)			
Skalar nitrite					(section C.7)		
Skalar phosphate						(section C.8)	
Skalar silicate							(section C.9)

4.2.1 Chlorophyll-*a*

Chlorophyll-*a* data has been collected during the surveys by water bottle sampling and subsequent laboratory analysis and through the use of an underway fluorometer which measures in a waveband set to detect chlorophyll-*a* fluorescence. Comparisons have been made of the sample/laboratory and fluorometer results for each survey and the results of the analyses are presented in Appendix C.3.

The statistical analyses have shown that relatively poor correlation exists between the fluorometer readings and the laboratory measured chlorophyll concentrations. However, the correlation between the two types of measurement shows an improvement for the last survey, Autumn 1994, with an increase in the comparability of results from different NRA vessels.

The relatively poor correlation still seen is a result of aspects of the sampling procedure and calibration of the fluorometer. To improve the correlation between the two measurements, it is recommended that:

- ❑ Triplicate samples should be taken at all sites. Previous research has shown that variability equal to that shown by the regression plots may result between triplicate filter paper samples on the same water sample.

- ❑ The laboratory analysis being used is a Spectrophotometric technique. In areas of low chlorophyll-*a* concentration a fluorometric technique allows more accurate determination of concentration. A move towards such a technique should be considered.

The fluorometer used by the NRA is calibrated by the manufacturers, Chelsea Instruments. The calibration technique used relies on a standard produced from a spinach extract; this is not an appropriate standard for marine applications. For accurate calibration in marine waters, it is necessary to calibrate against an algal solution. If a good calibration of the fluorometer can be established, all fluorometer data can be converted to chlorophyll-*a* concentrations which are of great use in the estimation of areas of eutrophic water. To achieve a better calibration, it is recommended that:

- ❑ a further water bottle sample should be taken at the beginning and end of each days' sampling, whilst suspending the fluorometer at the same depth at which the sample is taken.

If this simple approach to calibration is adopted, it will not only provide direct calibration of fluorometer results, but will also yield two surface samples each day which will be more readily applicable to the CASI imagery.

It should be noted that the requirements for surface fluorometer measurements has been recognised by the Vigilance team and a surface sampling system, based on a Turner fluorometer, was being developed on board when this vessel was visited during the course of the study.

4.2.2 Suspended particulate matter

Suspended particulate matter (SPM) concentration measurements are made through analysis of a filtered sample and can be inferred from the transmissometer reading. The laboratory detection limit of 3mg/l sets the minimum concentration that may be recorded by the laboratory. The operating range of the transmissometer allows accurate measurements up to approximately 50mg/l. Within this value range (3 to 50mg/l), a linear relationship is expected between the SPM concentrations and the transmissometer readings.

Appendix C.4 presents the results of the statistical analyses performed. In summary, a surprisingly poor correlation is seen between the SPM concentration measurements and the transmissometer readings, indicating a problem with the sampling procedure. Results from other large scale studies have shown that it is possible to produce a calibration for suspended solids from transmission over large scales, although further studies[7] have indicted the variability in calibration that may be caused by differing levels of organic material.

The key findings of the data analysis and the associated recommendations are summarised below:

- On a number of occasions the on-board transmissometer has been operated incorrectly, as is demonstrated by the reporting of transmission values in excess of 100%. Such a result could arise because the transmissometer window had not been properly cleaned, thus recording a higher transmission when placed in clear water or because of bubbles in the sample. These scientifically invalid results should have been noted by the scientists on board the vessels, which points to the necessity for a clear manual of procedures. Furthermore, it may also be appropriate to hold workshops or calibration exercises, in which the scientific personnel of the individual vessels may compare the procedures which they implement with the objective of attaining standardisation between the vessels.

- Another major source of error is in the measurement of suspended solids. As has been noted in section 3, the transfer of samples for suspended solids analysis to a shore based laboratory is inappropriate due to the potential alteration in the sample load caused by changes in the biological matter. Water sample filtering must therefore be carried out on the survey vessels and the filter papers transferred to the laboratory. It is also important to shake the water sample as sediment settles rapidly. Triplicate samples should be taken for more accurate results.

- In taking a water sample, the laboratory manuals state that a "suitable quantity" of water is filtered. This should be determined on the vessel by the use of a graph or look up table which relates the transmission to the volume sampled. It is suggested that the following working estimate be used as an interim measure and modified an the light of further campaigns:
    - for areas greater than ~80% transmission, a 5 litre sample should be used;
    - for areas with greater than ~ 90% transmission, a 10 litre sample should be used;
    - otherwise a 1 litre sample should be used.

Currently, only SPM concentrations up to 50mg/l can be made with the NRA transmissometer. Above this concentration, the overlap of particles within the 25cm path length of the transmissometer results in a non-linear relationship between SPM concentration and transmission. Transmissometers are now available with variable path lengths to account for higher SPM loading. However, these are still not suitable for measurement in areas such as the Humber and Severn Estuaries, where particulate matter loadings extend to above 500mg/l. At such levels, a different type of system must be used, namely the optical backscatter meter (OBS). Consequently, in order to be able to measure the wide range of SPM concentration

[7] NASH L, MATTHEWS A, SHIMWELL S AND BOXALL S, "Divisions of suspended particulate matter in the eastern English Channel," in preparation

found in UK waters, would require that all three systems. It is not considered appropriate for the NRA to adopt this approach currently, as problems would be encountered in intercalibration of results. However, the possibility of using such systems in the future should be considered on those vessels making measurements in high SPM regions.

4.2.3 Nutrients: ammonia, TON, nitrite, phosphate, silicate

Nutrient data have been collected both by bottle sample, with subsequent analysis at a shore based laboratory, and by the on-board Skalar autoanalyser system during three campaigns, namely Spring 94, Summer 94 and Autumn 94. For each of these campaigns it has been possible where data are available to compare the results from the two methods for each of the five determinands. The Skalar system was not an operational system on all of the four vessels during 1994, and this is apparent in the availability of results for the analyses.

The technique used to compare the data has been linear regression, in which the laboratory sample values have been regressed against the Skalar data. The regression results (appendix C.5 to C.9) have shown that:

- there is good agreement between the laboratory measured values and the Skalar values for TON, nitrite and silicate; this result indicates that good measurement and analysis procedures for these nutrients have been developed and are in use;

- for ammonia, there is fairly good agreement between the laboratory and Skalar values, except for in Autumn 1994 when it appear that there were problems with sample storage and transport;

- for phosphate, the regression results indicate that the Skalar system and sample analysis are not giving comparable results. This suggests that the calibration of the Skalar system may be drifting during the course of the measurements.

A key finding of the data analysis is that much of the data are unavailable for analysis because they are either below the differing limits of detection of one or more of the various laboratories or of the Skalar auto-analyser. However, this feature of the data has been less marked in recent surveys (eg there were consistently more data available for analysis for the Autumn 1994 survey) since the number of laboratories performing the analyses (and detection limits) has been reduced (namely to Llanelli and Nottingham), thus supporting this move towards laboratory rationalisation/standardisation.

4.3 Determination of spatial sampling frequency

The purpose of this analysis is to determine whether the spatial sampling frequency being used by the NRA at present is the optimum in terms of being representative of the variation in each determinand along the coast. In order to assess this the spatial correlation coefficient has been determined for sections of coastline. The magnitude of the spatial correlation coefficient reflects whether or not neighbouring measurements are correlated or uncorrelated and thus whether or not the sampling interval should be decreased or increased, respectively.

Appendix D describes the analyses performed on the data.

For the purpose of the spatial sampling analysis, the coastline was divided into littoral cells, which are regions defined as having similar sediment flow characteristics[8] and the analyses were performed on these cells as detailed in Appendix D. There are a total of twelve littoral cells between baseline sites 1 and 186, as shown in Figure 4.1.

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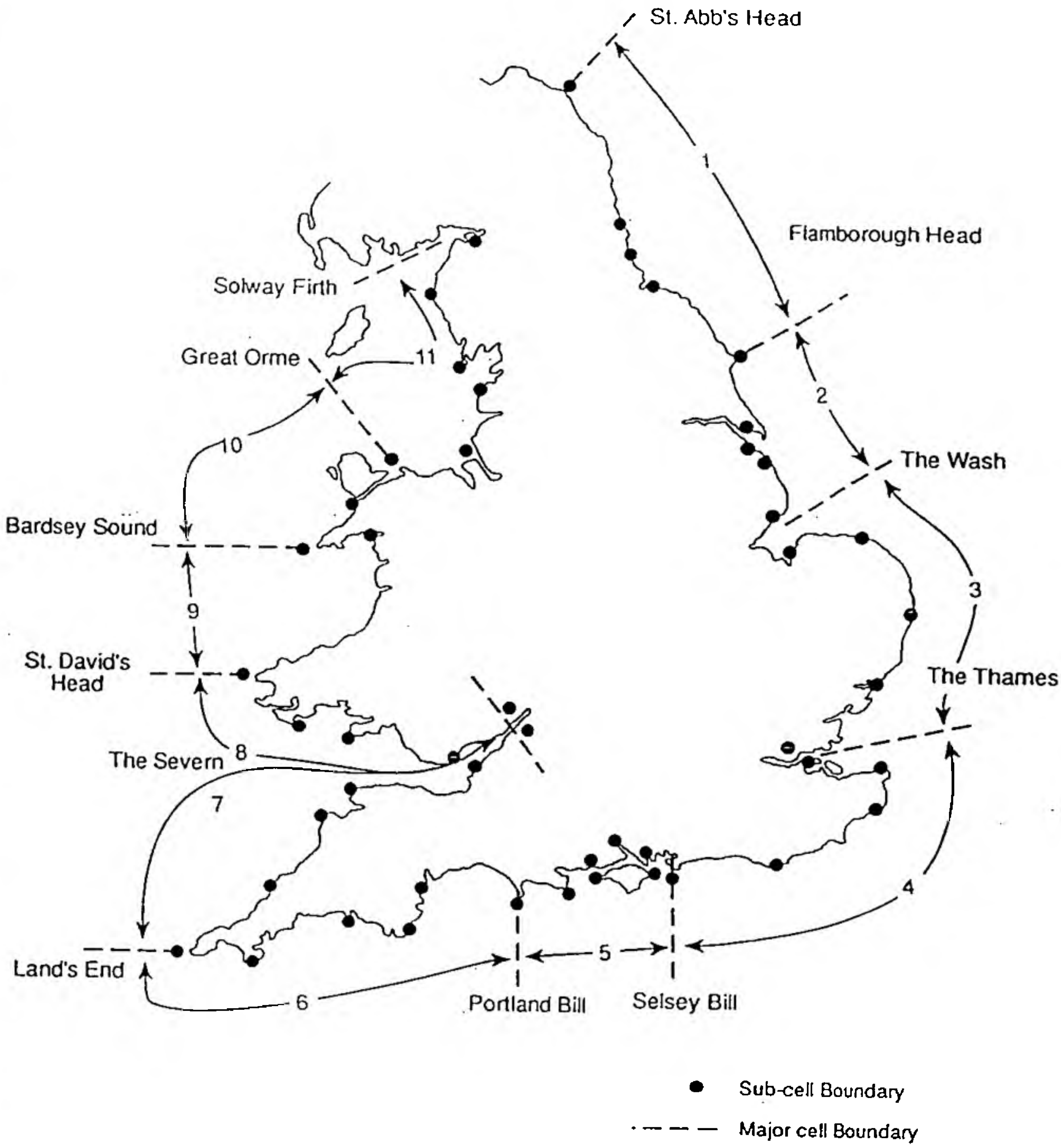
[8] MOTYKA J M AND BRAMPTON A H, "Coastal Management: Mapping of littoral cells", HR Wallingford report SR 328, January 1993

Figure 4.1: A diagram to show the position of littoral cells (courtesy of HR Wallingford Ltd)

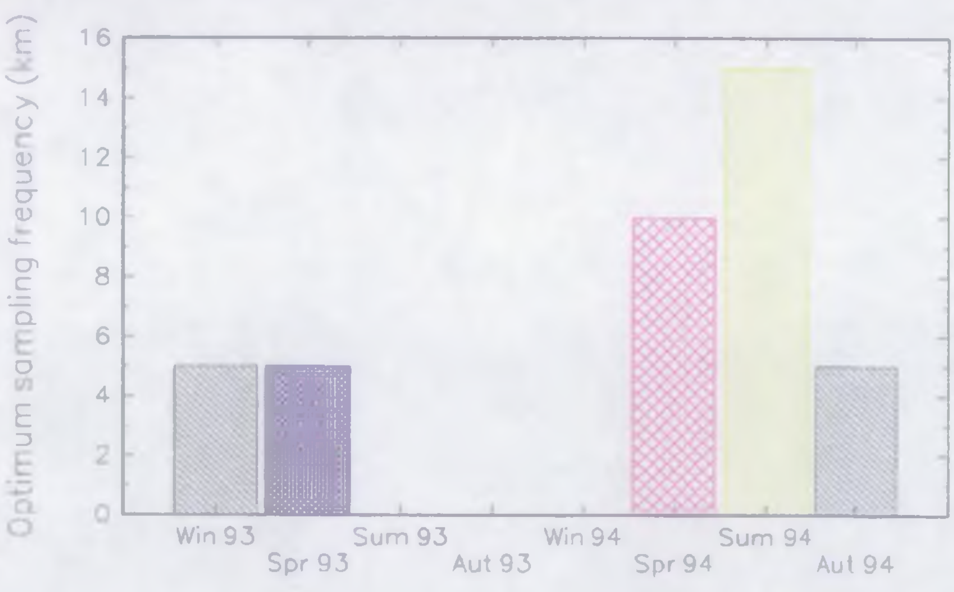


4.3.1 Chlorophyll-*a*

The spatial correlation analysis has indicated that the current practice of sampling for chlorophyll-*a* every 15km should be continued, given that there is insufficient data to support a recommendation for a reduced interval sampling strategy. This lack of data arises primarily through the chlorophyll concentrations in the analysed samples lying below the detection limit of the NRA laboratories. Emphasis should be placed on good quality calibration of the fluorometer, which would then provide chlorophyll-*a* measurements at a reduced sampling interval.

The optimum sampling analysis that it has been possible to perform has shown that for some stretches of coastline, eg Berwick-on-Tweed to Flamborough Head, the optimum sampling frequency varies with season and year. This variation in optimum sampling frequency is illustrated in Figure 4.2, which shows that the most appropriate sampling interval varies between 5km and 15km. This suggests that once a satellite based ocean colour scanner such as SeaWiFS or MERIS is operational, the satellite spatial resolutions of ~1km and ~250m, respectively, will be sufficient so as to enable routine monitoring of chlorophyll-*a* from space. SeaWiFS, for example, passes over the UK daily at noon and thus allowing for cloud coverage, between 50 and 100 images may be expected per year, from which chlorophyll-*a* concentrations can be estimated. Such data would be of particular interest in assessing longer term trends in the behaviour of chlorophyll-*a*.

Figure 4.2: A diagram to show the optimum sampling frequency for chlorophyll-a



The analysis has shown that the hot spots in chlorophyll-*a* vary spatially with season, and are obviously biased by areas of missing data. Generally, the North West coast between North Wales and the Solway Firth show the highest results in the last three campaigns, with the highest values being seen in the Wash in 1993. Winter campaigns show concentration maxima between 6 and 8µg/l, rising to in excess of 30µg/l in the Spring 1994 campaign. Concentrations in

Spring 1993 are somewhat lower, with a maximum of ~20µg/l. A further important point to note is that 30µg/l may not have been the peak in Spring 1994. Thus it may be concluded that in areas such as the North West coast, where concentration regularly exceed the eutrophication limit (10µg/l), it may be appropriate to carry out continuous sampling using *in-situ* samplers on moorings, eg marinised versions of the Sherlock/Merlin type systems. Such moorings have already been deployed off the East coast of England and the Dutch coast by MAFF and have recorded large peaks in chlorophyll which may last for very short time intervals (~ hours).

4.3.2 Suspended particulate matter

Spot samples collected at each baseline site are currently analysed for total SPM and then ashed at 500°C to determine the organic/inorganic fraction. The results are presented as total SPM and inorganic SPM and it is to these data that the spatial correlation coefficient analysis has been applied (see appendix D.4). It is recommended that the data be presented as total and inorganic SPM concentrations.

The spatial correlation analysis has indicated that the current practice of sampling for SPM every 15km should be continued, given that there is insufficient data to support a recommendation for a reduced interval sampling strategy.

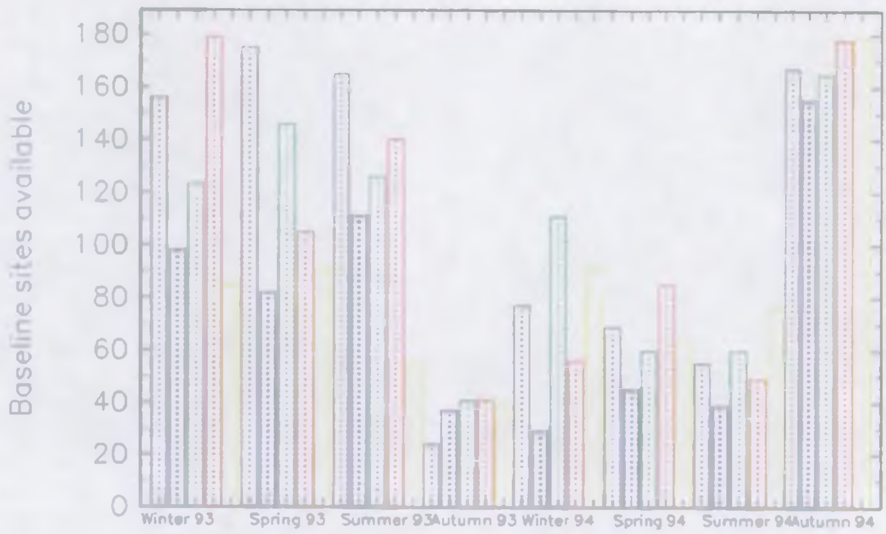
The analysis has shown that some optimum sampling may be occurring in cells 1, 6 and 9, with the present spatial strategy not fully reflecting the variability within these cells, which may be a result of frontal structures and riverine inputs. However, it has not been possible to determine an optimum sampling frequency for these regions as such an analysis requires reference to the underway transmission measurements which have been shown in section 4.2.2 to be poorly correlated to the spot measurements, thereby rendering any such analysis inappropriate.

4.3.3 Nutrients

The spatial correlation coefficient analysis has been applied to each nutrient data set, ie ammonia, TON, nitrite, phosphate and silicate, as detailed in sections D.5 to D.7. However, problems have been encountered due to the large number of data values which are missing, because of either being below the limit of detection or because sampling was not carried out. This is particularly evident in the Autumn 1993 to Winter 1994 periods, which correspond to datasets of key importance in understanding the natural cycle of nutrients, which are at their highest at this time of year. Prior to the Spring 1994 surveys, the number of NRA laboratories performing sample analysis was eight (Anglian, Northumberland, North West, Warrington, Wessex, Exeter, Llanelli and Nottingham), each with different detection limits. Consequently, there are variable amounts of data available for analysis for the various coastal regions surveyed. Since Spring 1994, only two laboratories (Llanelli and Nottingham) have undertaken sample analysis, thereby reducing this problem.

Figure 4.3 illustrates the number of results from the 186 baseline sites which were available for analysis in each season.

Figure 4.3: A diagram to show the baseline sites suitable for statistical analysis for nutrient data. The differing colours represent the five different nutrients considered, ie ammonia: black, TON: yellow, nitrite: blue, phosphate: green and silicate: red.



The detailed results of the data analyses are presented in Appendix D. In summary, these results have led to the following findings:

- the spatial sampling interval for all nutrients should remain at 15km as at present, since lack of data has meant that there are insufficient analysis results to allow a more suitable interval to be recommended;

- particularly poor sampling is achieved in the winter surveys because of inclement weather. Increased flexibility in allocation of ship time, with priority being given to baseline sampling should help overcome this problem;

- ammonia hot spots vary in locations from survey to survey, although the Tees Estuary shows consistently higher levels;

- the Bristol Channel consistently records the highest levels of TON and nitrite concentrations;

- the Llanelli limits of detection for TON and nitrite should be reviewed since they are more appropriate for the nutrient levels expected in Winter and Autumn (ie maximum) than for the lower levels expected in Spring and Summer. It is recommended that if the analysis instrumentation is capable of detecting lower levels than these, then they should be reported.

4.3.4 Metals

The results of applying the spatial sampling analysis to the laboratory metal concentration data are included in appendix D.8. For most of the metals, except dissolved copper, statistical

analysis was made difficult by the large number of data points below the levels of detection. In particular the higher detection limits of 1994, ie the Nottingham and Llanelli laboratories, have resulted in very few results.

In summary, the analysis results have led to the following findings:

- two results are presently recorded for each metal, dissolved and total. The purpose of measuring the total metal concentration, ie. the metal concentration including that held in the suspended particulate matter, is to provide a check on the dissolved metal result. Clearly, the value in the dissolved phase should not exceed that in the total phase. By observing the highest values in each, it is possible to cross check the analyses and determine whether transcription or contamination errors have occurred. This is not considered the best approach to checking the accuracy of measurements, and should be replaced by performing triplication of samples;

- low metal concentrations are seen along stretches of the coastline away from the estuaries and known inputs. The analysis results have indicated that a reduction in sampling frequency is appropriate in such regions. A decrease in the sampling frequency to every other site would cause no loss of information, a reduction to every third baseline site may cause limited loss;

- higher levels of metals are seen in estuarine locations, with the Bristol Channel being particularly noteworthy in this respect. It is recommended that the spatial sampling interval be decreased around known hot spots (eg every 5km) and in estuaries. It is suggested that the NMP strategy of sampling in three different salinity regions (ie 0-10ppt, 10-20ppt and 20-30ppt) be considered;

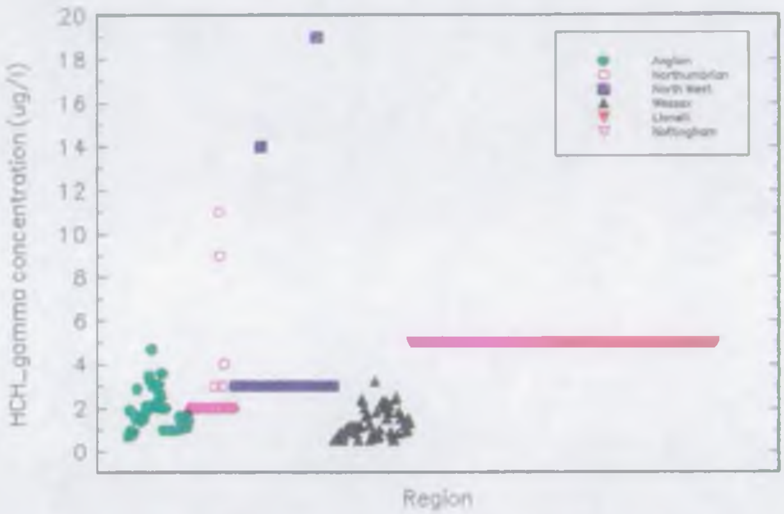
- the poorer detection limits achieved in more recent surveys and the variation in the detection limits between the Llanelli and Nottingham laboratories (eg for arsenic Llanelli laboratory had a detection limit of 2.5µg/l in 1994 whereas the Nottingham laboratory's detection limit was 1µg/l) indicates that there is a problem with setting the detection limit, or that the detection limits are not defined by the capabilities of the analysis instrumentation but are in fact NRA selected reporting levels. This requires further investigation. In particular, both the Llanelli and Nottingham laboratories should achieve the same lowest possible detection limit.

4.3.5 Organics

These determinands are measured at the Group Three sites, which are defined as being "sites of interest" and are irregularly spaced. The rationale behind their selection was that some sites should be analysed away from expected sources to establish the absence of organics in these areas. Otherwise all sites are concentrated around industrial areas.

It has not been possible because of the irregular sampling to determine the spatial correlation coefficient of the data and the required sampling strategy. Generally results are recorded as being less than the detection limit. The limits vary both between determinands and between laboratories, resulting in the reporting of results for some regions which would be below the limit of detection of another region. Standardisation on two laboratories, Nottingham and Llanelli, for data analysis has resulted in fewer results above the detection limits. Figure 4.4 illustrates how the laboratory detection limits vary for HCH-gamma, one of the measured organic compounds.

Figure 4.4: A diagram showing the different limits of detection of the laboratories for the organic contaminant, HCH-gamma



Generally, where results are above the limit of detection these relate to major industrial sites. In particular the area around Avonmouth in the high SPM loaded Bristol Channel shows results for many of the organic determinands. Another area where measurements are high is the Solway Firth. All these results are for 1993, however, and would have been recorded as below the limit of detection in 1994. It is likely the laboratories are reporting at a higher level (ie reporting limit) than they may actually measure (ie the true detection limit) and if all recorded data were available then more results would probably be seen.

To summarise:

- because of the problems with the detection limits and the random sampling strategy, the baseline levels of organic chemicals have not been proven;
- to make meaningful measurements, the detection limits for organics need reducing; both the Llanelli and Nottingham laboratories should report to the same lowest possible detection limit;
- the strategy for selecting the Group Three sites requires review in order to ensure that a systematic approach to selecting these sites is adopted;

- it is recommended that the measurement of organics should be reviewed annually as more information becomes available on the acceptable levels of these compounds and that the Marine Pollution Monitoring Management Group be consulted over this matter.

4.4 Analysis of temporal trends

The current temporal sampling strategy consists of performing four campaigns each year in Winter, Spring, Summer and Autumn. The purpose of the temporal trend analysis described in this section has been to determine if the sampling frequency needs to be modified, both in terms of season and year, in order to address the temporal variability in each determinand. The data available from the 1993 and 1994 baseline surveys are not adequate to perform a detailed temporal analysis for two reasons. Firstly, in order to determine any annual repetition in concentrations, a longer data set is required, for example of the order of ten years if trends over 5 years are expected. Secondly, the very sparse data available for the period Autumn 1993 to Winter 1994 means that the seasonal variability cannot be assessed.

The large number of missing data points and concentrations below the limit of detection have restricted the statistical analysis which could be applied. The correlation coefficient of the data over the 2 years has been calculated for each determinand at each baseline site. The results showed no spatial consistency. Generally, however, those baseline sites which recorded high concentrations or hot spots were found to be uncorrelated, emphasising the requirement to measure these at the current sampling interval if not more frequently. More frequent sampling could be achieved by the use of moored sensors which would record parameters such as chlorophyll-*a* concentration continuously. Correlated sites correspond to areas where levels were low throughout the measuring period. For example, most metals show no seasonal variability in areas away from estuaries. This suggests that the sampling frequency in these areas may be decreased, as has already been concluded.

For each determinand, the seasonal variability was assessed by investigation of baseline sites representative of hot spots and low levels. In each case, the sites chosen reflected those with the most measurements above the detection limits throughout the two year period. Figure 4.5 shows selected examples of determinand concentration plotted against time.

Concentrations of total SPM generally show the expected seasonal cycle with highest values in Winter 1993 and low concentrations in summer (except for baseline site 120, Newport Deep). Both years show low concentrations in summer. Poor winter sampling can be seen by the absence of total SPM data for the Autumn 1993 to Winter 1994 season.

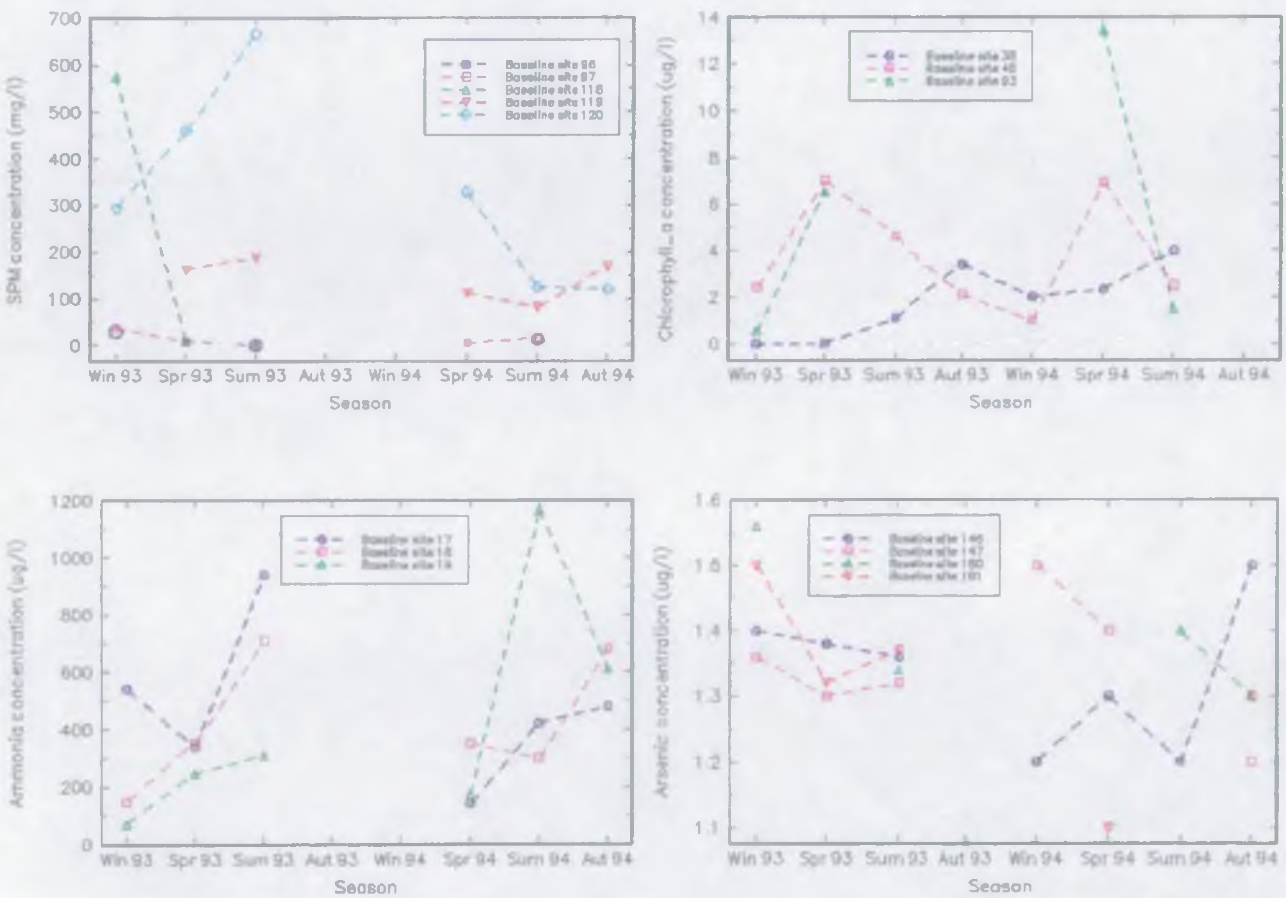
The seasonal variability of chlorophyll-*a* concentration is shown for three sites. The results show the anticipated seasonal variability with highest concentrations in Spring in both 1993 and 1994, for baseline sites 93 and 48. However, for baseline site 38, the Autumn concentrations are dominant. The high variability of chlorophyll-*a* concentration with season indicates that the deployment of continuous sampling devices on moorings would be desirable.

For ammonia, results are representative of the other nutrients, the hot spots are seen to occur in late summer / early autumn. The absence of data from the Autumn 1993 to Winter 1994 period is a major problem in establishing the natural background levels of nutrients which are maximum at this time of year. The sampling of nutrients must therefore be continued at the current temporal frequency until a full seasonal data set has been produced. Only then may the data be fully reviewed and recommendations made for modifying the sampling strategy.

Statistical analysis of the metals data has been made difficult by the large number of measurements below the limit of detection. The plot for arsenic shows that all levels are, far below the EQS level of 25µg/l, and these vary randomly between the sites shown with season. In this case it is anticipated that sampling may be decreased, as has already been assessed through the spatial analysis.

For organic contaminants, there are too few data for statistical analysis. However, in this case the baseline has yet to be established, and acceptable levels of organic chemicals may alter with time. It is thus suggested that the temporal sampling frequency remains as it is.

Figure 4.5: Temporal variation in certain determinands



4.5 Conclusions

Analysis of the data collected during the baseline surveys has shown that there are very many missing data values, thus restricting the analyses which could be performed on the data.

Many of the missing data can be attributed to problems with the laboratory limits of detection or because measurements/samples have not been obtained. Prior to Spring 1994, eight different laboratories analysed the data, resulting in eight different detection limits and many data being recorded as below these limits. Since Spring 1994, two laboratories have performed the analyses, namely Llanelli and Nottingham. However, the two laboratories often achieve different detection limits. This is not good practise and steps should be taken to ensure that both laboratories achieve the **same** lowest possible limit of detection.

The fact that in some cases detection limits appear to have become poorer with time, suggests that there may be some confusion over the analysing instrumentation's intrinsic detection limit and an NRA or laboratory selected limit above which data are reported, ie a reporting limit. Even if data below the reporting limit are not freely distributed, they should be recorded down to the detection limit.

The key finding of the analyses that have been performed are summarised in sections 4.2 through 4.4 and will not be repeated here. It is anticipated that by addressing the issues highlighted in this and other section of this report, that a more complete set of quality assured data will be obtained during future surveys and that good results, as is currently the case for nitrite and TON will be achieved. Such an improved dataset will allow more sophisticated statistical techniques to be applied, including multi-variate techniques (eg principal component analysis, multiple dimensional scaling, cluster analysis), with increased emphasis on hydrography.

5 ANALYSIS OF IMAGE DATA

5.1 Introduction

In this section the findings of the review of the CASI and thermal imager data are presented.

The image data were assessed in the following ways:

- the image quality was assessed in terms of the number of cloud and glint free images during the baseline surveys (section 5.2);
- the imagery of six sites of interest were studied in detail so as to ascertain what features were present in the imagery (section 5.3);
- the quality of the calibration run data and the procedures for obtaining calibration data were assessed (section 5.4).

The conclusions drawn are discussed in section 5.5.

5.2 Assessment of image data quality

The first method used to assess image quality involved the perusal of the flight log books and image database to assess the number of flightlines covered during each survey and the overall image quality in terms of cloud cover and sunglint effects. These results are presented on a national and regional basis.

Table 5.1: Summary of the statistical results for the flight lines analysis

	% flown	% of these that are cloud free	% of these that are glint free
November 1992	50.5	52.1	95.8
February 1993	97.4	68.1	97.8
May 1993	96.3	77.6	88.5
August 1993	95.8	68.4	86.8
May 1994	96.8	72.1	56.3
July 1994	79.1	51.9	63.5
September 1994	85.2	49.2	75.1
Average	85.9	62.8	80.5

The database of CASI image data held at the National Centre contains information on the availability and image quality for each survey carried out in 1994. Images are numbered sequentially when processed and are cross referenced to the national flight line number. By accessing any particular flight line number, the images available are displayed in terms of the image name, date, time and ancillary information, such as the amount of cloud or glint present. For previous years, the information must be gained from perusal of the instrument operator's flight log, which indicates the flight lines flown and the image quality in terms of weather conditions. This information is obviously subjective and may vary between instrument operators. (Stringent log books are now in use which should minimise this problem.) Therefore in order to compare the statistics produced for each survey the flight logs for one of the 1994 surveys, July 1994, was consulted so as to cross calibrate the results. The results showed that very little difference was seen between the two methods. In total three files of the 186 flightlines were recorded differently between the two methods. It was concluded that the results between surveys could be meaningfully compared.

National Results: table 5.1 presents the statistical results from all the flight lines analysed. The first survey only achieved 50.5% coverage but this is to be expected as it was the first time such a survey had been carried out operationally. The general decline in the number of flight lines covered was contrary to expectations. Discussion with the image analysis officers led to the understanding that the data were of increasing quality, and observation of the data available for each of the six sites confirmed this. The statistics show however that less than 50% of the flights from the most recent campaign were totally cloud free. The decrease in the number of flight lines covered may be explained by the poor weather conditions and a general decrease in the number of flying days for each campaign. There was therefore less opportunity to cover the 186 lines. There has also been an increase in experience of both the image analysis officers and the instrument operators. This has resulted in an increase in the criticism of data quality both in the air, in terms of the decision of whether to fly a particular line, and also during the processing procedure where lines with excessive glint problems may be discarded and marked as poor quality. One exception was during the May 1994 survey when almost half the data was affected by sunglint. This problem was picked up by the image analysis officers at the National Centre, and many flights were reflown. Time constraints however meant that this particular image set is still badly affected by sun glint. A more rigorous procedure has been adopted to attempt to synchronise aircraft and ship, and this has on occasions resulted in a slight drop in flight line coverage.

Having determined the average coverage and quality of the CASI image data, it was important to investigate if any bias existed in the data collection exercise and if so for what region. The order in which flightlines are flown depends on weather conditions, with a tendency to cover a section of the coastline until the weather or lighting conditions necessitate moving to another part of the country.

Table 5.2: Summary of flight line coverage

	% flight lines covered
all surveys	29.6
> 6	72.4
> 5	97.3
> 4	99.9

Table 5.2 clearly shows that nearly all flight lines have received image passes on more than 4 occasions out of the 7 surveys. It is therefore apparent that no particular flightline is being missed by using the existing method for determining where to fly.

Regional Results: the overall national average for the percentage cover is 85.9%, when taking into account the first survey in 1992, and 91.8% based on just the last six surveys. In order to compare the data coverage between regions, the statistics for those flightlines which were of interest to each region were compared. Some flightlines fall into two categories, as two regions may have a particular interest in a region on their boundary. For example there is an overlap in the area of interest between the Northumbrian region and the Anglia region as both are carrying out surveys in the Humber Estuary. The results for each region are presented in Appendix F.

The average coverage for the regions ranges between 80.5 % and 94.3%, with the Southern region receiving most coverage and the Anglian region having the lowest average coverage. All regions, however, receive within 5% of the national average coverage.

5.3 Assessment of Sites of Interest

The benefits of using remotely sensed data to address the national and regional business needs of the NRA both nationally and in its regions have been described in section 2. In order to assess the quality and potential use of the specific image data collected as part of the baseline coastal waters surveillance surveys, a number of sites of interest were selected for detailed review. The sites chosen were those most often requested, based on observation of the data request book held by the National Centre. The data request book clearly showed the interest in the baseline data (ie remotely sensed and *in-situ*) from the regions and from other government organisations, universities and consultancies. There is a clear need from the wider community for data of the type collected using the current strategy.

The data requests showed that information had been requested for the Oxwich Bay region as a result of the case in which bathers claimed paralysis caused by poor water quality. This data set was therefore extracted and further analysed. The River Tees has been a subject of a R&D study. The baseline data was therefore analysed for this area to establish what information regular monitoring may provide. The Spring 1994 data showed the presence of a large sewage outfall around Blackpool beach, and the consenting for this outfall was identified by the North West region as a key area of interest. The full archive of data for this area has therefore been examined. The remaining three areas are chosen as areas in which major scientific studies have been carried out in the past.

In assessing the images, issues of concern included:

- the image quality eg, is the image easily recognised or is more land required in the image? what is the radiometric quality of the images? what is the interpixel variability in radiance?
- the requirement for both CASI and the thermal video system, ie can one system be dropped thus making the survey more cost effective?
- what information does the image data offer above the underway data, which has similar spatial resolution capability (albeit in one dimension);
- whether the baseline sampling sites are representative of the region being measured, or should they be moved to be more so?
- do these sites of interest illustrate how the baseline survey is addressing the business needs of the NRA?

The images investigated by this review represent 10% of the total image archive of the National Centre. All data were accessed in January 1995, at which time no geocorrection had been applied. Subsequently the geocorrection procedure has been implemented. Observation of this data at the National Centre has led to the conclusion that the geocorrected data is of high quality. The key benefit of geolocating the data is in the use of image data to provide accurate spatial estimates of, for example, chlorophyll-*a* and suspended particulate matter. This matter is currently under investgiation at the National Marine Centre for Instrumentation and Marine Surveillance.

The Tees Estuary: the River Tees has been identified as a region of interest by NRA North West and has been the subject of R&D flights. It is covered by three baseline image flightlines, one to the North, one to the South and one actually flying down the River. The River Tees imagery is of good quality, with imagery variable from each of the campaigns. Generally, the water coming out of the mouth of the Tees is warmer with a higher reflectance, most probably caused by higher sediment concentration. The three image flight lines result in some overlap at the river mouth, though it is suggested that the flightline down the River might be extended slightly further to sea, as the frontal structures within the mouth extend to a greater distance than the North/South flightlines coverage. The water quality is extremely variable in the region, and it is thought unlikely that the ship samples may fully address this variability, although three baseline sites are situated in this area.

The continuous data locates a clear frontal structure off the mouth of the Tees in Autumn 1994, but in all other campaigns, the data simply shows a high variability in both temperature and transmission. In the laboratory measurements of suspended solids, the central Tees sampling point located in the mouth of the estuary is consistently higher, representing the input of sediment from the river noted on the imagery. The higher sediment concentration from within the river is more likely to be a natural source

Although the CASI data show large variations in ocean colour, the thermal imagery of this region most clearly highlights the various industrial inputs. This is because they are generally due to the input of cooling water which does not have a different suspended particulate matter load. A combination of the two systems is therefore required at allow a full picture of the region to be drawn and to give an indication of optimum sampling locations.

Flamborough Head: this is a key area of conservation, and an understanding of the water flow around the headland is a requirement for conservationists working within the area. This case demonstrates the complementary monitoring capability of the CASI and thermal data.

The image quality for Flamborough Head was high, with the headland partly obscured by cloud on only one occasion. A clear frontal feature was seen in both the colour and thermal imagery, though the extent of this was not clear as it extended off the end of the image. It was not therefore possible to conclude whether the front was the beginning of the large Flamborough/Frisian front which extends across the North Sea or whether it was a local feature. This feature is also visible in the temperature recorded by the Towfish from each of the surveys. In July 1994, the thermal data shows few features, with sediment plumes being picked up in the CASI data. The quarterly nature of the baseline survey would allow an archive of vegetation in the intertidal zone of this important conservation area to be compiled. Classification of vegetation is being investigated presently at the National Centre.

The position of the flightlines results in the tip of the headland being overflown twice. This has allowed an assessment of the radiometric quality of the CASI imagery to be made. A number of land targets were selected, as these would not change between flights, and the radiance value on each image compared. The values were seen to vary greatly, with for example, a value of 3633 in one image compared to 4429 in the other. The difference is likely to be due to varying incoming light and the direction of flight. For the determination of geophysical parameters such as suspended particulate matter concentration, the actual radiance values are not as important as the ratio of particular wavelengths. By observation of the spectral shape of the pixels across the twelve channels it is clear the ratio varies little, and it is therefore considered that the radiometric quality is adequate. Normalising for the incoming light may alleviate some of these problems.

Chichester Harbour: Chichester Harbour is situated on a part of coastline which is heavily indented resulting in this area being often excluded during the standard flight lines. A great deal of interest has been expressed by NRA Southern for flights in this region in order to characterise and map the salt marsh populations. The CASI, with appropriate bandsets, provides an ideal tool for this, as has been shown by recent work at the National Centre where the marshes have been classified without recourse to ground truth data. If this technique could be further explored it may prove worthwhile adding an additional flightline to the baseline survey which passes through the marshlands so as to allow seasonal mapping of marshes.

In addition the CASI data shows the presence of sandbanks at the mouth of the Harbour whose position can be clearly located. The movement of these sandbanks with season has implications for both harbour authorities and for flood defence planners. Using geocorrected data the shift in sandbanks over time can easily be mapped.

Baseline ship campaigns would not be feasible in the Harbours themselves, but small boat work could be timed to coincide with the baseline flights if they were extended. The baseline ship surveys do not go close to the entrance to Chichester Harbour. However, the Qubit data from Vigilance shows a general increase in transmission westwards in all campaigns. This represents a decrease in suspended particulate matter (SPM) load from Selsey Bill, where the SPM is high, towards Portsmouth where it is lower. This pattern is verified by observation of the image data which shows high SPM around Selsey Bill, with a plume structures being drawn Eastward.

For this site of interest, the CASI data provides a useful means of monitoring sediment transport and sandbank movement, in addition to allowing classification of inter-tidal vegetation.

Christchurch and Poole: the area chosen here is representative of four flight lines, extending from Studland Point in the West to Hurst Spit in the East. Images were available for each campaign, and were of generally good quality, although with some glint present in the May 1994 data set and some cloud in the May 1993 data set. Neither was of a magnitude to preclude data interpretation. The data from September 1994 was, however, badly affected by cloud cover and little of interest could be gained from this data.

A number of oceanographic features are clearly shown by the imagery. The shingles bank in the Hurst narrows is visible in each of the CASI images of this area, illustrating the capability of CASI data to map bottom bathometry in shallow water. Similarly the sandbank at the entrance of Poole harbour is visible. The resultant sediment structures to the south of the mouth of Poole Harbour are seen to vary little throughout the image period, with sediment being constrained by the training bank to the south. Sediment flow varies to the north between images, with evidence of water flow onshore to the North East of the mouth in May 1994, where this area is clear in the other images. This would result in water from within the harbour being brought onshore, which may have implications for beach failures.

The sediment from Poole harbour flows generally South Eastward, and at certain times produces a front off Studland Point, which is marked both by a variation in reflectance and a clear temperature signal in the thermal video data. In Christchurch Bay an area of low reflectance is noted in all images close to the coast. The thermal data also picks up a clear frontal structure off Hengistbury Head in May 1994 with a cold eddy feature visible in September 1994. In this case the thermal data provides a clearer indication of the frontal position than is seen in the CASI data, and illustrates that the single baseline sampling point is not wholly representative, being situated sometimes within the eddy structure.

Small inputs are shown both by higher temperature signals, and raised reflectance which appear to be associated with outfalls in Bournemouth. These are not of a scale that would be detected by the current pattern of ship sampling, but are evident in the high resolution image data enabling focused ship measurements to be made if required.

The features noted in the imagery are not well represented in the ship data. Three baseline sampling stations are present in the area represented by the imagery, at The Needles, Hengistbury Head and Anvil Point. This corresponds to one baseline site in each image, obviously not enough to perform any calibrations of, for example, suspended particulate matter concentration. Qubit data from this area tends to be located some distance offshore, because of the shape of the coastline. This results in the features noted in both the temperature and colour imagery being missed by the Towfish sensors, as they are generally close to the coast, for example, the sediment structures around the mouth of Poole Bay. The image data therefore offers the optimum means of identifying the processes in this area of coastline requiring detailed near shore investigations.

Oxwich Bay: a number of visitors to Oxwich Bay on the South Wales coast have suffered temporary paralysis. It is a matter of interest therefore to determine if the cause of the paralysis was bathing in water of poor quality. The area is devoid of industry and it is therefore suggested that eutrophication may have been caused by entrapment of water high in ammonia which is present in an outfall around the Mumbles headland. The imagery from the CASI shows some flow of higher reflectance water around the Mumbles headland, with water of similar reflectance characteristics being shown in Oxwich Bay itself. Thermal video data records a front off the Mumbles with a fairly constant temperature signal in the bay itself. Qubit data are not available for Oxwich bay as the baseline bypasses this small bay which is located on an indented part of the coastline.

The data from the National baseline survey cannot alone provide an answer as to why bathers in this region have suffered paralysis. Observation of the imagery has, however, shown how remote sensing methods provide a clear spatial view. Further analysis of the remote sensed data set, in association with other data such as tidal state and weather conditions may well reveal the answer, together with detailed *in-situ* measurements of ammonia.

Blackpool: in May 1994 a large circular feature was noted in the CASI imagery of Blackpool, which appeared to correspond to an outfall, situated just off one of the main bathing beaches. The consent for this outfall was one of the major problems identified by NRA North Western region. Imagery from the other campaigns was therefore investigated to see if this was a one off feature. For example, this feature may have been associated with a period of heavy rainfall when a storm overflow outfall is put into operation resulting in the discharge of untreated sewage.

In May 1994 the large circular feature is situated between the Central and Southern Piers, with a second less intense feature just to the south of the South Pier. It was not possible to establish if this feature had a thermal signal as the thermal data of this region was of poor quality. In July 1994 the CASI data contains 80% land at the point of interest, and the position of the feature noted in May is not visible. In September 1994, no signal is seen in the CASI data, but a warm feature is noted on the thermal data corresponding to the feature to the South of the South Pier. In August 1993, a slight feature is seen corresponding to the lower of the two patches. It is thought probable therefore, that the lower of the two patches is caused by a more permanent outfall. This has less distinct reflectance characteristics which may be due to more treatment having been applied to the sewage. The large feature seen in May 1994 may well be caused by raw sewage from the storm outfall.

Again the ship data does not show any sign of this feature. There is no apparent increase in transmission or chlorophyll-*a* at this location during most campaigns. Unfortunately the data from May 1994 has a large gap covering all the Blackpool coastline. The Blackpool baseline site does not record any hot spots in any of the determinands measured. Therefore the imagery has allowed identification of an outfall feature that would not have been possible using traditional means.

5.4 Analysis of calibration run data

The image data recorded by the CASI is in spectral radiance units. It is important to convert these numbers accurately into geophysical parameter. Two main parameters are usually extracted from ocean colour data, which when used in association with thermal imagery provides a full understanding of the water quality: these are suspended particulate matter concentration and chlorophyll-*a* concentration.

The CASI may be set up with up to 16 channels at any wavelength between approximately 400 and 1000nm. The bandset selected by the NRA includes a number of bands located around the known position of chlorophyll-*a* fluorescence at approximately 685nm. This allows the Fluorescence Line Height technique to be applied, in which the disturbance in the reflectance spectrum caused by chlorophyll-*a* florescence is calculated. The height of this peak may be related directly to the concentration of chlorophyll-*a*. The calculation of SPM from aircraft imagery relies on the principle of light reflectance from particles.

Good *in-situ* measurements of these parameters are required in order to fine tune existing algorithms, which in the case of chlorophyll-*a* are either blue/green ratio algorithms or Fluorescence Line Height algorithms, and in the case of SPM are usually based on channel ratio algorithms. To this end a number of calibration exercises were carried out in 1994, during which the ship and aircraft took coincident measurements.

The calibration procedures used to date have attempted to address chlorophyll-*a* calibration issues. Suspended particulate matter (SPM) calibrations have not been addressed. The geolocation and vector analysis procedures used are however common to the two parameters such that calibration for SPM should not prove to be a difficult task.

The raw CASI image data is geolocated using the manufacturers' software. This technique requires some fine tuning post processing which necessitates the inclusion of land in the image. This is therefore a key requirement of any calibration exercise. The geolocated image is then processed in terms of chlorophyll-*a* concentration using the Fluorescence Line Height technique. These two files make up the image data. The latitudes and longitudes of the ship sampling points are converted to the image projection and the points stored as vectors which may be overlaid on the images. The point is then modified to a cross representing a circle of 100m diameter. The mean image FLH value within this circle is then related to the ship measured chlorophyll-*a* value.

The FLH should be linearly related to the chlorophyll-*a* concentration. Unfortunately the low chlorophyll concentrations noted in the calibration exercise have meant that a good correlation has not been possible to date.

In total eight calibration exercise were carried out in 1994, using a combination of all four vessels. The aircraft flew over the path of the ship, which collected water samples more regularly than the 15 km baseline sites, but without diverting from the baseline track. Unfortunately, none of these calibration exercises resulted in good quality data for a number of reasons. In two campaigns the laboratory samples were wasted by either being left on the quay, or outside the laboratory. In June a good range of chlorophyll-*a* was measured in the laboratory samples taken from Vigilance. However, geolocation of the imagery was not possible due to the absence of land in the image.

The June exercise over Sea Vigil showed a very low range in chlorophyll-*a*, between 1.7 and 2.59μg/l. A similar problem was noted in the case of Sea Vigil in September 1994. On other occasions not enough points were coincident to enable a regression to be carried out between the aircraft measured Fluorescence Line Height and the laboratory chlorophyll-*a*.

5.5 Conclusions

The image data collection strategy has shown no regional bias and has resulted in good coverage for all seven campaigns. Image data quality is high in terms of cloud and glint free images. The number of flightlines flown has decreased in the last campaigns and may continue to do so, as efforts are made to coincide the ship and aircraft. This is an important requirement for the accurate calibration of the imagery and for the integration of results from the chemical and image data.

The image data has been shown through analysis of the six sites of special interest to address many of the business needs of the NRA. The image data identifies the locations and extent of mixing zones and discharge footprints which will provide information for the positioning of sampling sites in post-consenting studies. Sediment concentrations and the movement of subsurface features, such as sandbanks, will provide detailed information for flood defence and civil engineering applications. The conservation responsibilities of the NRA will be aided by the ability of the CASI imagery to map vegetation in the intertidal zone. Finally, the measurements of chlorophyll-*a* concentration over wide spatial areas using CASI imagery will provide clear information in support of the Urban Waste Water Directive. In particular, knowledge of chlorophyll concentrations is required if coastal waters are to be graded into chlorophyll concentration bands and in assessing the number of square kilometres susceptible to eutrophication.

CASI and thermal imagery constitute complimentary techniques for the interpretation of oceanographic features from aircraft imagery. When combined with the detailed chemical analyses from the laboratory samples and underway instrumentation, they afford the NRA a highly effective tool for increasing the understanding of coastal processes and water quality in the NRA's 3 nautical mile limit of responsibility.

A number of problems with the chlorophyll calibration exercises have been identified, namely:

- a low range of chlorophyll-*a* concentrations being encountered;
- lack of the ship and aircraft coincidence;
- the absence of land from the imagery.

These problems have been noted by the National Centre and will be addressed in any future campaigns.

At present calibration exercises are performed without alteration from the baseline track. In future they should be carried out in transects perpendicular to the coast, as has been the case on the Netherlands for the last decade. This should ensure that a greater range of chlorophyll concentrations are encounters, ranging from very low values offshore to high values close to the coast. In addition, this will ensure that land is present within the image.

In addition opportune calibration exercises should be performed in response to the presence of phytoplankton blooms. These may be identified from the fluorescence data onboard the coastal survey vessel, by public complaint, or from satellite data once a suitable satellite (SeaWiFS, MERIS) is available. If no coastal survey vessel is available, then samples should be taken from a small boat. Care must be exercised in this instance to ensure samples are transferred immediately to the laboratory for filtering and analysis. Such opportunistic exercises will provide data from the higher ranges of chlorophyll-*a* expected in coastal waters.

Finally it is noted that use of the FLH technique for the variable coastal waters is somewhat complicated since the position of the fluorescence peak varies with chlorophyll and SPM concentrations as well as with the various stages of the growth cycle of the phytoplankton. Consequently, the peak position varies and it is recommended that the CASI bandsets used by the NRA are reviewed to ensure that the peak is always within the spectral bands used.

6 SURVEY DESIGN

6.1 Introduction

In this section the findings of the previous four sections are brought together with the objective of recommending the best approach to meeting the current and future business needs of the NRA.

Section 6.2 reviews the contribution made by the baseline coastal waters survey to meeting the business needs of the NRA (as detailed in section 2). Section 6.3 discusses possible rationalisation of the measurements made in support of EC directives. Section 6.4 discusses the sampling strategy most appropriate for chlorophyll, SPM, metals, nutrients and organic contaminants. Section 6.5 presents the recommendations for modification to the existing surveys.

6.2 Contribution of surveys to meeting NRA's business needs

The baseline coastal waters surveillance surveys have afforded the NRA an unique dataset, not otherwise available. The airborne sensors provide synoptic measurements from which the extent, locations and movement of any phenomena affecting water colour or temperature can be identified. Furthermore, through the choice of appropriate bandsets, CASI can also provide information on terrestrial vegetation cover including salt marshes and marine intertidal algae. The *in-situ* ship-based measurements provide detailed information concerning determinand concentrations and other physical oceanographic parameters, as well as providing a mechanism for calibration of the airborne chlorophyll concentration measurements. Through the latter, the wide area CASI data can be converted into quantitative chlorophyll concentrations, which in turn can be used to divide coastal waters into chlorophyll concentration bands. Each technique in itself provides valuable information for use in coastal water monitoring, however, this information is greatly augmented by a combination of the complementary techniques. For example, the airborne data can be used to set the context for *in-situ* measurements and to identify the optimum location at which *in-situ* measurements could be made.

The business needs of the NRA and the potential for the coastal baseline surveys to help fulfill these needs have been discussed in detail in section 2. In summary, the various business needs translate into a requirement for information concerning the following phenomena:

- mixing zones;
- thermal anomalies;
- movement of bodies of water;
- discharge and pollution footprints;
- sediment transport and surface SPM concentrations;
- chlorophyll concentrations;
- HNDAs;
- eutrophic areas;
- terrestrial and intertidal vegetation cover,

as well as the measurement of chemical determinands (nutrients, organics, metals) and physical oceanographic parameters. In addition, the flood defence and conservation related business needs require that information concerning river flooding be known. Tables 6.1, 6.2 and 6.3 summarise the potential contribution to be made by the baseline coastal water surveys to fulfilling the various NRA business needs through providing information concerning the various phenomena listed above.

Table 6.1: Possible use of airborne and in-situ data in satisfying the NRA's monitoring requirements

		EC Directives					UK National (Marine) Monitoring Plan	Surveillance monitoring
		Bathing WQ	Quality of shellfish	Dangerous substances	Titanium Dioxide	Urban Waste Water		
AIRBORNE	mixing zones	✔ (in support of WQ investigations)	✔ (harmful phenomena identification)	✔ (sampling location)	✔ (sampling location)		✔ (sampling location)	✔ (all aspects)
AIRBORNE	thermal anomalies	✔ (in support of WQ investigations)		✔ (sampling location) identification			✔ (sampling location)	✔ (all aspects)
AIRBORNE	movement of water bodies	✔ (in support of WQ investigations)	✔ (harmful phenomena identification)					✔ (all aspects)
AIRBORNE	discharge & pollution footprints	✔ (in support of WQ investigations)	✔ (harmful phenomena identification)	✔ (sampling location) identification	✔ (sampling location)		✔ (sampling location)	✔ (all aspects)
AIRBORNE	sediment transport & SPM concs.		✔ (harmful phenomena identification)	✔ (standstill provision)			✔ (sampling location)✔	✔ (all aspects)
AIRBORNE	chlorophyll concs. & eutrophic area	✔ (in support of WQ investigations)	✔ (harmful phenomena identification)			✔ (HNDA identification)		✔ (all aspects)
AIRBORNE	HNDAs					✔ (HNDA identification)		✔ (all aspects)
AIRBORNE	eutrophic areas	✔ (in support of WQ investigations)	✔ (harmful phenomena identification)			✔ (HNDA identification)		✔ (all aspects)
AIRBORNE	vegetation cover					✔ (intertidal green algae)		✔ (all aspects)
SHIP	in-situ data	✔ (may be of relevance)	✔ (data overlap) between baseline survey & directive measurements	✔ (data overlap)		✔ (chlorophyll calibration)	✔ (data overlap)	✔ (all aspects)

Table 6.2: Possible use of airborne and in-situ data in satisfying the NRA's regional operational requirements

		discharge impact assessment and pre-consenting studies	development impact assessment	detection of trends and general WQ characterisation	R & D	defensive studies	post pollution incidents	real time WQ management	model development & validation
AIRBORNE	mixing zones	✔	✔		highly dependent on R & D topic	case specific	✔		✔
	thermal anomalies	✔	✔		highly dependent on R & D topic	case specific	✔		✔
	movement of water bodies	✔			highly dependent on R & D topic	case specific	✔		✔
	discharge & pollution footprints	✔	✔		highly dependent on R & D topic	case specific	✔		✔
	sediment transport & SPM concs.		✔		highly dependent on R & D topic	case specific			✔
	chlorophyll concs. & eutrophic areas	✔	✔	✔	highly dependent on R & D topic	case specific		✔	✔
	HNDAs	✔	✔	✔	highly dependent on R & D topic	case specific			✔
	vegetation cover			✔	highly dependent on R & D topic	case specific			
SHIP	in-situ data	✔	✔	✔	highly dependent on R & D topic	case specific		✔	✔

Table 6.3: Possible use of airborne and in-situ data in satisfying other current and future NRA needs

		flood defence*	conservation**	EnvAge
AIRBORNE	mixing zones			✔ (surveillance)
	thermal anomalies			✔ (surveillance)
	movement of water bodies			✔ (surveillance)
	discharge and pollution footprints			✔ (surveillance)
	sediment transport & SPM concs.	✔ (monitoring model inputs)		✔ (surveillance)
	chlorophyll concs. & eutrophic area			✔
	HNDAs			✔ (surveillance)
	vegetation cover	✔ (monitoring natural defences)	✔ (monitoring natural defences)	✔ (surveillance)
SHIP	in-situ data	✔ (model inputs)		✔ (surveillance)

* in addition CASI is of use in assessing flood situations

**in addition CASI is of use in providing information on river flow, etc

As is summarised in the previous tables, the techniques used in the baseline coastal water surveys can greatly assist the NRA in meeting its business needs. However, this review has concluded that through a number of relatively minor modifications to the current survey format, a more rationalised, cost effective and quality assured system will be achieved, better able to meet the needs of the NRA. These modifications are detailed below.

6.3 Rationalisation of surveys and measurements

A large number of measurements are taken by the NRA in support of the various EC Directives (Bathing Water Quality, Quality of Shellfish Waters Directive, Dangerous Substances Directive, Titanium Dioxide Directive, Urban Waste Water Treatment Directive, National Monitoring Plan). These measurements are taken independently and this review has concluded that some rationalisation of sampling would be desirable for those determinands which are required to be measured quarterly or less.

Table 6.4 summarises the quarterly (or less frequently) measurements made in support of the various Directives.

Table 6.4: Summary of measurements made in support of EC Directives etc

Quality of shellfish	Dangerous substances	Titanium Dioxide	Urban Waste Water	UK National Monitoring Plan
Monthly: *Salinity, Dissolved Oxygen Saturation* **Quarterly:** *pH*, colouration (after filtration), *suspended solids*, petroleum hydrocarbons **Every 6 months:** Organohalogenated Substances (*DDT*, Lindane, Parathion and *Dieldrin*), Silver, *Arsenic, Cadmium, Chromium, Copper, Mercury, Nickel, Lead, Zinc*	At National Network sites all determinands from the list below should be monitored **quarterly**. At sites down-stream of known discharges only determinands specific to the discharges should be monitored. *Aldrin, Dieldrin, Endrin, Isodrin. Cadmium and its Compounds*, Carbon Tetrachloride, Chloroform, *DDT (all isomers), para-para DDT, Hexachlorobenzene, Hexachlorobutadiene, Hexachlorocyclohexane (all isomers). Mercury and its Compounds*, Pentachlorophenol and its Compounds 1, 2 Dichloroethane, Trichloroethylene, Perchloroethylene, Trichlorobenzene From the list below only determinands specific to the relevant discharge(s) should be monitored **monthly**: *Lead, Chromium, Zinc, Copper, Nickel, Arsenic*, Iron, *pH*, Boron, Vanadium, Tributyltin, Triphenyltin, Mothproofing Agents (PCSDs, Cyfluthrin, Sulcofuron and Permethrin)	**Quarterly:** Water: Iron (total dissolved, hydrated oxides and hydroxides) **Annually**: Sediment: Titanium, Iron (total hydrated oxides and hydroxides). Living organisms: Titanium, Chromium, Iron, Nickel, Zinc, Lead. Diversity and relative abundance of benthic fauna: presence of morbid anatomical lesions in fish	Winter nutrients: *including TON, NH^3, NO^3*. Data of use in assessment of eutrophication. Percentage cover of algal growth (for areas > 10 hectares), *chlorophyll-a concentration*, cell counts, *summer nutrients*. These measurements should be taken **weekly** between May and September, Winter nutrients: **three** times between December and February.	Unfiltered Water: *γ and α-Hexachlorocyclohexane*, **β-Hexachlorocyclohexane*. **Dieldrin*, **Aldrin*, **Endrin*, **Isodrin*, *Hexachlorobenzene*, **Hexachlorobutadiene*, Pentachlorophenol, *DDT (op DDT), *Priority Hazardous Substances (Carbon Tetrachloride, Chloroform, Trifluralin, Endosulfan, Simazine, Atrazine, Azinphos-ethyl, Azinphos-methyl, Dichlorvos, Fenitrothion, Fenthion, Malathion, Parathion, Parathion-methyl, Trichloroethylene, Tetrachloroethylene, Trichlorobenzene, 1,2-Dichloroethane, Trichloroethane) *Dissolved Oxygen*, *Suspended Solids, Chlorophyll a*, Secchi-depth, *Salinity, Temperature*, Oyster Embryo Bioassay Filtered Water Sample: *Mercury, Cadmium, Copper, Lead, Nickel, Zinc, Chromium, Ammoniacal Nitrogen, Nitrate as N, Nitrite as N, Orthophosphate as P, Silicate as Si* Total Surficial Sediment: Aluminium, *Mercury, Cadmium, Copper, Lead, Nickel, Zinc, Arsenic, Chromium*, Tributyl Tin, Polychlorinated Biphenyls, **Dieldrin*, **Aldrin*, **Endrin*, *Hexachlorobenzene, DDT (pp TDE, pp DDE, pp DDT)*, Oyster Embryo Bioassay These measurements should be taken **quarterly** for water quality at estuarine sites; **annually** at intermediate sites annually for sediment samples; twice per year (Winter and Summer) for oyster embryo bioassay at estuarine sites, once per year at intermediate sites; to be decided for sediment, biological tissue analysis and benthos after analysis of the spatial survey

Measurements in support of the Bathing Water Quality Directive have not been included since these measurements are shore-based and thus cannot be incorporated into the baseline surveys. Measurements made as part of the quarterly baseline surveys are shown in italics in Table 6.4. Comparison of these determinands and those required to be measured in support of EC Directives reveals that there is scope for rationalisation. In particular:

- ❑ the baseline survey and the UK National Monitoring Plan should be combined in the case of estuarine sampling, such that those determinands common to both activities are measured during the baseline surveys;

- some of the measurements required by the Quality of Shellfish Directive may be undertaken at the same time as the baseline surveys, depending on site accessibility;

- measurements of chlorophyll and nutrient concentration made during the baseline surveys can be used in support of the Urban Waste Water Directive.

6.4 Survey strategy

Chlorophyll

It is recommended that the current strategy of measuring chlorophyll concentrations during surveys in Spring, Summer, Autumn and Winter continue. The optimum spatial sampling frequency for chlorophyll-*a* is dependent on season and shows no similarity between 1993 and 1994. It is therefore difficult to recommend an improved spatial sampling interval and the continued sampling at 15km intervals is recommended.

Results of the data analysis have indicated that hot spot concentrations of 30μg/l have been recorded. The occurrence of such high values, which may well not represent the peak concentration, suggest that in such hot spots (eg North coast of Wales) fixed moorings with *in-situ* sensors for measuring chlorophyll should be used.

SPM

The sampling frequency for SPM should remain at 15km at present. However, it is recommended that SPM calibration runs are performed during which measurements are required more frequently. These may be used for the calibration of the CASI imagery using ratio algorithms to estimate surface suspended sediment concentration.

Metals

Only a very few dissolved metals, such as manganese, show a clear seasonal cycle in coastal waters. The detailed distribution of others depend upon their marine geochemistry and the relative strengths of inputs (rivers, benthic and atmospheric sources), exchange with boundary water masses, and removal processes (especially association with particles).

Concentrations of metals measured in recent research work in the North Sea and in the Channel, are significantly below the EQSs and in most cases detection limits applied by NRA labs, except for identified "hot spots" as in industrialized estuaries. The majority of data produced by the NRA labs and commented upon in this report are therefore consistent with these research findings. Comparison of EQS values and typical ranges of metal concentrations found in coastal waters in these research investigations [9] [10] [11] are given in Table 6.5.

Table 6.5 Typical concentrations of some dissolved trace metals in coastal waters of England, compared to Environmental Quality Standards

	As	Cd	Cu	Hg	Ni	Pb	Zn
Research work data	19 nM 1.4µg/l	0.2 nM ≈0.022 µg/l	6 nM ≈0.38 0 µg/l	2.7pM 0.54 ng/l	7 nM ≈0.410 µg/l	0.2 nM ≈0.04 0 µg/l	12 nM ≈0.78 0 µg/l
EQS	25µg/l	2.5µg/l	5 µg/l	0.3µg/l	30µg/l	25µg/l	40µg/l

The major impact of trace metals on biota are expected to be where there are high concentrations of these elements eg close to discharges, or in industrialized estuaries. There is therefore a strong argument to modify current sampling strategies for metals to focus more on these input zones, and to reduce considerably sampling in more pristine locations where the existing data from the NRA surveys and recent research studies have indicated natural processes dominate with concomitant low metal concentrations.

It is suggested that this might be accomplished by:

i) continuing to perform seasonal surveying with increased spatial frequency in hot spots and appropriate estuaries. It is recommended that a sampling strategy be considered for estuarine locations based on that used in the National Marine Plan, in which sampling locations are representative of the 0-10ppt, 10-20 amd 20-30ppt salinity ranges;

ii) reducing the sampling in other coastal areas such that surveys are conducted once per 5 years with the spatial sampling being reduced to every other or third baseline site;

iii) once it has been established that there is a downward trend in metal concentration in a particular hot spot or estuary, the reduced sampling procedure (ie ii) above) can be implemented.

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[9] MICHEL P, AVERTY B, NOEL J AND SANJUAN J, "Evaluation of dissolved and particulate arsenic flux in the Dover Strait" (Fluxmanche programme) 16, 1993

[10] STATHAM P, et al, "Fluxes of Cd, Co, Cu, Fe, Mn, Ni, Pb and Zn throught he Strait of Dover into the Southern North Sea", Oceanologica Acta 16, 1993

[11] COSSA D, SANJUAN J AND NOEL J, "Mercury transport in waters of the Strait of Dover", Marine Pollution Bulletin 26, 1994

Nutrients

In contrast to metals, dissolved inorganic nutrients have a clearly defined seasonal cycle[12]. This cycle is driven by the uptake of nutrients by phytoplankton during the spring (and to a lesser extent autumn) blooms giving low dissolved nutrients, with subsequent recycling in the water column and release of these nutrients during the winter period, leading to increasing dissolved inorganic nutrient concentrations until the next spring bloom. This background situation has superimposed upon it other inputs such as major rivers, and in some cases benthic releases, which may influence phytoplankton production in the near-shore zone. The seasonal change means that the chlorophyll in the water column will also follow a seasonal cycle. Suspended particulate material can also have a seasonal signature because of greater re-suspension during the winter and autumn, which is due to generally greater wind strengths and hence bottom stress during these periods

This natural seasonality means that to follow effectively the impact of man made inputs of nutrients (rivers, discharge from sewage plants etc) seasonal monitoring is mandatory, as is currently undertaken by the NRA coastal vessels. Additionally there has been data produced on annual inputs of nutrients to coastal waters, indicating in some areas an increasing trend. To follow effectively the impact of any such inputs on the quality of near-shore waters is within the remit of the NRA, and it is thus essential for seasonal monitoring to be maintained. Sampling on longer time scales would allow no opportunity for any such increases to be monitored and identified over background trends, and for the implementation of national strategies to deal with any such problems.

In addition, it is recommended that:

- ❑ the possibility of measuring the nutrient ratio nitrate:phosphate:silicate be considered as it is important in determining the composition of bloom forming algae;
- ❑ other nutrients such as urea and dissolved organic nitrogen should also be measured once operational measurement systems are available.

Organic contaminants

It has been difficult to draw any conclusions concerning the optimum sampling strategy for organics because of the limited number of measurements that are above the limit of detection. In order to make meaningful measurements, the detection limits need reducing. If possible the limits of detection should be improved and then the current practice of making measurements in Spring, Summer, Autumn and Winter (boat only) should be continued for at least a year, or until it is possible to establish a baseline for the organic contaminants. If no seasonal variability is seen to exist and after appropriate baseline values have been determined, the monitoring could then be reduced to once per year and in due course follow the pattern recommended for metals.

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[12] BENTLEY D, et al, "Flux de nutriments entre la Manche et al Mer du Nord. Situation actuelle et evolution depuis dix ans", Oceanologica Acta 16, 1993

If any hot spots are detected then it is recommended that these should continue to be monitored on a seasonal basis.

Finally it must be emphasised that the measurement of organics should be reviewed annually as more information becomes available on the acceptable levels of these compounds. It is recommended that the Marine Pollution Monitoring Management Group be consulted over this matter.

6.5 General recommendations

In the light of the findings of the review of the data collection and processing chain and the various analyses performed on the data, the following modifications to the current survey formats are recommended. A summary of the recommendations relating to the various determinands measured is given in Table 6.6.

Rec 1 Staff briefings/ manual

Rec 1.1 It is recommended that the NRA laboratory scientists are provided with an overview of how the samples are taken and how the results of their work are used.

Rec 1.2 It is also recommended that the NRA vessel scientists are collectively briefed on the various methods they should be using for data collection, instrument calibration etc, with the objective of ensuring standardisation of measurements and procedures between the various boats.

Rec 1.3 A comprehensive manual should be produced which details sampling and laboratory procedures (and associated Quality Control) to be applied to all aspects of data collection, analysis and reporting.

Rec 2 Limits of detection

Rec 2.1 It is recommended that all data above the limit of detection be recorded.

Rec 2.2 All laboratories should operate to the same lowest achievable limit of detection.

Rec 3 Sample storage

Rec 3.1 Concern exists over the storage and transport of some samples and it is recommended that these procedures be reviewed and clarified.

Rec 4 Ancillary data requirements

Rec 4.1 It is recommended that ancillary data be recorded at the time of the baseline surveys, including meteorological data (also required during the month prior to the survey) and tidal data.

Rec 5 General sampling procedures

Rec 5.1 Triplication of spot samples should be undertaken so as to improve confidence in the data.

Rec 5.2 The measurement of total metals should be abandoned and replaced by triplication of dissolved samples.

Rec 5.3 Steps should be taken so as to ensure that no metallic or potentially contaminating components are in contact with, or near the water sample used for metal analyses.

Rec 5.4 The water sample size taken for use in suspended sediment analysis should be selected according to the transmissometer reading. It is suggested that the following working estimate be used as an interim measure and modified in the light of further campaigns:

- for areas greater than ~80% transmission, a 5 litre sample should be used;
- for areas with greater than ~ 90% transmission, a 10 litre sample should be used;
- otherwise a 1 litre sample should be used.

Rec 5.5 Filtration of the SPM sample should take place on the boat and the sample should be well shaken. Prewashed, oven dried, preweighed filter papers should be used and place in labelled Petri dishes. Samples should be fixed with magnesium carbonate.

Rec 5.6 Should there be a future requirement for nutrients to be sampled at both surface and deeper water, the use of a lever action, or equivalent messenger activated Niskin bottle, is recommended. This bottle is also suitable for sampling a range of determinands , including metals, nutrients and some organics.

Rec 5.7 The profiler probes should be monitored continuously rather than at set depths and the data subsequently screened to remove any unwanted data.

Rec 5.8 The possibility of using towed undulating systems to give underway profiling should be considered.

Rec 5.9 It is recommended that total, organic and inorganic values of SPM be recorded.

Rec 6 Instrumentation

Rec 6.1 The Towfish fluorometer should be calibrated during the surveys rather than relying solely on the makers' calibration. It is recommended that this calibration be performed at the beginning and end of each daily survey. At each time, the Towfish should be brought in when coming on to the sampling station so as to allow a near surface measurement to be made whilst simultaneously taking a water sample for chlorophyll analysis at the laboratory. If an improvement in the correlation between the fluorometer and laboratory measured chlorophyll-*a* is achieved, a decrease in the use of water samples would be appropriate.

Rec 6.2 If it is not already the case, it is recommended that the Skalar autoanalyser be automatically calibrated so as to ensure any drifts in the response of the instrument are identified.

Rec 6.3 The CASI instrument provides high quality ocean and land colour data. It is recommended that the CASI bandsets are reviewed to ensure that the optimum bands are being used for monitoring chlorophyll, SPM and vegetation.

Rec 6.4 The thermal video system currently in use has demonstrated the benefits to the NRA of flying a thermal sensor. However, to enable further scientific use of the thermal data requires that the system measures absolute temperature. Firstly using the present system, a procedure could be adopted which requires the alteration in offset and gain to be recorded. This could then be used in conjunction with coincident ship truth data to calibrate the image. Alternatively, the thermal video currently used could be replaced with a calibrated thermal scanning system. To improve data handling, it is recommended that the thermal video data be spatially integrated with the CASI data and displayed simultaneously with the corresponding CASI image.

Rec 7 Calibration runs

Rec 7.1 It is recommended that measures are taken to improve the calibration of CASI imagery using the Fluorescence Line Height technique. In particular, calibration runs should take place perpendicular to the coastline as this will ensure a larger range of chlorophyll concentration is encountered and will guarantee the presence of land in the imagery.

Rec 7.2 Ideally, the NRA vessels should be organised so as to ensure some overlap in coverage (and thus sampling) occurs between 'neighbouring' vessels during each of the baseline surveys. However, it is recognised that in practice this may be difficult to achieve. To overcome this, it is recommended that a boat inter-calibration exercise be performed each year so as to maximise the quality assurance of the measurements made by the two vessels.

Rec 8 Data storage systems

Rec 8.1 All nutrient data, previously stored separately, should be stored in Qubit files. The data collected should be automatically referenced to Easting/Northing and time whilst on the boat.

Table 6.6: Summary of survey modifications

	Proposed sampling strategy	
	Method modifications	**Survey format recommendations**
Chlorophyll	- undertake on-board calibration of fluorometer - triplicate samples - review CASI bandset	- continue Spring, Summer, Autumn and Winter surveys - present spatial sampling strategy satisfactory - improve CASI calibration runs
SPM	- on-board filtration - triplicate samples - select water samples based on transmission - shake samples	- present strategy adequate - improve CASI calibrations
Metals	- triplicate samples - total metal concentration measurement unnecessary	- continue seasonal surveying with increased spatial frequency in hot spots and appropriate estuaries. - possible reduction in surveying once downward trends and baseline established - reduce sampling otherwise to once per 5 years, at every 2nd or 3rd baseline site
Nutrients	- review storage and transport strategy - triplicate samples	- continue present strategy
Organics	- triplicate samples	- continue present strategy with decreased detection limit, then a) once baseline established, if no seasonal variability, reduce surveys to once per year b) if any hotspots detected, continue to monitor on seasonal basis
Comments	- perform boat inter-calibration exercises	

7 CONCLUSIONS AND WAY AHEAD

7.1 Conclusions

During this study it has become apparent that the NRA has developed a considerable expertise in performing baseline coastal waters surveillance surveys, which places them among the leaders in Europe in conducting such operational monitoring campaigns.

The baseline surveys performed to date have allowed the NRA to modify and develop its procedures for data collection and analysis such that the current system constitutes a well-rounded approach to operational monitoring and demonstrates the feasibility of conducting such surveys. Review of the baseline survey dataset has enabled the survey procedures now in place to be critically assessed. The conclusion of this review is that the expertise developed in performing the baseline coastal waters surveys to date should be built on so as to provide a smooth running and efficient coastal monitoring service for EnvAge.

The combined use of remote sensing (CASI, thermal imager) and conventional in-situ data gathering techniques constitute the optimum practicable approach to operational data collection in support of the NRA's business needs. The ship-based measurements provide detailed information concerning determinand concentrations in specific locations whereas airborne instruments provide synoptic measurements from which the extent and location of spatial features, eg HNDAs, chlorophyll-rich patches, mixing zones, thermal anomalies, discharge footprints and sediment transport can be identified. The complementary capabilities of the two techniques can be exploited so as to ensure maximum use of NRA resources and funds. For example, the airborne data can be used to identify the most appropriate location (eg inside a plume) for *in-situ* sampling. Furthermore, the *in-situ* chlorophyll measurements can be used to calibrate the airborne measurements, thus enabling conversion of the qualitative CASI information into quantitative chlorophyll concentrations, which in turn can be used to grade coastal waters into chlorophyll concentration bands. Such a grading scheme has obvious application in classifying waters according to their susceptibility to eutrophication. Use of airborne sensors constitutes the most practical and cost-effective method for <u>wide area</u> data collection required in generating such a grading scheme.

The baseline coastal waters surveillance survey constitutes an effective means of meeting many of the business needs of the NRA in the areas of statutory and surveillance monitoring, regional operational activities, flood defence and conservation, as discussed in section 2. In particular, given a number of modifications to its sampling site coverage, the baseline survey would provide a rationalised approach to data collection in support of the UK National Monitoring Plan, the Dangerous Substance Directive, the Urban Waste Water Treatment Directive and the Quality of Shellfish Waters Directive.

In addition to providing a means for *monitoring* the quality of coastal waters, the baseline surveys yield a dataset of great importance in environmental *surveillance*, an activity which will be given increased emphasis in EnvAge. This dataset is of interest not only to the NRA but also to commercial organisations and the R&D community. Regular aerial and ship-based surveys provide a mechanism for establishing seasonal and yearly trends and variations, as well as longer term effects resulting from climate change. Furthermore, the expertise that has been accrued by the NRA in analysis of the airborne data, will prepare the way for operational use of data from a new generation of satellite based coastal zone imaging instruments (eg SeaWiFs, MERIS, OCTS), which are similar in concept to the CASI instrument and are well suited to environmental surveillance.

In reviewing the data collected during the past eight baseline surveys, it has become apparent that there are very many missing data, which necessarily reduce the scientific value of the dataset. This lack of data has arisen because of problems in performing the measurements and storage and transit of the samples, although principally because of variations in the limits of detection of the laboratories performing the analyses. A number of recommendations have been made in section 6.3 as to how these problems could be reduced or overcome. In particular, it is considered extremely important that all laboratories should operate to the same level of detection, which should be the lowest possible level achievable. This will ensure that many data previously lost will be recorded. Finally, attention is drawn to the clear distinction between the terms *detection* limit and *reporting* limit. The detection limit is governed by the capability of the analysis procedures and the associated instrumentation, the reporting limit is a level chosen such that any values above this limit are noted and reported. Review of the data suggests that some confusion has arisen over these two terms.

A large amount of data has been collected during the past baseline surveys (for example, 30 gigabytes of remote sensed data is collected per survey). It is considered essential that data storage, manipulation and distribution mechanisms are put in place so as to ensure a data processing capability able to cope with the ever increasing data volumes and associated demand.

7.2 Way ahead

It is recommended that the modifications to the current format of the baseline surveys, detailed in Section 6, be implemented and that another review to be conducted in approximately 2 years in order to assess the effectiveness of the revised format. It is suggested that the National Marine Analyst Quality Control Scheme should be given specific responsibility to oversee and audit quality control aspects of the determinand analyses and of the sampling strategy in future surveys. Implementation of the various recommended modifications should yield a dataset with a considerable reduction in missing values. Given a more complete dataset, more sophisticated multi-variate statistical analyses could be performed on the data, eg principal component analysis, multiple dimensional scaling, cluster analysis, thereby facilitating data reduction for further analysis.

In addition to these modifications to the survey format, it is proposed that the following suggestions be considered:

- it would be desirable for the airborne system's hire period to be extended at the time of each of the baseline surveys in order to allow flights to be made in response to regional requests;
- there is a need to assess the extent to which the CASI/thermal system can identify effluent plumes using the existing archive of data;
- on occasions the crews of the NRA vessels are having to work extremely long hours in order to complete their data collection activities, which has obvious implications for data quality. It is recommended that the number of scientific crew be increased (eg 4 per vessel), as this would allow a reduction in the working hours of the individual crew members, whilst still performing the same workload;
- in order to increase the usefulness of the baseline survey data to the Regions, it is recommended that the National Centre for Instrumentation and Marine Surveillance consider providing a standard set of regional value-added products (eg regional maps showing chlorophyll concentrations, surface SPM concentrations, discharge footprint etc) on a routine basis (eg after every survey);
- in order to obtain maximum usage of and benefit from the data collected during the baseline surveys, the employment of a dedicated image analyst/oceanographer should be considered.

A SPOT SAMPLING DETERMINANDS MEASURED

A.1 Determinands measured at every baseline site

Determinand	Properties	Units	Limit of detection
Group 1 - measured at every baseline site			
Mercury	Dissolved	ug/l	0.03
Mercury	Total	ug/l	0.03
Cadmium	Dissolved	ug/l	0.25
Suspended Solids 105 C	-	mg/l	5
Solids Non-Volatile 500 C (Ash)	-	mg/l	5
Orthophosphate	Filtered	ug/l P	5.0
Chlorophyll A	Total	ug/l	0.2
Ammonia	Filtered	ug/l N	6.0
Nitrite	Filtered	ug/l N	2.0
Silicate	Saline Filtered	mg/l Si	0.025
Copper	Dissolved Saline ppb	ug/l	0.5
Lead	Dissolved Saline	ug/l	2.5
Zinc	Dissolved Saline ppb	ug/l	4.0
Arsenic	Dissolved ppb	ug/l	2.5
Chromium	Dissolved Saline ppb	ug/l	1.5
Nickel	Dissolved Saline ppb	ug/l	3.0
Total Oxidised Nitrogen	Saline Filtered	mg/l N	0.010

A.2 Determinands measured at every third baseline site

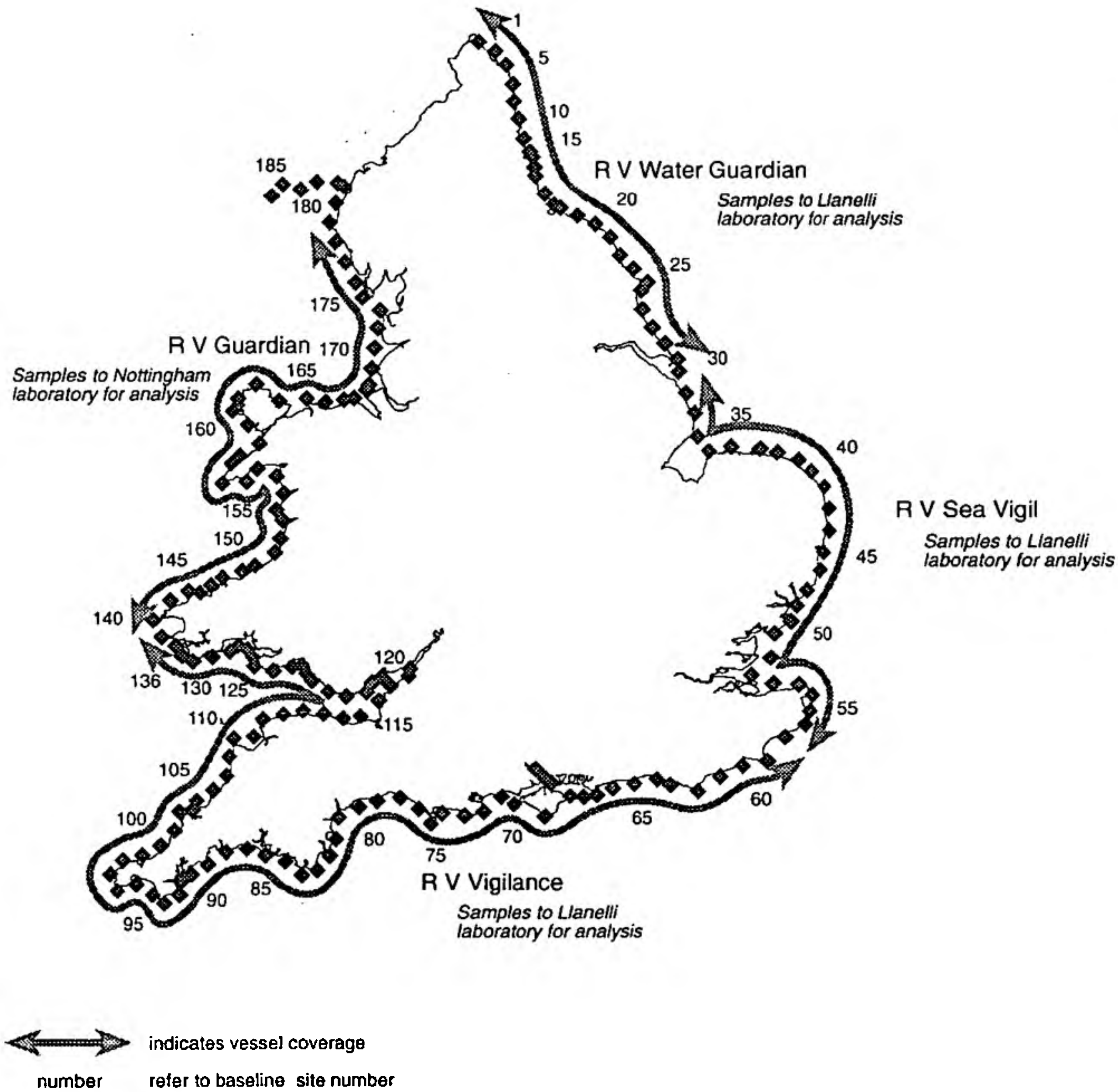
Determinand	Properties	Units	Limit of detection
Group 2 - measured at every third baseline site			
Cadmium	Total	ug/l	0.25
Copper	Total Saline ppb	ug/l	0.5
Lead	Total Saline	ug/l	2.5
Zinc	Total Saline ppb	ug/l	5.0
Arsenic	Total ppb	ug/l	2.5
Chromium	Total Saline ppb	ug/l	2.0
Nickel	Total Saline ppb	ug/l	3.0

A.3 Determinands measured at occasional sites of interest

Determinand	Properties	Units	Limit of detection
Group 3 - measured at occasional sites of interest			
Isodrin	Total	ng/l	2.5
Hexachloro-Benzene	Total	ng/l	1.0
Hexachloro-Butadiene	Total	ng/l	1.0
PCB 28		ng/l	1.0
PCB 52		ng/l	1.0
PCB 101		ng/l	1.0
PCB 118		ng/l	1.0
PCB 138		ng/l	1.0
PCB 153		ng/l	1.0
PCB 180		ng/l	1.0
Aldrin		ng/l	2.5
DDE-PP'		ng/l	1.0
DDE-OP'		ng/l	2.0
DDT-OP'		ng/l	1.0
DDT-PP'		ng/l	1.0
Dieldrin		ng/l	2.5
Endrin		ng/l	2.5
HCH-Alpha		ng/l	1.0
HCH-Beta		ng/l	1.0
HCH-Delta		ng/l	1.0
HCH-Gamma		ng/l	1.0
TDE-OP'		ng/l	2.0
TDE-PP'		ng/l	1.0

B NATIONAL BASELINE SITE LOCATION

B.1 BASELINE SITE LOCATIONS AND NRA VESSELS COVERAGE



B.2 Baseline site information

Site number	location	easting, northing
1	"BERWICK"	401443,652107
2	"CASTLEHEAD ROCKS"	413450,644616
3	"SHORESTON OUTCARS"	421779,633985
4	"CRASTER"	426513,620379
5	"WARKWORTH"	427260,606770
6	"BRIG HEAD"	430730,594089
7	"BLYTH"	434352,579260
8	"TYNE (NORTH)"	438454,569686
9	"TYNE (MIDDLE)"	438895,569078
10	"TYNE (SOUTH)"	439317,568451
11	"MARSDEN"	440937,566073
12	"WEAR (NORTH)"	442341,559707
13	"WEAR (MIDDLE)"	442402,558854
14	"WEAR (SOUTH)"	442433,557927
15	"PINCUSHION ROCK"	443338,551556
16	"BLACKHALL"	449679,538324
17	"TEES (NORTH)"	455462,530528
18	"TEES (MIDDLE)"	456231,529147
19	"TEES (SOUTH)"	459667,527892
20	"SKINNINGROVE"	472910,521798
21	"SANDSEND"	486288,515059
22	"ROBIN HOODS BAY"	497341,505265
23	"SCARBOROUGH OUTFALL"	504454,492103
24	"FILEY BRIGG"	514516,481769
25	"FLAMBOROUGH (NORTH)"	524552,472901
26	"BRIDLINGTION"	520418,466428
27	"HORNSEA"	520801,451653
28	"BEACON HILL"	528006,438358
29	"WITHERNSEA"	536920,426310
30	"SPURN HEAD"	546422,414537
31	"HAILE SAND FLAT"	547030,405650
32	"THEDDLETHORPE"	552061,390130
33	"CHAPEL ST LEONARDS"	558791,374579
34	"OUTER DOGS HEAD"	560595,357290
35	"WASH"	568866,346069
36	"OVERY, STAHE"	585400,349600
37	"CLEY, LOOKOUT"	605700,347800
38	"SHERINGHAM"	617400,345300
39	"MUNDESLEY"	632100,339700
40	"LESSINGHAM"	642300,331000
41	"WINTERTON"	652700,319400
42	"GORLESTON"	656000,303600
43	"KESSINGLAND"	656200,287300

44	"DUNWICH CLIFFS"	651400,271400
45	"THORPENESS"	649000,257600
46	"SHINGLE STREET"	638759,242982
47	"FELIXSTOWE"	630400,231200
48	"WALTON"	627500,220000
49	"JAYWICK"	616000,210600
50	"MAPLIN BANK"	613300,192600
51	"MEDWAY BUOY"	600023,179518
52	"SHIVERING SAND BUOY"	614810,173220
53	"EAST MARGATE"	632640,172140
54	"EAST BRAKE"	642560,164290
55	"GOODWIN FORK BUOY"	640780,152520
56	"SOUTH FORELAND"	637420,142840
57	"SANDGATE BAY"	623350,133160
58	"DUNGENESS"	610960,115460
59	"RYE BAY"	593690,111730
60	"BEXHILL"	576710,103760
61	"BEACHY HEAD"	560440,92640
62	"NEWHAVEN"	541170,97470
63	"BRIGHTON"	531560,101530
64	"WORTHING"	514840,98340
65	"MIDDLETON-ON-SEA"	499850,95140
66	"SELSEY BILL"	486600,89740
67	"NAB TOWER"	477220,89080
68.1	"EAST BRAMBLES"	454500,99090
68.2	"CALSHOT"	449950,102320
68.3	"DOCKHEAD"	442954,109622
68.4	"WEST PRINCESSA"	467490,89410
69	"ST CATHERINES"	449780,74450
70	"THE NEEDLES"	427320,83450
71	"HENGISTBURY HEAD"	417670,88880
72	"ANVIL POINT"	404752,77529
73.	"ST ALDHELMS"	391444,74806
74	"WEYMOUTH BAY"	374897,77068
75	"PORTLAND BILL"	366887,68905
76	"CHESIL"	357708,80056
77	"BRIDPORT"	344060,88033
78	"SEATON"	327371,85782
79	"SIDMOUTH"	314357,81023
80	"EXMOUTH"	298768,73910
81	"TORBAY"	296654,57937
82	"DARTMOUTH"	292251,45010
83	"START POINT"	282855,34413
84	"SALCOMBE"	271484,31174
85	"BIGBURY BAY"	260244,41176
86	"PLYMOUTH"	246016,46192
87	"EAST LOOE"	232461,50530

88	"FOWEY"	216744,48055
89	"DODMAN POINT"	203301,38283
90	"ST ANTONY HEAD"	191045,31497
91	"FALMOUTH"	183960,26360
92	"BLACK HEAD"	183110,15940
93	"LIZARD"	171990,9880
94	"MULLION"	163430,15910
95	"PENZANCE"	151330,23980
96	"RUNNEL STONE"	137160,18980
97	"CAPE CORNWALL"	132110,31440
98	"THE CARRACKS"	141640,42920
99	"GODREVY ISLAND"	156000,45800
100	"ST AGNES"	168780,52800
101	"NEWQUAY"	179500,63850
102	"TREVOSE"	182760,77920
103	"PADSTOW"	191671,79737
104	"PORT ISAAC"	194930,86330
105	"BOSCASTLE"	207848,93942
106	"BUDE"	217387,104811
107	"MOREWENSTOWE"	218976,118706
108	"HARTLAND POINT"	222623,132318
109	"BIDEFORD"	237456,133833
110	"BULL POINT"	244082,147356
111	"COMBE MARTIN"	258542,150774
112	"FORELAND"	272883,153182
113	"PORLOCK"	287856,150676
114	"MINEHEAD"	302829,147589
115	"BRIDGWATER BAR"	315221,149213
116	"WESTON-SUPER-MARE"	328422,160435
117	"CLEVEDON"	337342,171688
118	"AVONMOUTH"	350046,178825
119	"NO. 1 BEACON"	351230,184940
120	"NEWPORT DEEP"	330560,178100
121	"CARDIFF ROAD"	323990,174200
122	"LAVERNOCK"	319740,166990
123	"ABERTHAW"	304980,163990
124	"NASH POINT"	291470,167040
125	"PORTHCAWL"	279540,175580
126	"KENFIG"	275210,180890
127	"PORT TALBOT"	271670,187250
128	"MUMBLES"	264920,185970
129	"OXWICH"	251470,183060
130	"WORMS HEDH"	237680,186370
131	"LLANELLI"	236580,193880
132	"BURRY PORT"	232570,199170
133	"CARMARTHEN"	225390,201800
134	"CALDEY ISLAND"	219540,197440

135.1	"OLD CASTLE HEAD (INNER)"	206575,187970
135.2	"OLD CASTLE HEAD (OFF)"	207020,193620
136.1	"ST GOVANS (INNER)"	192260,184790
136.2	"ST GOVANS (OFF)"	192490,190400
137	"TURBOT BANK"	184870,194230
138	"ST ANNS"	180565,201679
139	"SKOMER"	170162,208214
140	"SOUTH BISHOP"	164072,220936
141	"ABEREIDDY"	176570,235494
142	"STRUMBLE HEAD"	189368,242641
143	"FISHGUARD"	197672,241368
144	"PWLL-COCH"	205900,246887
145	"CARDIGAN ISLAND"	214591,252771
146	"PENY-BADELL"	229134,257723
147	"NEW QUAY HEAD"	238369,261216
148	"PEN PIGYN"	252332,270982
149	"ABERYSTWYTH"	256604,281058
150	"ABERDOVEY"	258140,294925
151	"PEN-BWCH POINT"	253277,302489
152	"BARMOUTH"	259294,315297
153	"SHELL ISLAND"	253581,327524
154	"PWLLHELI"	240180,333514
155	"PORTH CEIRIAD"	232708,323561
156	"BARDSEY"	214489,322368
157	"PORTH YSGADEN"	220695,337909
158	"DINLLAEN"	227616,343224
159	"DYLAN"	241352,352029
160	"ABERFFRAW"	232901,366233
161	"PENRHOS"	222588,376813
162	"HOLYHEAD"	225804,385602
163	"MIDDLE MOUSE"	239518,396995
164	"RED WHARF"	255740,384043
165	"ORME"	275785,386259
166	"LLANDDULAS"	289027,383149
167	"CHESTER FLAT"	302955,385626
168	"WELSH CHANNEL"	311290,386391
169	"HE 1 BUOY"	319146,391814
170	"NORTH WIRRAL"	321644,395462
171	"FORMBY POINT"	323261,408435
172	"GUT"	325516,423234
173	"BLACKPOOL"	327725,438035
174	"KING SCAR"	329673,450801
175	"HILPSFORD"	317047,460468
176	"DUDDON"	311551,471698
177	"SELKER"	304434,486678
178	"CALDER HALL"	297170,501675
179	"WHITEHAVEN"	292652,516620

180	"WORKINGTION"	297151,531356
181	"SOLWAY BUOY"	303426,543740
182	"MIDDLE BUOY"	298653,546533
183	"BALCARRY"	283026,546912
184	"ABBEY HEAD"	271290,541294
185	"MEGGERLAND"	258289,545024
186	"ST NINIANS"	250301,536374

C COMPARISON OF SHIP AND LABORATORY DATA

C.1 Introduction

In this appendix the statistical techniques used to compare the measurements taken using different techniques are discussed together with the corresponding results.

C.2 Analysis performed

Data taken using different techniques at the same position were analysed to determine any correlations between the data; this involved extracting the Qubit (transmission and chlorophyll) and Skalar data (phosphate, ammonia, nitrite, silicate and TON) around the baseline points and regressing these against the corresponding shore laboratory results. Table C.1 summarises the regressions performed and identifies the sections in this appendix in which the analysis results are discussed. These results take the form of a regression plot and a summary of the regression statistics (r^2, slope and intercept) for each of the analyses performed. A regression line passing through the origin and having a unit slope plot is obtained with perfectly correlated data. This corresponds to the regression statistics r^2=1 or 100%, slope =1, intercept=0. Deviations from these values reflect a lack of correlation between the datasets.

Table C.1: Summary of regression analyses performed

Ship measurements	Laboratory measurements						
	chlorophyll-a	total SPM	ammonia	TON	nitrite	phosphate	silicate
QUBIT chlorophyll-a fluorescence	(section C.3)						
QUBIT % transmission		(section C.4)					
Skalar ammonia			(section C.5)				
Skalar TON				(section C.6)			
Skalar nitrite					(section C.7)		
Skalar phosphate						(section C.8)	
Skalar silicate							(section C.9)

C.3 Chlorophyll regression results

Figure C.1: Seasonal regression plots of laboratory measured chlorophyll-a against fluorescence

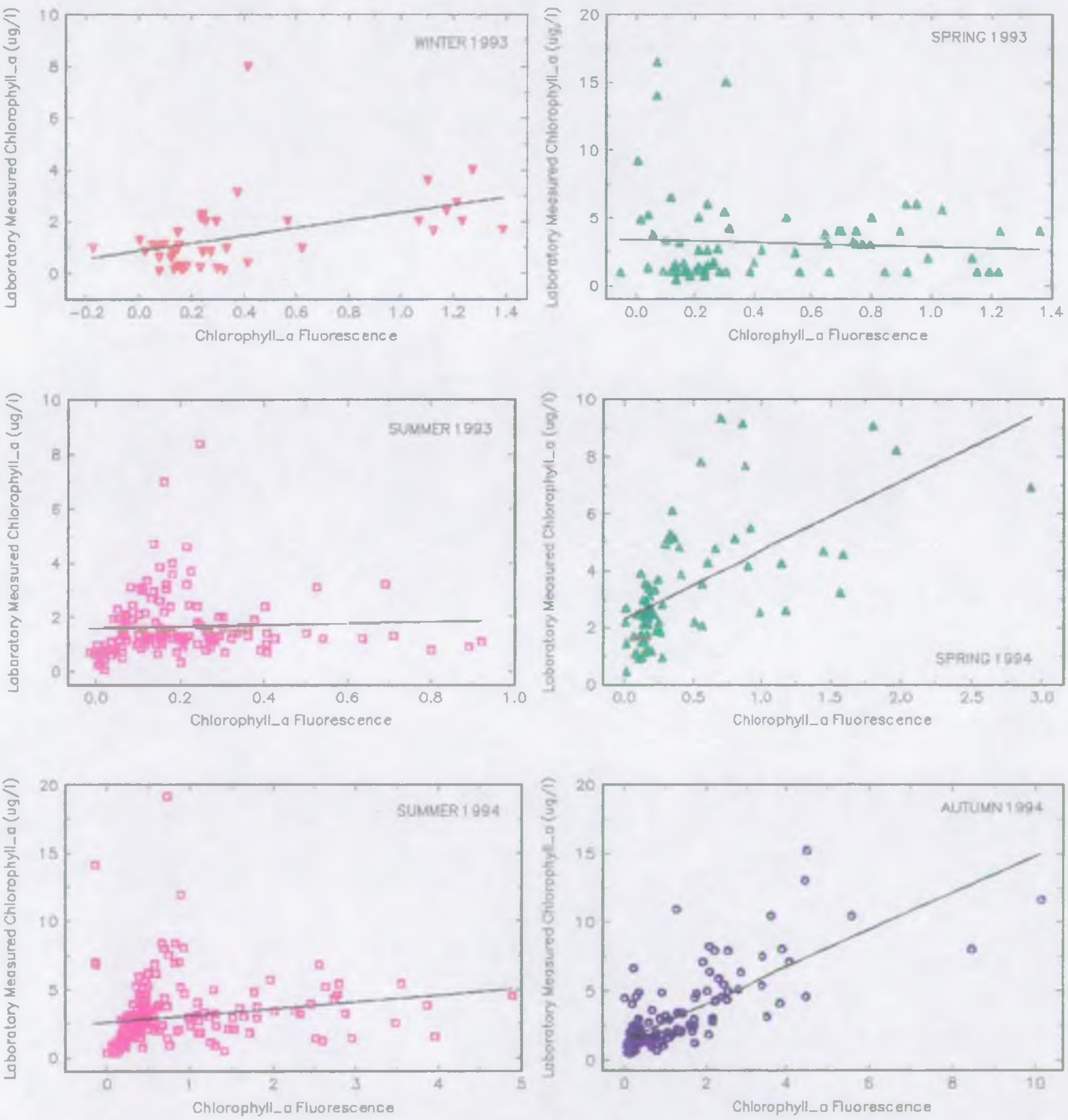


Table C.2: Summary of the regression results for chlorophyll

	r^2	slope	intercept	no. of data points
Winter 1993	19.31%	1.48	0.87	42
Spring 1993	0.17%	-0.36	3.43	73
Summer 1993	0.07%	0.19	0.189	132
Spring 1994	38.52%	2.42	2.28	74
Summer 1994	5.94%	0.63	2.36	177
Autumn 1994	58.7%	1.35	1.37	171

Comparisons have been made of the laboratory analysed sample and fluorometer results for each survey. All available data from each campaign have been included in the statistical analysis. Qubit data (as discussed in section 3.3.1) was selected by comparison of the latitude and longitude of the baseline sites as the time stamp applied to the laboratory data is not always reliable. The results of regressing the laboratory measured chlorophyll-*a* concentrations against the fluorometer readings for each season are included in Figure C.1 The regressions statistics are summarised in Table C.2.

In Winter 1993 only 42 of the 186 baseline points are suitable for statistical analysis. Data from the Sea Vigil region has been excluded from the regression as a calibration appears to have been applied to this data prior to its being logged in the Qubit file. Other Qubit data is of good quality. Laboratory samples are however sparse, in particular in the Wessex region where many values are recorded as less than the limit of detection of 1μg/l. The data show a linear trend, but the relatively low correlation coefficient of 0.64 illustrates the amount of scatter in the results. It also should be noted that there is a distinct lack of data between fluorometer readings 0.7 and 1.0.

In Spring 1993, 73 points are available for the regression, but these show no linear trend. The results are from the Water Guardian, Vigilance and Coastal Guardian regions. Again many results along the South Coast are recorded as below the limit of detection. As this is the Spring campaign, it may be that the bloom in phytoplankton has passed, since values of less than 1μg/l would not be anticipated in a bloom event.

In Summer 1993 the regression again results in no linear correlation. In this case almost all points are used in the regression, except those for the Sea Vigil region. The poor correlation may be caused by the low concentrations of chlorophyll-*a* causing inaccuracies of the measurement of fluorescence.

The Summer 1993 and 1994 figures suggest that there were two water types present in the data set, resulting in two populations in the regression plots. However, the analyses performed do not support this view.

The data from Autumn 1993 and Winter 1994 are sparse and no regression analysis has been carried out on these.

The correlation coefficient for Spring 1994 of 0.62 shows an improvement in the correlation between the fluorometers and the laboratory samples. Data in this case is taken from the Water Guardian and Vigilance regions, as both Sea Vigil and Coastal Guardian appear to have applied a calibration which results in distinct populations in the scatter when all data is plotted.

The Summer 1994 data shows a similarly low correlation as that for Summer 1993, with a coefficient of only 0.24. This again suggests problems with low levels of chlorophyll-*a*.

The highest correlation coefficient is found for the most recent data set, Autumn 1994. In this case 171 of the 186 baseline sites are suitable for statistical analysis, with no calibrations applied to the data prior to recording in the Qubit file. These results show an increased comparability between the data obtained on the four different NRA vessels.

C.4 SPM regression results

Figure C.2: Seasonal regression plots of laboratory measured total SPM against % transmission

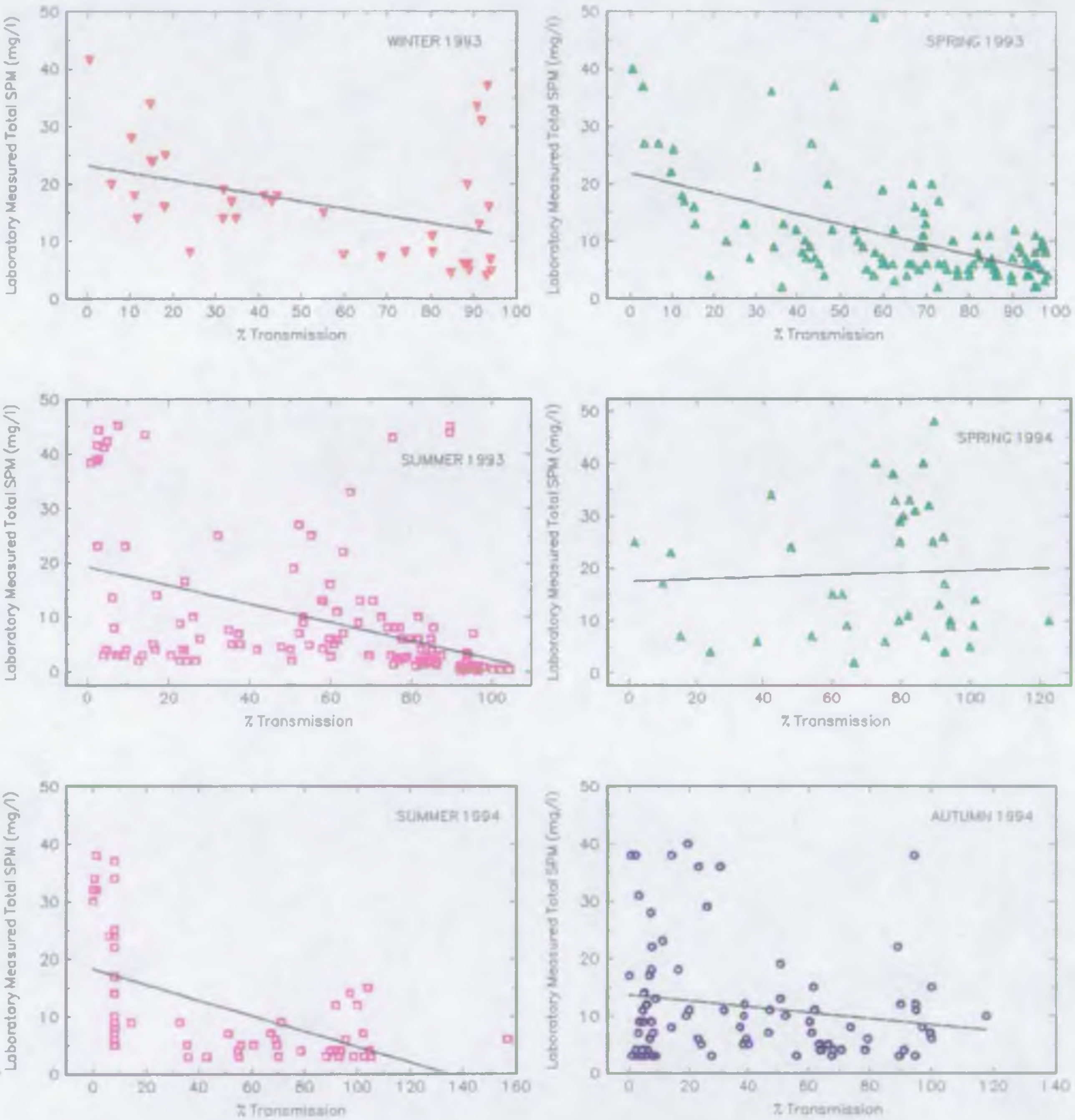


Table C.3: Summary of the regression results for total SPM

	r^2	slope	intercept	no. of data points
Winter 1993	17.94%	-0.12	23.20	46
Spring 1993	30.16%	0.18	21.95	107
Summer 1993	20.33%	-0.17	19.27	131
Spring 1994	0.23%	0.02	17.54	44
Summer 1994	31.58%	-0.14	18.28	59
Autumn 1994	3.10%	-0.05	13.73	89

Suspended particulate matter (SPM) concentration measurements are made through analysis of a filtered sample and can be inferred from the transmissometer reading. The laboratory detection limit of 3mg/l sets the minimum concentration that may be recorded by the laboratory. The operating range of the transmissometer allows accurate measurements up to approximately 50mg/l. Within this value range (3 to 50mg/l), a linear relationship is expected between the SPM concentrations and the transmissometer readings. The results of regressing the laboratory measured suspended particulate matter (SPM) concentrations against the transmissometer readings for each season are included in Figure C.2. The regressions statistics are summarised in Table C.3. No linear trends are seen between either total or inorganic suspended particulate matter concentrations and transmission throughout the campaigns, indicating problems with the sampling procedure. Notably, some transmissometer values are recorded throughout the data set as being in excess of 100%, which is clearly an error.

C.5 Ammonia regression results

Figure C.3: Seasonal regression plots of laboratory measured ammonia against Skalar measured ammonia

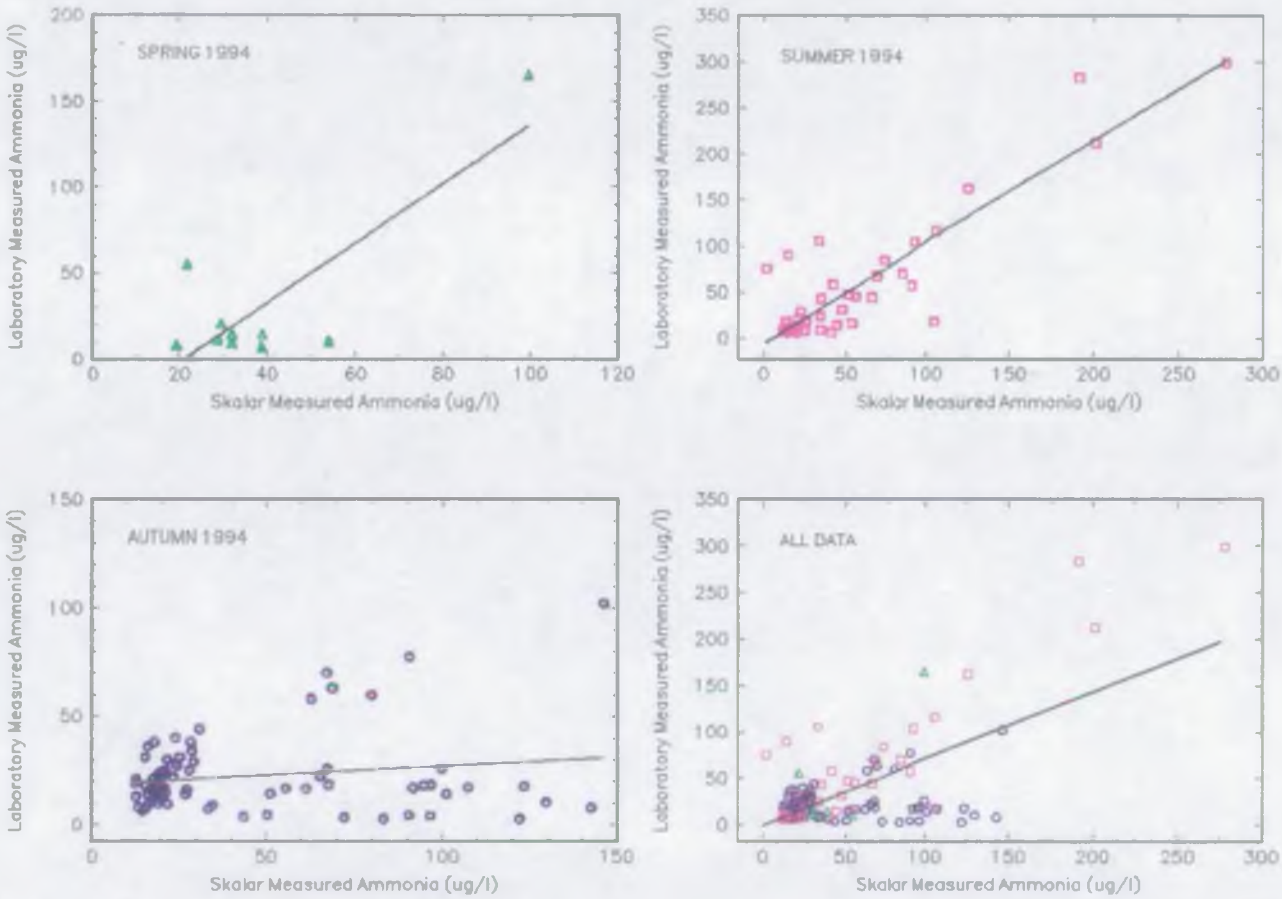


Table C.4: Summary of the regression results for ammonia

	r^2	slope	intercept	no. of data points
Spring 1994	67%	1.73	-36.69	10
Summer 1994	81%	1.10	-5.93	51
Autumn 1994	3%	0.08	18.72	71
All data	45%	0.72	-0.84	132

Regression results for ammonia are summarised in table C.4. The corresponding regression plots are shown in figure C.3.

Results for ammonia are available in Spring 1994 from only one of the four NRA vessel, Vigilance, since this was a research exercise prior to the establishment of routine monitoring of ammonia as part of the baseline survey. Only ten points could be used in the regression, for two reasons: on a number of occasions the Skalar results were recorded as "no data" or as being below the detection limit of ~11 μg/l. Additionally, a large number of points were found to have concentrations above the limit of detection with the Skalar system but were recorded as below the limit of detection in the laboratory (< 6 μg/l). As the detection limits are of similar magnitude, it is assumed that the laboratory samples had been degraded during storage and transport as discussed in Section 3. The few remaining points and their distribution cannot be considered representative.

In Summer 1994 a total of 51 points were available from all four vessels. However, data from Coastal Guardian was sparse, with numerical results from only 25 of the 50 baseline sites within this region. Some of these points are missing because if the vessel was substantially off track, then the latitude and longitude would not have been considered close enough to include this point in the analysis. Many data points from Vigilance, representing those recorded around the coast of Sussex, Dorset, Devon and Cornwall, show results below the limit of detection. The majority of these are also below the limit of detection of the laboratory, although a number of points occur where the shore laboratory ammonia concentration is low relative to the Skalar measurement. This is again probably due to problems with storage and transport. Data from Water Guardian and Sea Vigil show a similar significant number of results below the limit of detection, and also missing values. The regression between the two methods for the residual data shows a good linear trend, with a correlation of 0.899 and a slope close to 1.

In Autumn 1994 there are 71 points used in the regression. No data is available from Water Guardian or from Sea Vigil, and only limited data are present from Coastal Guardian. The majority of these points are therefore from Vigilance. The different limits of detection of the two shore laboratories used during 1994 means that some samples are recorded as a numeric result from the Nottingham laboratory with a limit of detection of < 2.7 μg/l, whilst being recorded as below the limit of detection on the Skalar system. The resulting regression exhibits very little trend.

When combining all the results from the three campaigns the resultant regression is biased by the poor result from Autumn, resulting in more scatter. The correlation coefficient is 0.673, with a slope close to 1, showing that the numeric values being measured by the two systems are in close agreement. Differences are likely to be due to the storage and transport of the samples between the ship and the laboratory leading to a decrease in concentration in the laboratory sample.

C.6 Total oxidised nitrogen regression results

Figure C.4: Seasonal regression plots of laboratory measured TON against Skalar measured TON

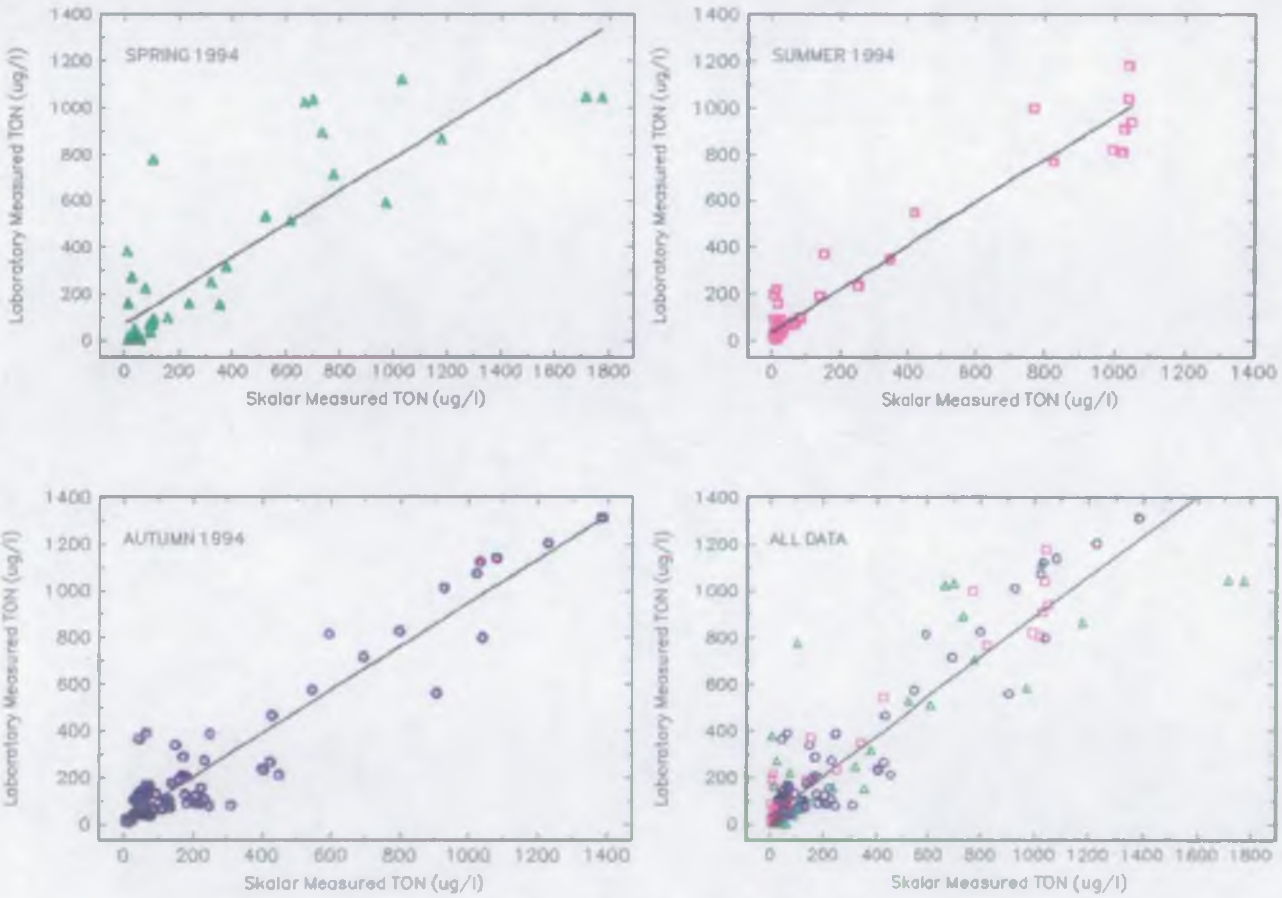


Table C.5: Summary of the regression results for TON

	r^2	slope	intercept	no. of data points
Spring 1994	76%	0.73	52.93	53
Summer 1994	94%	0.92	44.26	43
Autumn 1994	92%	0.93	15.84	118
All data	86%	0.86	33.20	214

Regression results for TON are summarised in Table C.4, and the corresponding plots in Figure C.5.

In Spring 1994, 53 results are used to perform the regression between laboratory measured and ship measured Total Oxidised Nitrogen (TON). These results are all from the Vigilance and Coastal Guardian regions, with no Skalar TON data having been recorded for either Water Guardian or Sea Vigil. There is a large range in values seen with some being recorded as below the limit of detection of the Skalar system, (~3 µg/l) and others in excess of 1700µg/l. These higher values agree well between the two measuring systems, and may therefore be considered to be real. The resulting regression analysis produces a clear linear trend, with a correlation coefficient of 0.87 between the two systems across the entire range.

In Summer 1994 only 43 values are used, collected by Water Guardian and Vigilance. Skalar data were recorded by Sea Vigil, but all laboratory results were below the limit of detection of 10µg/l. No Skalar data was recorded by Coastal Guardian, and in any case all laboratory samples are below the limit of detection of 20µg/l. For the available data, the resulting regression analysis is good, with a correlation coefficient of 0.97 and a slope of 0.92 representing a good agreement in numerical values.

Autumn 1994 provides the largest numbers of TON results for this analysis with data from 118 points spread evenly around the country. The resulting regression shows a clear linear trend with a correlation coefficient of 0.96. The laboratory data does not consistently underestimate the level or vice versa, with results appearing to be fairly evenly distributed, and with a slope close to 1.

When all the TON results are combined a clear linear trend exists between the two data sets, with a correlation coefficient of 0.929 and a slope of 0.858.

C.7 Nitrite regression results

Figure C.5: Seasonal regression plots of laboratory measured nitrite against Skalar measured nitrite

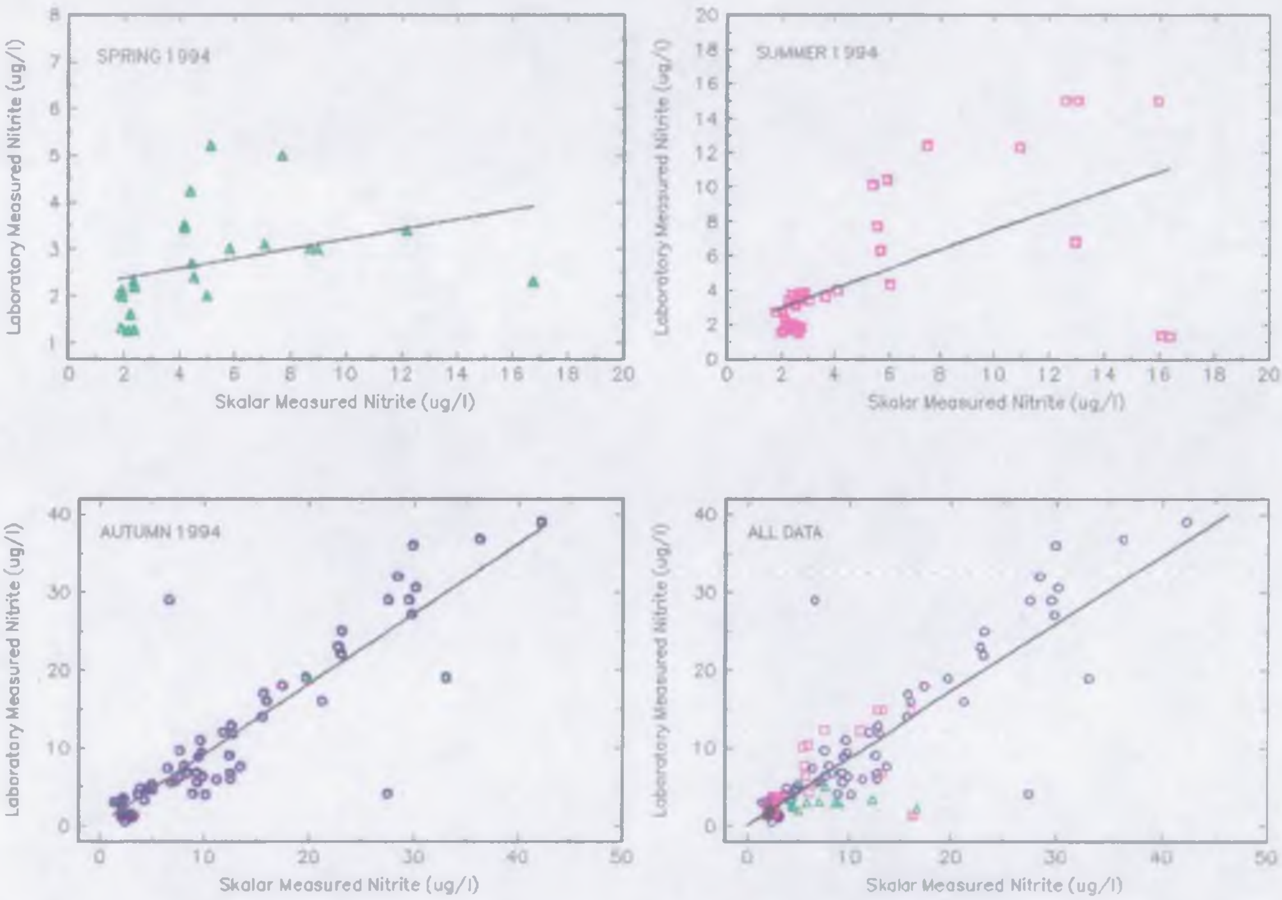


Table C.6: Summary of the regression results for nitrite

	r^2	slope	intercept	no. of data points
Spring 1994	3%	0.04	2.13	40
Summer 1994	75%	0.90	1.56	23
Autumn 1994	77%	0.90	0.20	60
All data	75%	0.86	0.10	123

Regression results for nitrite are summarised in table C.6, with corresponding plots in figure C.5.

Results are available for Spring 1994 from Vigilance and Coastal Guardian, covering baseline sites 51 to 186. Of these sites, 40 are used in the regression with the scarcity of points being due to the same reasons as described before. Levels are generally low, with those values that are recorded on the vessel being generally slightly higher than those in the laboratory. This has resulted in many results falling below the Llanelli laboratory limit of detection of 2 µg/l. More data are available in the Coastal Guardian region because samples are analysed at the Nottingham laboratory which has a limit of detection of 1.2 µg/l. The resultant regression shows little trend, and illustrates clearly how the laboratory samples have recorded much lower values than those on the vessel.

In Summer 1994 only 23 points are available for the regression. These were all collected by Vigilance between baseline points 51 and 138. Skalar data was collected by Coastal Guardian between points 138 and 186, showing a good range in concentrations of nitrite between 1 and 44µg/l. All these results were recorded, however, as being below the limit of detection of the Nottingham laboratory of 7µg/l. It is assumed, therefore, that there was some problem in the transport or storage of these samples. The remaining samples show a reasonable correlation between laboratory and Skalar data, with a correlation coefficient of 0.866.

In Autumn 94 a total of 60 points are available for analysis, again between baseline points 51 and 186, representing measurements by Vigilance and Coastal Guardian. Results are again below the limit of detection in the laboratory samples, which are 3 µg/l for the Llanelli laboratory and 0.55 µg/l for the Nottingham laboratory. In the case of the Llanelli results, the data generally agrees between the two methods, whereas for the Nottingham data results are commonly quoted as being less than 0.55 µg/l in the laboratory and between 2 and 4 µg/l with the Skalar system. The remaining results produce a clear correlation between the laboratory and the ship based data, with a correlation coefficient of 0.876.

In this case the regression resulting from all three nitrite data sets shows a clear correlation of 0.864, with the ship based and shore based measurements returning similar numeric values for the same sample.

C.8 Phosphate regression results

Figure C.6: Seasonal regression plots of laboratory measured phosphate against Skalar measured phosphate

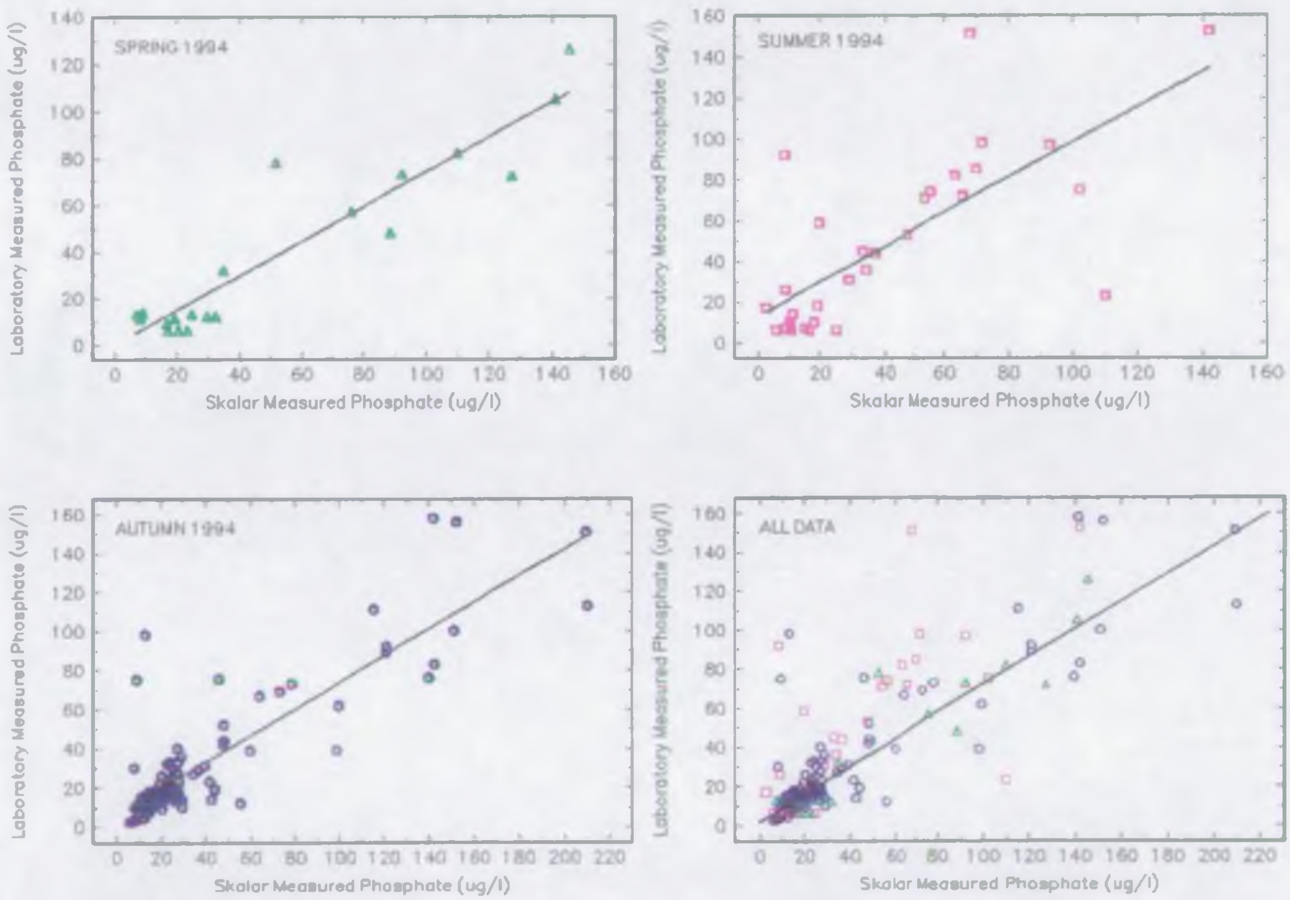


Table C.7: Summary of the regression results for phosphate

	r^2	slope	intercept	no. of data points
Spring 1994	86%	0.67	1.63	24
Summer 1994	63%	0.94	9.63	31
Autumn 1994	75%	0.68	5.58	106
All data	72%	0.68	7.06	161

The regression results for phosphate are summarised in table C.7, with corresponding plots being shown in Figure C.6.

In Spring 1994 there are only 24 results available for regression of phosphate values between Skalar and laboratory. All of these are from the Vigilance region. There were no Skalar data from Water Guardian for this campaign, and no data were recorded in the laboratory or the ship for Sea Vigil. For the Coastal Guardian region there are no Skalar data and the laboratory data are generally below the limit of detection of 8µg/l. Concentrations in the Vigilance data are generally low, with many samples falling below the limit of detection of both the laboratory and the Skalar system. The regression on these few points is hardly representative, but shows a good linear trend, with a correlation coefficient of 0.926.

In Summer 1994 the situation is little better with only 31 results to be used in the regression. In this case Skalar data was collected by both Water Guardian and Sea Vigil, but all the laboratory results fell below the limit of detection of 5 µg/l. In the case of Coastal Guardian no Skalar data was recorded. Many Vigilance results also fall below the limit of detection of the Skalar system, again raising the question of whether this limit of circa 8 µg/l is adequate if the Skalar system is to be used in isolation. A clear linear trend is seen in the data with a good agreement between absolute numeric values.

Autumn 1994 has 106 results which may be used in the regression, spread evenly around the coastline. There is a wide range of values, between 2 and 250µg/l. The resulting regression shows a high linear correlation of 0.868, which is particularly good considering the wide range of concentrations.

When all the phosphate results are combined a linear relationship is found, with a correlation coefficient of 0.851. The slope of the regression is 0.684, and the intercept is circa 7. Assuming that a linear relationship exists, this indicates that the Skalar system and sample analysis are not giving comparable results.

C.9 Silicate regression results

Figure C.7: Seasonal regression plots of laboratory measured silicate against Skalar measured silicate

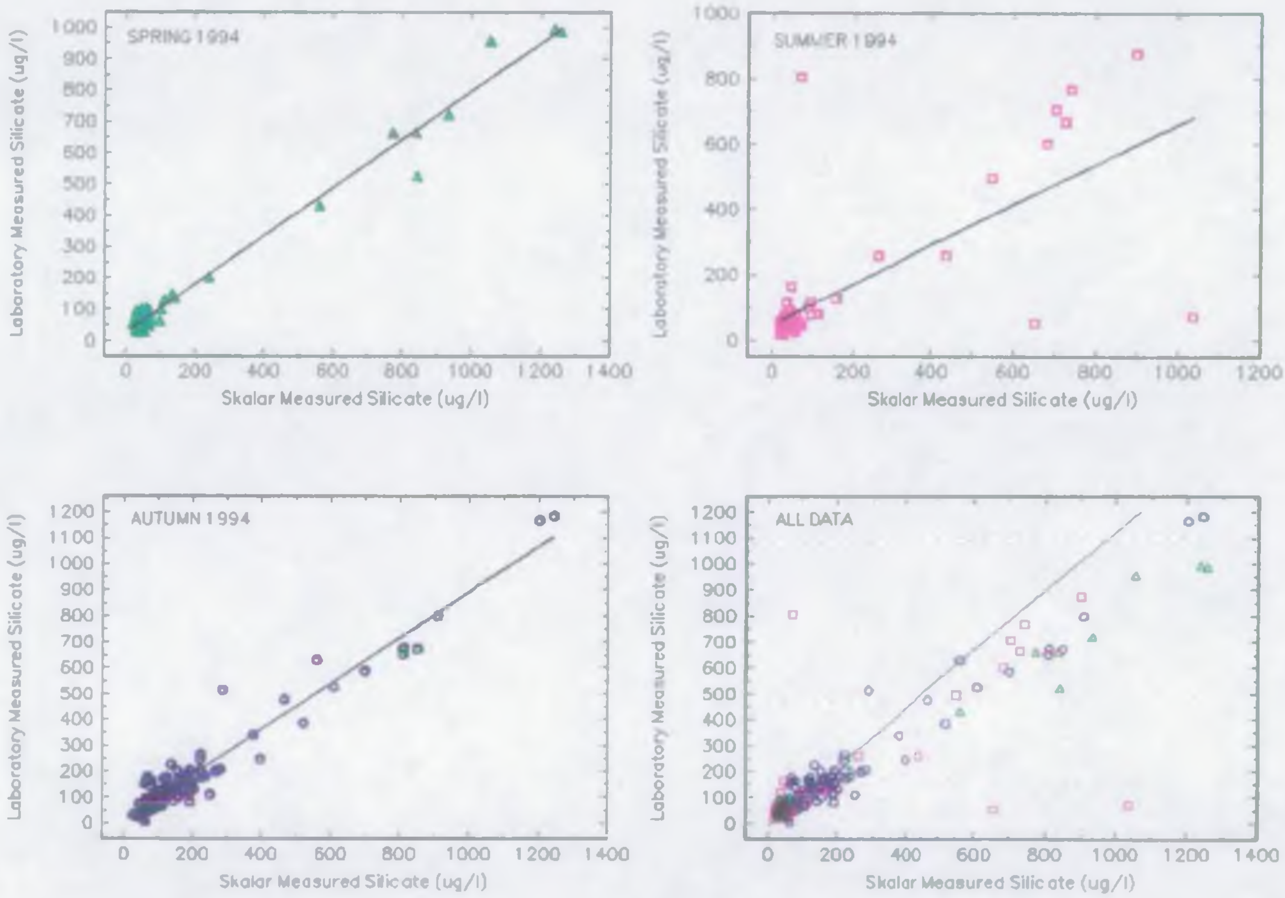


Table C.8: Summary of the regression results for silicate

	r^2	slope	intercept	no. of data points
Spring 1994	98%	1.25	-21.02	64
Summer 1994	97%	1.06	-11.26	50
Autumn 1994	94%	1.06	5.13	122
All data	95%	1.13	-8.40	326

The regression results for silicate are summarised in table C.8, with the plots shown in figure C.7.

Silicate results are available for Spring 1994 for a total of 64 sites in the Vigilance and Coastal Guardian regions. Neither laboratory or Skalar data were recorded for the Sea Vigil region between sites 31 and 51. There are no Skalar data from the Water Guardian region, and the laboratory results from here are all below the limit of detection. Again many values may not be used for this analysis as they have been recorded as below the limit of detection of the laboratory even though there are readings from the Skalar system. The resulting values produce a good linear correlation, with a coefficient of 0.99 and a good agreement in numeric values, shown by the slope value of 1.25.

In Summer 1994, 50 values are used in the regression taken from Water Guardian and Vigilance. There is Skalar data from the Sea Vigil region, but all laboratory samples from this region are below the limit of detection. There is no Skalar data from the Coastal Guardian region. With the remaining data, the resultant regression is again good, with a correlation coefficient of 0.987 and a slope of 1.062.

Autumn 1994 resulted in the largest number of points for regression, with 122 corresponding numeric results in both Skalar and laboratory. The results are from all four of the vessels. The main reason for more results being available is the higher level of silicate in the water samples, resulting in less of the laboratory samples falling below the limit of detection of 25 µg/l. The resulting regression shows a clear linear trend, with a correlation coefficient of 0.968, and a good agreement in absolute numeric values, with a slight tendency for the laboratory results to return a higher value than the Skalar results for the same point.

When data from the three campaigns is combined a very good linear trend, with a correlation coefficient of 0.977 is shown between the two methods of detection. In general the laboratory results slightly underestimate the concentration of silicate, shown by the negative value for the intercept of ~8.

D SPATIAL SAMPLING FREQUENCY ANALYSIS

D.1 Introduction

The purpose of the analysis described in this Appendix is to determine whether the spatial sampling frequency being used by the NRA at present is the optimum in terms of being representative of the variation in each determinand along the coast. In order to assess this the spatial correlation coefficient has been determined for sections of coastline. The magnitude of the spatial correlation coefficient reflects whether or not neighbouring measurements are correlated or uncorrelated. Section D.2 describes the statistical techniques used in the analysis. Sections D.3 to D.8 detail the results for chlorophyll-*a*, SPM, ammonia, TON and nitrite, phosphate and silicate and metals, respectively.

D.2 Analysis performed

Spot sample measurements are taken every 15km. In order to establish whether this sampling frequency is appropriate for describing the variability in the individual determinand concentrations, the variability between baseline site measurements was assessed. The coastline was divided into a number of sections called littoral cells, each cell containing between 9 and 25 baseline sites. Littoral cells are regions defined[13] as having similar flow characteristics. (Figure 4-10 of section 4 shows the position of the littoral cells.) Within each of these littoral cells and for each determinand, the spatial correlation coefficient, as given by the following equation, was determined:

$$R_s = \frac{\frac{1}{N_s} \sum_{\text{all pairs with separation } s} D_i \, D_{i+s}}{\frac{1}{N_0} \sum_{\text{all pairs}} D_i \, D_i}$$

$$D_i = W_i \, (d_i - q_i).$$

where D_i are the trend-removed and weighted data. In these formula, the weights W_i may not be constant, d_i are the spot data, q_i is the trend at that data point and N_i is the number of elements summed.

The correlation coefficient, R_s, is a measure of how well a given baseline site measurement can be predicted given the measurements made at its neighbouring baseline sites. If the mean

[13] MOTYKA J M AND BRAMPTON A H, "Coastal Management: Mapping of littoral cells", HR Wallingford report SR 328, January 1993

correlation coefficient between neighbouring baseline site measurements for a given cell is greater than 0.8, the cell may be considered as oversampled since by decreasing the sampling frequency to every other site, the measured valued would still be expected to be 80% accurate. If the mean correlation coefficient of a cell is less than 0.5, then the variability between neighbouring measurements is greater than 50% thus necessitating an increased sampling frequency in order to record this variability.

The results of applying this analysis to the data from each of the baseline surveys are presented in the form of a tables in sections D.3 to D.8. In these tables, cells for which the correlation coefficient exceeded 0.5 are identified by a ✓; cells for which the correlation coefficient was less than 0.5 are identified by a ✕ ; a dash (-) identifies those cells to which the analysis has not been applied because of lack of data (either below the limit of detection or no measurements made). In particular the Autumn 1993 and the Winter 1994 campaigns have large areas of missing data.

The correlation coefficient between second nearest neighbour baseline site measurements (ie comparing sites 30km apart) was also determined. Where significant results were obtained, these are discussed in the text.

Where cells were found to be consistently uncorrelated (ie a correlation coefficient consistently less than 0.5), indicating that some undersampling may be occurring, a further analysis has been carried out to determine the optimum sampling frequency. In these cases, the continuous data were subsampled so as to simulate measurements at 5km and 10km baseline site intervals. The spatial correlation analysis described above was then applied to these simulated sites. Such analyses are only possible for those determinands which are measured both by water sample and continuously, ie. the nutrient data from 1994 when the Skalar auto-analyser was in operation, and the chlorophyll-*a* data from all campaigns, which may be compared with the fluorometer data.

D.3 Chlorophyll

The spatial correlation coefficient analysis has been applied to the spot sampled chlorophyll data for each campaign and the results are shown in Table D.1.

Table D.1: Summary of the results of the spatial correlation analysis for chlorophyll

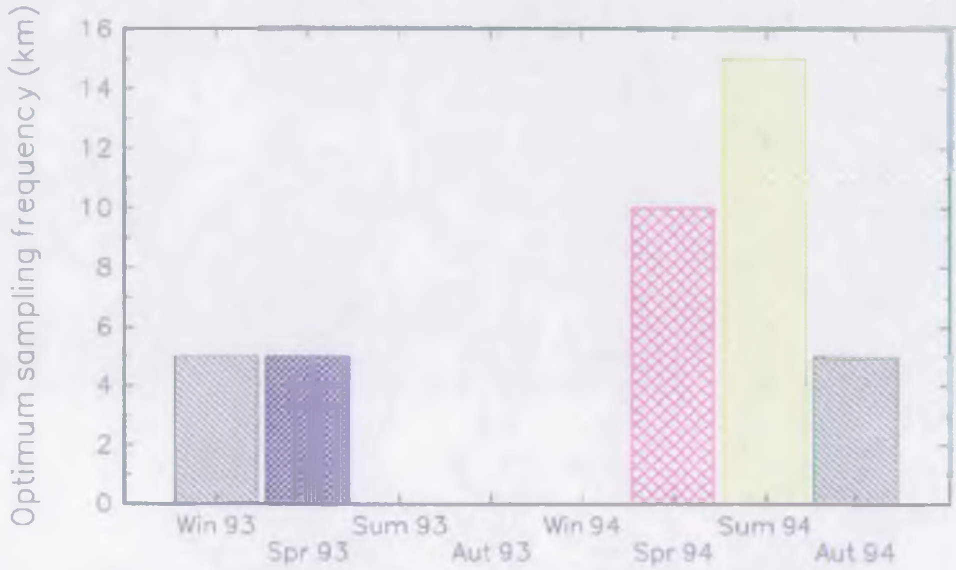
	1	2	3	4	5	6	7	8	9	10	11
Winter 1993	✘	✘	✘	-	-	-	-	-	✘	✘	✘
Spring 1993	✘	✘	✓	-	✘	-	-	-	✘	-	✘
Summer 1993	✘	-	-	✘	✘	✘	✓	✓	✘	✘	✘
Autumn 1993	-	-	-	✘	-	-	-	-	-	-	-
Winter 1994	✘	✘	✘	-	-	-	-	-	-	-	-
Spring 1994	✘	✘	✘	-	-	✘	✓	✓	✓	✘	✘
Summer 1994	✓	✓	✘	✓	✘	✓	✓	✘	✘	✘	✘
Autumn 1994	✘	✘	✘	✓	✘	✓	✘	✓	✘	✘	✓

Many cells in the 1993 campaigns show results less than the limit of detection, especially in the Wessex region whose measurements were analysed by the Llanelli laboratory which reported chlorophyll-*a* concentration to the nearest 1μg/l. This resulted in much of the South coast being below the limit of detection.

Most cells are seldom or never correlated. Highly variable chlorophyll-*a* concentrations are to be expected for cells 1, 2, 5 and 10 as they each contain a number of large riverine inputs, for example the Tyne and Tees in cell 1, the Humber in cell 2, the Solent in cell 5 and the Mersey in cell 10. High levels of chlorophyll-*a* could be expected around these estuaries due to natural and anthropogenic sources. It may be concluded therefore that some undersampling is occurring here, with the baseline values not being representative of the full variance in chlorophyll-*a* along these sections of coastline. The analysis carried out to establish a more optimum sampling frequency is discussed later in this section. Cells 7 and 8 are consistently correlated with cell 8 in Summer 1994 and cell 7 in Autumn 1994 being just below the threshold of 0.5. The results of further analysis show, however, that the data are not correlated with their second neighbours. The sampling frequency in use is therefore the optimum for these cells.

An optimum sampling analysis was carried out on Cell 1, which showed the lowest correlation coefficients at 15 km throughout the campaigns, except for in Summer 1994 when this cell was correlated. Cell 1 stretches from Berwick-on-Tweed to Flamborough Head, containing three major estuaries, the Tyne, Tees and Wear. Figure D.2 shows the variation in the optimum sampling frequency with season and year.

Figure D.2: A diagram to show the optimum sampling frequency for chlorophyll-a



D.4 Suspended particulate matter

The spatial correlation coefficient analysis was applied to both total and organic SPM measurements and the results are shown in tables D.2 and D.3.

Table D.2: Summary of the results of the spatial correlation analysis for total SPM

	1	2	3	4	5	6	7	8	9	10	11
Winter 1993	✗	✗	✗	✓	✗	✗	✗	✓	✗	✗	✗
Spring 1993	✗	✓	✓	✗	✗	✗	✓	✓	✗	-	✗
Summer 1993	✗	✗	✗	✗	✓	✗	✓	✓	✗	✗	✗
Autumn 1993	-	-	-	✓	✗	-	-	-	-	-	-
Winter 1994	-	✗	✗	-	-	-	-	-	-	-	✓
Spring 1994	-	-	-	✓	✗	-	-	-	✗	✗	✗
Summer 1994	-	-	-	-	-	-	-	-	-	-	-
Autumn 1994	✗	-	✗	✗	✓	-	-	✓	-	-	✓

Table D.3: Summary of the results of the spatial correlation analysis for inorganic SPM

	1	2	3	4	5	6	7	8	9	10	11
Winter 1993	-	-	-	✗	-	-	-	-	-	-	-
Spring 1993	-	-	-	-	-	-	-	-	-	-	-
Summer 1993	-	-	-	✗	✓	✗	✓	✓	-	-	-
Autumn 1993	-	-	-	✓	-	-	-	-	-	-	-
Winter 1994	-	-	-	-	-	-	-	-	-	-	✓
Spring 1994	-	-	-	✓	✗	-	-	✗	✗	✗	✗
Summer 1994	-	-	-	-	-	-	-	-	-	-	-
Autumn 1994	✓	-	-	✗	-	-	-	-	-	-	-

It is difficult to state conclusively if the two measurements follow the same patterns as so many of the results for the ashed SPM are not applicable for statistical analysis. This is because results are often missing. One reason for this was the incorrect determinand list being used for the Anglian region.

Generally, cells 7 and 8 show the highest correlations through the two year period, corresponding to the areas in which the highest values of SPM are found. These cells show a steady linear increase in concentration towards the Severn Estuary, and the variance between baseline points within the cell is therefore low. However, in such cells, where there are strong gradients, it is not recommended that sampling be reduced. Cells 1, 6, 9 and 10 are never correlated, and therefore some undersampling is occurring here, with the present strategy not fully reflecting the variability within these cells, which may be a result of frontal structures and riverine inputs.

In both total and ashed SPM the highest values are consistently located in the Upper Bristol Channel, with values of total SPM varying between 200 and 600mg/l depending on season, and corresponding ashed SPM concentrations of 150 to 500mg/l. The Thames Estuary shows high levels of total SPM, but relatively low concentrations of ashed SPM. This indicates that particulate matter within the Thames Estuary is of mainly organic origin.

D.5 Ammonia

Table D.4: Summary of the results of the spatial correlation analysis for ammonia

	1	2	3	4	5	6	7	8	9	10	11
Winter 1993	-	-	✗	✗	✗	✗	✗	✗	✗	✗	✗
Spring 1993	✓	✗	✗	✗	✗	✓	✗	✗	✗	✗	✗
Summer 1993	✗	✗	✗	✗	✓	✗	✓	✓	✗	✗	✗
Autumn 1993	-	-	-	-	-	-	-	-	-	-	-
Winter 1994	-	-	-	-	✓	✗	✗	-	-	-	-
Spring 1994	✗	✗	-	✗	✗	✗	-	-	-	-	-
Summer 1994	✗	✗	✓	-	✗	✗	✗	-	-	-	-
Autumn 1994	✓	✗	✓	✗	✗	✓	✓	-	✓	✗	✓

The results of applying the spatial correlation coefficient analysis to ammonia are shown in Table D.4.

Cells 2, 4 and 10 are shown to be uncorrelated during all campaigns where data were available. No cell is seen to be consistently correlated and thus some undersampling is occurring. On only one occasion is a high correlation in excess of 0.8 recorded, and it may therefore be stated that even in the correlated cells oversampling is not occurring.

The optimum sampling frequency was determined for cells 2, 4, and 10 in 1994. Skalar data was subsampled to simulate sampling intervals of 10 km and 5 km. Much of the data was unsuitable for this analysis having a large number of values below the limit of detection of the Skalar system or missing values. In Autumn 1994 in both cells 4 and 10 the data was found to be correlated when the sampling interval was decreased to 5 km, thus indicating that such a sampling interval is optimum. Data for cell 2 was unsuitable for analysis, as were all data from the Spring and Summer campaigns.

In Autumn 1994, 6 of the 10 analysed cells are correlated. This may be due to the higher concentrations seen at this time of year. Where concentrations are lower, for example in Spring 1993 and Spring 1994, the data is less correlated. At low levels analysis techniques decrease in accuracy which may explain this result. The limits applied to the data in 1994 are higher than those in 1993, resulting in more results below the limit of detection in later campaigns.

The highest concentrations of ammonia vary between the campaigns. One region, between baseline sites 17 and 18, which is the Tees Estuary is high in ammonia during all campaigns, although in some cases it is not the highest result recorded.

D.6 TON and nitrite

Table D.5: Summary of the results of the spatial correlation analysis for TON

	1	2	3	4	5	6	7	8	9	10	11
Winter 1993	-	-	✗	✓	✗	-	✓	✓	-	-	-
Spring 1993	-	-	✓	-	-	-	-	-	-	-	✗
Summer 1993	-	-	✓	-	-	-	-	-	✗	✗	✓
Autumn 1993	-	-	✗	✓	-	-	-	-	-	-	-
Winter 1994	-	-	✓	-	-	-	✗	-	-	-	-
Spring 1994	-	-	-	-	-	-	-	-	✓	✗	✗
Summer 1994	✗	-	-	-	✗	-	-	-	-	-	-
Autumn 1994	✗	✗	✗	✓	✗	✗	✓	✓	✗	✓	✓

Table D.6: Summary of the results of the spatial correlation analysis for nitrite

	1	2	3	4	5	6	7	8	9	10	11
Winter 1993	✗	-	✓	✓	-	-	-	✗	✓	✗	✓
Spring 1993	✗	✗	✓	-	-	-	-	-	✓	✗	✗
Summer 1993	✗	✗	✓	-	-	-	-	-	-	-	-
Autumn 1993	-	-	✗	✓	-	-	-	-	-	-	-
Winter 1994	-	-	✓	-	-	-	-	-	-	-	-
Spring 1994	-	-	-	-	-	-	-	-	✓	✓	✓
Summer 1994	-	-	-	-	-	-	-	-	-	-	-
Autumn 1994	✗	-	✓	-	✗	✓	✗	✗	✗	✗	✓

The results of applying the spatial correlation coefficient analysis to Total Oxidised Nitrogen (TON) and nitrite are shown in Tables D.5 and D.6.

The spatial correlation coefficient analysis has not been very successful due to the large number of results below the limit of detection. Particular problems were encountered with data form the Llanelli laboratory with its relatively high limit of detection. Nitrite results follow a similar pattern. This is to be expected as nitrite is one component of TON (see table D.6). Generally TON results are greater than nitrite with more values exceeding the limit of detection.

Highest levels of TON and nitrite are consistently found in the Bristol Channel.

D.7 Phosphate and silicate

Table D.7: Summary of the results of the spatial correlation analysis for phosphate

	1	2	3	4	5	6	7	8	9	10	11
Winter 1993	✗	✓	✓	✓	✗	✗	✓	✓	✗	✓	✓
Spring 1993	-	-	✓	✓	✗	✓	✓	✓	✓	✗	✗
Summer 1993	-	✗	✓	✓	✗	-	✓	✓	✗	✓	✗
Autumn 1993	-	-	✗	✗	✗	-	-	-	-	-	-
Winter 1994	-	-	✓	-	-	-	✓	-	-	-	-
Spring 1994	✗	-	-	-	-	-	-	-	-	-	-
Summer 1994	-	-	-	-	-	-	-	-	-	-	-
Autumn 1994	✗	-	✗	✗	✗	✗	✓	✓	✓	✓	✓

Table D.8: Summary of the results of the spatial correlation analysis for silicate

	1	2	3	4	5	6	7	8	9	10	11
Winter 1993	✗	✓	✗	✓	✗	✗	✓	✓	✗	✗	✓
Spring 1993	✗	✗	✓	-	-	-	-	-	✗	✗	✗
Summer 1993	-	✗	✓	✓	✗	✗	-	✓	✗	✗	✗
Autumn 1993	-	-	✗	✗	✗	-	-	-	-	-	-
Winter 1994	-	-	✓	-	-	-	-	-	-	-	-
Spring 1994	-	-	-	-	-	-	-	✓	✗	✗	✓
Summer 1994	-	-	-	✓	✗	✓	✓	-	-	-	-
Autumn 1994	✗	✗	✗	✗	✗	✓	✓	✓	✗	✗	✓

Phosphate and silicate results are shown in tables D.7 and D.8 respectively. These two determinands behave fairly similarly, with generally more values above the established limit of detection than were seen in the TON and nitrite results. Cells 1 and 5 are uncorrelated for all campaigns for phosphate. Further analysis has shown that phosphate measurements remain uncorrelated until a 5km separation is achieved.

Silicate measurements are uncorrelated in cells 1, 5, 9 and 10 . Further analysis to determine the optimum sampling interval has shown that it varies between 5km and 1km depending on season and year.

Again there are problems with the 1994 limit of detection for phosphate being relatively high and more suited to the annual maximum in nutrient levels seen in Autumn and Winter. For silicate more results are found above the limit of detection, although the same trend applies.

Both phosphate and silicate show their highest values around the Bristol Channel for all seasons.

D.8 Metals

Table D.9: Summary of the results of the spatial correlation analysis for dissolved nickel

	1	2	3	4	5	6	7	8	9	10	11
Winter 1993	-	-	✗	-	-	-	-	-	-	-	✗
Spring 1993	✗	✓	✗	✗	✗	-	-	-	-	✗	✗
Summer 1993	✗	-	-	✗	✗	-	-	✗	✗	✗	✓
Autumn 1993	-	-	-	✗	✗	-	-	-	-	-	-
Winter 1994	-	-	-	✓	✗	-	-	-	-	-	-
Spring 1994	✗	-	-	-	-	-	-	-	-	-	-
Summer 1994	-	-	✗	-	-	-	-	-	-	-	-
Autumn 1994	-	-	-	-	-	-	-	-	-	-	-

Nickel: table D.9 shows the results of the spatial correlation coefficient analysis for dissolved nickel. Many cells have not been analysed as the data are below the limit of detection. From the Spring 1994 campaign onwards the limits of detection of the laboratories have increased; this results in only one cell from the last campaign being suitable for statistical analysis. Up until winter 1994 more results are available, but these generally show that the nickel results were uncorrelated.

Although it is not possible to determine the optimum sampling frequency directly from data from underway sampling, it is probable that the areas in which sampling could be decreased are those where levels are consistently low, and are as such not used in the analysis. Two littoral cells, numbers 6 and 7, show up clearly as being unsuitable for analysis at all times. These cells represent the coastline from Portland Bill to Lands End and from Lands End to The River Severn respectively. The values here are consistently low, indicating no inputs of nickel along this coast. It may therefore be possible to decrease the sampling interval to alternate baseline sites along this part of the coastline.

For total nickel, and all total metal measurements, there were insufficient data on which to perform an analysis.

Table D.10: Summary of the results of the spatial correlation analysis for dissolved zinc

	1	2	3	4	5	6	7	8	9	10	11
Winter 1993	✗	✗	-	✗	✗	✗	✗	-	✗	✗	✗
Spring 1993	✗	✓	✗	✗	✗	✗	✗	✗	-	-	✗
Summer 1993	✗	-	-	✗	✗	✗	✗	✗	-	✗	✗
Autumn 1993	-	-	-	✗	✗	-	-	-	-	-	-
Winter 1994	✗	✗	✗	✗	✗	✗	✗	-	-	-	✗
Spring 1994	-	-	✗	✗	-	-	-	-	✗	✗	-
Summer 1994	-	-	-	-	-	-	-	-	-	-	-
Autumn 1994	✗	✗	-	-	-	-	-	-	-	-	-

Zinc: table D.10 shows the results of applying the spatial correlation coefficient analysis to the dissolved zinc measurements. Only one zinc result shows a correlation throughout the entire two year measuring period. During the first five campaigns, results are available but are shown by this analysis to be highly variable. The sampling strategy being used at present is not therefore describing the full variability of dissolved zinc in coastal waters. As no *in-situ* zinc measurements are taken it has not been possible to establish an optimum sampling frequency. From Spring 1994 to present, almost all values fall below the established limit of detection at Llanelli of 4 μg/l. This may lead to the assumption that sampling could be cut, but the results from 1993 show that this needs further consideration.

The measurements of total zinc were analysed to see if there had been any obvious transcription or analysis errors. Some hot spots in the dissolved zinc results were found to have corresponding high levels in the total results. For example in Autumn 1994, Site 172 (Gut) had levels of dissolved zinc of 55.8 μg/l, with corresponding levels of total zinc of 67.9 μg/l. There are other results, however, where the results for total zinc indicate some error in that for dissolved zinc. For example, in Winter 1993 Site 128 (Mumbles) shows levels of 215 μg/l with corresponding total zinc levels of 11.1 μg/l. As sources of metals may be a single point, it is feasible that a hot spot in dissolved zinc would have no effect on the total zinc measurement some 15 km distant.

Table D.11: Summary of the results of the spatial correlation analysis for dissolved arsenic

	1	2	3	4	5	6	7	8	9	10	11
Winter 1993	-	-	✘	✘	✘	✘	✓	✘	✘	✘	✓
Spring 1993	-	-	-	✓	✓	✓	✓	✓	✘	✘	✘
Summer 1993	-	-	-	✓	✘	✓	✓	✓	✘	✓	✓
Autumn 1993	-	-	-	✓	✘	-	-	-	-	-	-
Winter 1994	-	-	-	-	-	-	-	-	-	-	✓
Spring 1994	-	-	-	-	-	-	-	-	✘	✘	✓
Summer 1994	-	-	-	-	-	-	-	-	✓	✘	✓
Autumn 1994	-	-	-	-	-	-	-	-	✘	✓	✓

Arsenic: results from the spatial analysis of the arsenic data are shown in table D.11. They may clearly be divided into two groups: the first four and the last four campaigns. The Llanelli limit of detection for arsenic is 2.5µg/l, and this has resulted in no numerical results for the 1994 campaigns. Results are available for the final three littoral cells which are measured by the Nottingham laboratory which has a limit of detection of 1µg/l. The higher limit of detection from the Llanelli laboratory means that the data may not be analysed statistically, and in addition is providing little information to the user. In addition the relatively large number of cells in 1993 that are correlated suggests that arsenic is being oversampled. In littoral cell 7, for example, further analysis has shown a high correlation exists with up to the fourth neighbour in each of the first three campaigns. It may be possible to decrease sampling in this region, which stretches from Lands End to the River Severn.

Analysis of the hot spots in the dissolved arsenic data and comparison with total arsenic data, shows that levels are generally similar. One exception is the Bristol Channel region which shows high levels in both dissolved and total arsenic. For example in Spring 1993 dissolved arsenic values in the Upper Bristol Channel vary between 2.2 and 2.8µg/l, with total arsenic levels between 2.4 and 7.7µg/l. This region appears to have high levels of arsenic throughout the first four campaigns, but was not high enough to exceed the limit of detection in the later campaigns.

Table D.12: Summary of the results of the spatial correlation analysis for chromium

	1	2	3	4	5	6	7	8	9	10	11
Winter 1993	-	-	-	-	-	-	-	-	-	-	-
Spring 1993	-	-	-	-	-	-	-	-	-	-	-
Summer 1993	-	-	✗	-	-	-	-	-	-	-	-
Autumn 1993	-	-	-	-	-	-	-	-	-	-	-
Winter 1994	-	-	-	-	-	-	-	-	-	-	-
Spring 1994	-	-	-	-	-	-	-	-	-	✗	-
Summer 1994	-	-	-	-	-	-	-	-	-	-	-
Autumn 1994	-	-	-	-	-	-	-	-	-	-	-

Chromium: as is clearly apparent from Table D.12 little statistical analysis could be carried out on the chromium results due to the majority being below the limit of detection, which was either 0.5 or 1µg/l in 1993. The 1994 limits of 2µg/l for Nottingham and 1.5µg/l for Llanelli have again resulted in very few results.

No obvious hot spots appear throughout the campaigns. One value of 28µg/l is recorded at Site 25 (Flamborough) in Spring 1993. No corresponding total chromium value is available but that at Site 24 (Filey Brig) is 1µg/l. This combined with the exceptionally high value suggests that this is a transcription error. It is suggested that this value is checked and if necessary, deleted. Relatively high levels of dissolved chromium between Sites 160 (Aberferaw) and 166 (Llanddulas) in Winter 1994 are accompanied by a rise in total chromium levels relative to surrounding cells.

Table D.13: Summary of the results of the spatial correlation analysis for dissolved lead

	1	2	3	4	5	6	7	8	9	10	11
Winter 1993	-	-	-	-	-	-	-	-	-	-	-
Spring 1993	-	-	-	-	-	-	-	-	-	-	-
Summer 1993	✗	-	-	-	-	-	-	-	-	-	-
Autumn 1993	-	-	-	-	-	-	-	-	-	-	-
Winter 1994	-	-	-	✗	✗	✗	✓	-	-	-	-
Spring 1994	-	-	-	-	-	-	-	-	-	-	-
Summer 1994	-	-	✗	-	-	-	-	-	-	-	-
Autumn 1994	-	-	-	-	-	-	-	-	-	-	-

Lead: table D.13 shows that in the case of dissolved lead, almost no cells have enough numerical values to carry the spatial sampling statistical analysis.

Most hot spots in dissolved lead were found to be between 2.5 and 4µg/l. There is no particular pattern through the campaigns corresponding to, for example, a major estuary with high surrounding population density. One extremely high value of 87 µg/l is found in Spring 1994. It is not possible to cross check this as there are no corresponding total lead results.

Cadmium: no spatial correlation coefficient analysis was applied to the dissolved cadmium results as all values were very low and the majority fell below the limit of detection. It has not therefore been possible to conclude statistically whether the sampling strategy is correct in terms of space.

The hot spots, which are in fact all those values which fall above the limit of detection show a clear increase in cadmium levels in the Upper Bristol Channel, between baseline sites 115 and 120 (Bridgwater and Newport). These results also show raised levels in total cadmium. The occurrence of elevated concentrations of dissolved cadmium in the Severn Estuary has been reported in the literature[14].

Table D.14: Summary of the results of the spatial correlation analysis for dissolved copper

	1	2	3	4	5	6	7	8	9	10	11
Winter 1993	✗	✗	-	✓	-	-	✓	-	✗	✓	✗
Spring 1993	✗	✗	-	✗	✗	✗	✓	✓	✗	-	✗
Summer 1993	✗	✓	-	✗	-	-	-	✓	✗	✗	✗
Autumn 1993	-	-	-	✗	✗	-	-	-	-	-	-
Winter 1994	-	✗	✗	-	✗	-	✗	-	-	-	✗
Spring 1994	-	-	✗	-	-	-	✓	✓	✗	✗	✗
Summer 1994	✗	✓	✓	-	✗	✗	✓	✓	-	-	✓
Autumn 1994	✗	-	✓	✗	✗	✗	✗	✗	-	-	✗

Copper: the copper results show the most highly correlated cells of all the metals (see table D.14). In particular cells 7 and 8 (Land Ends to St Davids Head) show themselves to be relatively highly correlated. More copper results are above the limit of detection of the laboratories used. It is not possible to conclude the optimum sampling frequency in the uncorrelated cells. However, in a certain number of cells, particularly 7 and 8, further analysis has shown that the sites are correlated with their fourth neighbour, suggesting that the sampling frequency could be reduced.

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14 HARPER D J, "The distribution of dissolved cadmium, lead and copper in the Bristol Channel and the outer Severn estuary", Marine Chemistry, 33(1/2), 1991

Dissolved copper hot spots are fairly random between the seasons with no apparent increase in the Upper Bristol Channel as shown in many of the other metals. One hot spot in Winter 1993 of 165µg/l of dissolved copper is verified by a value of total copper of 220 µg/l. This is found at Site 27 (Hornsea) and suggests either a source of copper or contamination of the sample. Conversely a value of 57 µg/l in Spring 1993 is not supported by the total copper result.

There is a growing concern about the increased use of copper based anti-fouling paints for small boats, since the general ban on tributyl tin based paints has led to an increased use of these alternative materials[15]. This source of copper may in part explain the elevated concentrations of copper seen in some regions.

Mercury: the sample taken for mercury analysis is analysed for total mercury content. This is partly because levels of mercury are low, and would generally fall below the limit of detection if only the dissolved phase were measured. Most cells still showed a significant number of results below the limit of detection meaning that detailed analysis has not been possible.

The levels of mercury seem to be stable around the country, with hot spots rarely occurring. The highest values are seen in Spring 1993, with a maximum of 0.645µg/l located around the Rivers Tyne and Wear.

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[15] CLAISSE D AND ALZIEU C, "Copper contamination as result of antifouling paint regulations", Marine Pollution Bulletin, 26, 1993

E LABORATORY ANALYSES

E.1 Llanelli Laboratory

Suspended Solids:	Filtration and gravimetry
Chlorophyll-a:	Slow acetone extraction and spectrophotometry
Copper:	Differential pulse anodic stripping voltammetry
Nickel:	Differential pulse anodic stripping voltammetry
Cadmium:	Differential pulse anodic stripping voltammetry
Lead:	Differential pulse anodic stripping voltammetry
Zinc:	Differential pulse anodic stripping voltammetry
Mercury:	Cold vapour generation/fluorescence
Phosphate:	Automated colorimetric analysis
Silicate:	Automated colorimetric analysis
TON:	Automated colorimetric analysis
Nitrite:	Automated colorimetric analysis
Ammonia:	Automated colorimetric analysis

E.2 Nottingham Laboratory

Suspended Solids:	Filtration and gravimetry
Chlorophyll-a:	Slow acetone extraction and spectrophotometry
Arsenic:	Pretreatment and analysis by hydride generation
Mercury:	Cold vapour generation/fluorescence
Phosphate:	Air segmented continuous flow
Silicate:	Air segmented continuous flow
TON:	Air segmented continuous flow
Nitrite:	Air segmented continuous flow
Ammonia:	Air segmented continuous flow

F REGIONAL IMAGE STATISTICS

Table F.1: Northumbrian and Yorkshire

	no. flown	%	no. cloud free	%	no. glint free	%
November 92	15	75	9	60	15	100
February 93	20	100	18	90	20	100
May 93	18	90	17	94.4	17	94.4
August 93	19	95	17	89.5	17	89.5
May 94	20	100	6	30	14	70
July 94	13	65	2	15.4	13	100
September 94	16	80	8	50	15	93.7

Table F.2: Anglian

	no. flown	%	no. cloud free	%	no. glint free	%
November 92	17	56.7	7	41.2	16	94.1
February 93	30	100	20	66.6	29	96.7
May 93	25	83.3	20	80	25	100
August 93	26	86.6	13	50	24	92.3
May 94	30	100	24	80	23	76.7
July 94	28	93.3	21	75	20	71.4
September 94	13	43.3	6	46.2	11	84.6

Table F.3: Southern

	no. flown	%	no. cloud free	%	no. glint free	%
November 92	17	68	13	76.5	16	94.1
February 93	24	96	17	70.8	23	95.8
May 93	25	100	21	87.5	23	92
August 93	25	100	21	87.5	19	76
May 94	25	100	24	96	25	100
July 94	24	96	20	83.3	19	79.2
September 94	25	100	21	84	24	96

Table F.4: Southwestern

	no. flown	%	no. cloud free	%	no. glint free	%
November 92	12	27.3	3	25	12	100
February 93	43	97.7	23	53.5	41	95.3
May 93	43	97.7	37	86	32	74.4
August 93	43	97.7	37	86	41	95.3
May 94	41	93.2	37	90.2	20	48.8
July 94	36	81.8	30	83.3	24	66.7
September 94	41	93.2	27	65.8	40	97.6

Table F.5: Welsh

	no. flown	%	no. cloud free	%	no. glint free	%
November 92	22	40.7	9	40.9	21	95.5
February 93	53	98.1	34	64.2	50	94.3
May 93	54	100	42	77.7	48	88.8
August 93	53	98.1	50	94.3	48	90.6
May 94	45	83.3	37	82.2	29	64.4
July 94	39	72.2	16	41	35	89.7
September 94	48	88.8	17	35.4	46	95.8

Table F.6: Northwestern

	no. flown	%	no. cloud free	%	no. glint free	%
November 92	19	67.9	11	57.9	19	100
February 93	27	96.4	19	70.4	26	96.3
May 93	27	96.4	13	48.1	27	100
August 93	27	96.4	23	85.2	26	96.3
May 94	23	82.1	15	65.2	22	95.7
July 94	22	78.6	18	81.8	21	95.5
September 94	28	100	17	60.7	24	96

Table F.7: Summary statistics

Area	Average percentage coverage
National	85.9
Northumbrian and Yorkshire	86.4
Anglian	80.5
Southern	94.3
South Western	84.1
Welsh	83.0
Northwestern	88.3