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Nutrient Levels and Statutory Quality Objectives for Estuaries and Coastal Waters

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NUTRIENT LEVELS AND STATUTORY QUALITY OBJECTIVES FOR ESTUARIES AND COASTAL WATERS

Y J Rees, S C Nixon, W Parr and P van Dijk

Research Contractor:
WRc plc
Henley Road
Medmenham Marlow
Buckinghamshire SL7 2HD

National Rivers Authority
Rivers House Waterside Drive
Almondsbury Bristol BS12 4UD

R&D Note 70

National Rivers Authority
Rivers House
Waterside Drive
Almondsbury
BRISTOL
BS12 4UD

Tel: 0454 624400
Fax: 0454 624409

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Research Contractor
This document was produced under R&D Contract 353 by:

WRc plc
Henley Road
Medmenham Marlow
Buckinghamshire
SL7 2HD

Tel: 0491 571531
Fax: 0491 579094

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NRA Project Leader
The NRA's Project Leader for R&D Contract 353:

R Robinson - South Western Region

Additional Copies
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CONTENTS

CONTENTS (Continued) Page

LIST OF TABLES

LIST OF FIGURES

PREFACE

This document reports the initial research undertaken to develop a classification scheme for nutrients based on observed levels of total inorganic nitrogen and soluble reactive phosphorus in the coastal waters and estuaries of the UK. Since the completion of this research in March 1992, complimentary work has been undertaken to assess the options for classifying tidal waters on their trophic status (NRA R&D Note 248, project 0423). Both the proposed nutrient classification and the options for trophic status classification are being further considered and developed for possible inclusion and implementation in the NRAs proposed General Quality Assessment (GQA) schemes for estuaries and coastal waters (NRA Project 0469). Further information, if required, should be sought from the NRAs Project Leader for the development of GQA schemes, Dr Mark Everard at Head Office, Bristol.

EXECUTIVE SUMMARY

Under the Water Resources Act 1991 all controlled waters may be subject to a system of classification. At present there is no suitable classification for estuarine or coastal waters but the NRA has developed outline schemes dividing water quality into four classes based on water and sediment quality, and biological and aesthetic criteria.

This report proposes a classification scheme for the nutrient component of the schemes for estuarine and coastal waters based on existing levels of inorganic nitrogen and phosphorus in UK estuarine and coastal waters. The scheme is designed to reflect the extent of contamination from natural and anthropogenic sources and is not intended to relate directly to algal production or eutrophication. However, the relevance of the scheme to other nutrients and to eutrophication potential is commented on briefly.

A single scheme is proposed for estuarine and coastal waters based on the measurement of salinity-related nutrient levels in the winter months. The scheme consists of four classes which represent low, average, elevated and severely contaminated status. The class boundaries have been derived from data which were not collected specifically for the development of the classification scheme.

Separate sampling strategies are proposed for estuarine and coastal waters. The strategy for estuaries is more sophisticated to counter the higher spatial and temporal variability in nutrient quality typically observed in these waters.

The scheme is severely constrained because of the lack of comparable data from a truly representative sample of UK estuaries and it is considered essential that the class boundaries and the sampling strategy are reviewed in the light of data collected for the scheme.

KEY WORDS

Nutrients, UK Estuarine and Coastal Waters, Statutory Quality Objectives.

1. INTRODUCTION

Sections 82 and 83 respectively of the Water Resources Act 1991 required that all controlled waters may be subject to a system of classification and that Statutory Water Quality Objectives (SWQOs) may be set in relation to such waters by the Secretary of State for the Department of the Environment (DoE). Similar powers are laid down in Scotland (Schedule 23 sections 30A to 30E of the Water Act 1989 which amended the Control of Pollution Act 1974).

The NRA (1991a) has proposed to the DoE that SWQOs should consist of three elements, namely:

- achievement of relevant use-related environmental quality objectives (EQOs), i.e. compliance with relevant environmental quality standards (EQSs);
- achievement of target class of relevant classification scheme;
- compliance with EC directives.

At present, no classification scheme exists for coastal waters and the existing National Water Council (NWC) scheme for estuaries is considered unsuitable for a statutory scheme because of its subjectivity and the limited determinands it covers. In 1990, a sub-group of the NRA Water Quality Survey Group proposed a framework for a new tidal waters classification scheme which has components relating to water (including nutrient concentrations), aesthetic and biological quality, and also to sediment accumulation of persistent toxic substances. They also proposed that coastal waters be separated into two zones (NRA 1991a):

- nearshore waters, extending from the landward limit to a line 200 metres offshore from the spring tide low water mark; and
- offshore waters, extending from the 200 metre line to the Three Nautical Mile Limit.

This document reports the research undertaken to develop the nutrient components of the proposed classification scheme. More detailed information relating to the data obtained is presented in Appendix A.

2. PROJECT OBJECTIVES

The overall objectives of the project, as described in the Project Investment Appraisal, was:

"to establish levels of nutrients (combined nitrogen and phosphorus) occurring in UK coastal and estuarine waters and utilise these data in the development of a system classifying estuarine and coastal waters into 4 classes which reflect the extent to which they are affected by natural and anthropogenic land-derived sources of nutrients."

The specific project objectives were as follows:

1. To review published literature and other sources of data on the concentrations of combined nitrogen and phosphorus species measured in UK estuarine and coastal waters. To document this information in a form which can be used for the future amendment of class limiting thresholds (as derived in 3 and 4 below) should this prove necessary.

2. To consider the feasibility of deriving a single unified classification system for nutrients in estuarine and coastal waters. In the event that a unified system is not found to be feasible, to set out the need for and merits of separate systems.

3. To use the information collated in 1 to establish typical 'natural' background concentrations of combined nitrogen and phosphorus species and to propose threshold levels which can be used to define the first class of the series representing waters substantially unaffected by anthropogenic sources.

4. To use the information collated in 1 to propose threshold levels for a further three classes of waters representing increasing concentrations of nutrients and broadly relating to increasing degrees of anthropogenic impact.

5. To demonstrate the implications of the proposed class limiting thresholds for a representative range of UK estuarine and coastal waters to which the classification scheme will apply.

6. To define a sampling and analytical strategy consistent with the class limiting thresholds proposed which is appropriate for future monitoring and classification of estuarine and coastal waters.

7. To comment briefly on the relationship between the proposed classification system and nutrient standards developed elsewhere, observed algal populations and standing crops, and also on the occurrence of nuisance blooms of algae, using relevant data collated by the contractors in relation to NRA Project No. 053 (Development of further EQSs).

8. To comment, briefly, on the possible relevance of standards for other algal nutrients (e.g. silica).

3. COLLATION OF DATA ON NUTRIENTS IN TIDAL WATERS

3.1 Approach adopted to collate data

The first stage of the study was to review existing information on nutrient levels in estuarine and coastal waters. A literature review was conducted, however, very few useful published data were found, and the project, therefore, relied heavily on the use and analysis of unpublished data.

Possible sources of unpublished data on levels of nutrients in tidal waters, including NRA Regions, universities and other research establishments were approached. Data was requested on levels of nitrogen and phosphorus, and also some interpretation parameters such as dissolved oxygen, salinity and temperature, in estuarine and coastal waters from 1986 onwards. The data request was accompanied by a questionnaire asking for details of sampling and analytical strategy so that the suitability of the data could be quickly assessed.

3.2 Availability of data

The response of the data requests varied greatly but was generally positive. A number of conclusions about the nature of the data were drawn:

1. Most of the organisations approached were unable to deliver data in the format requested. A large proportion of data arrived as hardcopy and the data sent on disk were in several different formats because NRA Regions and RPBs have their own data handling facilities. Several large data sets only available as hardcopy were not used because of time restrictions.

2. There was no standard sampling strategy and often factors such as spring/neap and daily tidal cycle were not taken into account. This meant that much of the data was incompatible and unsuitable for the development of a classification scheme.

3. There was no standard analytical procedures. Nutrient levels were measured as a variety of fractions and recorded in different units; for example, one data set may hold information as µmoles l^{-1} nitrate and ammonia, whereas another data set may hold results as mg l^{-1} ammonia or ammonium-N only.

4. Most of the data were from the larger more contaminated estuaries. Very few data sets were available from sites which could be deemed to be 'unaffected by man's activities'.

3.3 Summary of the data received

Of the data available, a total of 42 estuaries and 5 coastal sections had data on winter nutrient concentrations (see Section 6.1). The highest nutrient levels were observed in the Nene and the Thames estuaries, where nutrient levels often exceeded 10 mg l^{-1} total inorganic nitrogen (TIN) and 1.5 mg l^{-1} soluble reactive phosphorus (SRP). The least contaminated sites were the Firth of Lorne, Loch Eil, Loch Linnhe and Loch Fyne with nutrient levels often less than 0.1 mg l^{-1} TIN or SRP. A summary of the data received is given in Table 3.1. Further details can be found in Appendix A. Examples of average winter levels of TIN and SRP in some UK estuaries (1986 - 1990) are given in Figures 3.1 and 3.2, respectively.

Table 3.1 An overview of the data broadly suitable for use in the project

	England	Wales	Scotland
Estuaries			
Number of data sets used	27	3	12
Maximum winter nitrogen (mg l^{-1} TIN)	12.40	3.80	6.70
Maximum winter phosphorus (mg l^{-1} SRP)	1.62	0.06	0.12
Coastal waters			
Number of data sets used	3	2	0
Maximum winter nitrogen (mg l^{-1} TIN)	7.10	2.30	-
Maximum winter phosphorus (mg l^{-1} SRP)	0.15	0.14	-

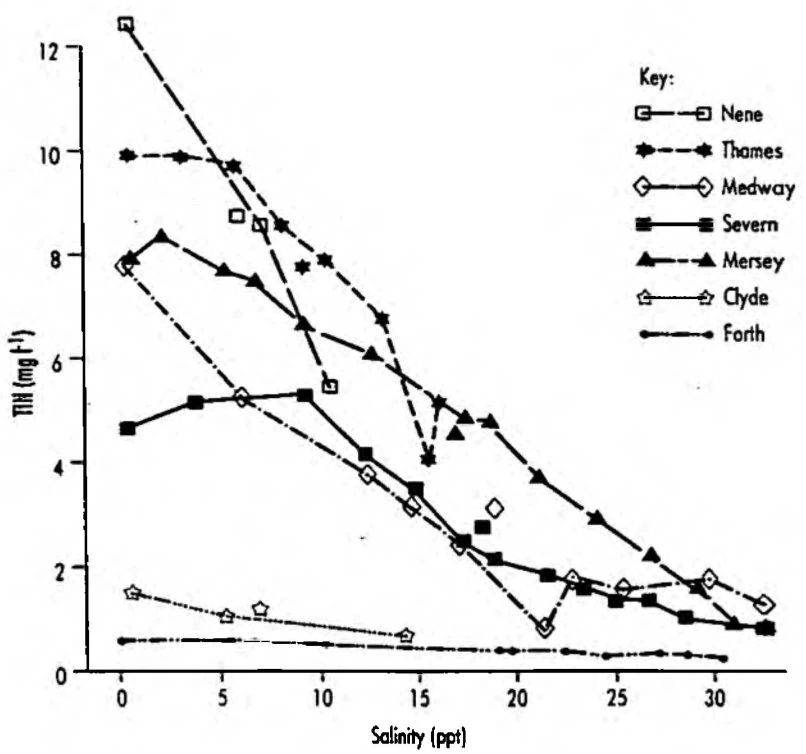

Figure 3.1 Average winter levels of TIN in some UK estuaries (1986-1990)

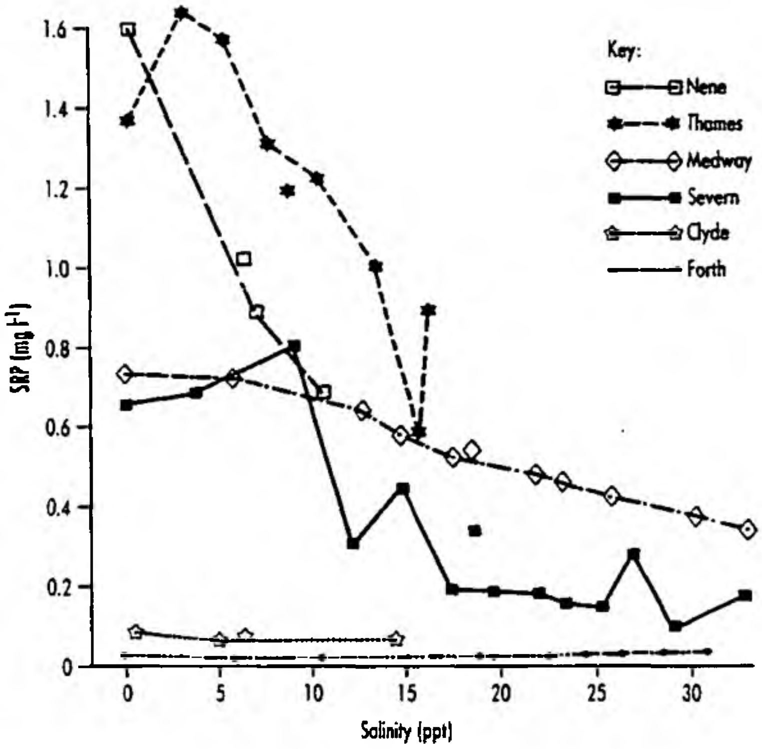

Figure 3.2 Average winter levels of SRP in some UK estuaries (1986-1990).

4. FACTORS AFFECTING NUTRIENT CONCENTRATIONS

The derivation of a classification scheme for nutrient levels in tidal waters is difficult due to the complexity and size of the spatial and temporal variability typically observed. It is, therefore, necessary to reduce this variability. To do this factors affecting levels of nutrients in tidal waters need to be identified and the data restricted to take these factors into account. Data were not available to either identify or determine the relative importance of all possible sources of variability in tidal water nutrient levels. However, the effect of restricting data to reduce the variability associated with some of the factors considered to be the most important is demonstrated using data from the Severn estuary in Figure 4.1.

4.1 Factors associated with spatial variability

Some of the identifiable factors associated with the spatial variability of nutrient levels observed in tidal waters are:

- salinity;
- sampling depth;
- position in the estuary;
- the location of contaminating inputs.

The changes in nutrient levels along the length of an estuary, as the more contaminated freshwater in diluted by the less contaminated saline water, are typically at least as great as those between estuaries. This change in nutrient levels is best accounted for by relating nutrient levels to salinity in the classification scheme (Figure 4.1, line B).

Of the factors listed above, sampling depth would be important in stratified tidal waters, particularly if relatively contaminated freshwater was confined to the upper layers. With regard to the position in the estuary, there may be distinct differences in water quality across the width of estuaries, possibly in relation to bankside inputs and possibly because when an estuary is very wide the Coriolis force may induce a horizontal separation of the flow, with outgoing flow on the right hand side in the northern hemisphere, and the incoming flow on the left hand side. The location of contaminant inputs into the receiving waters, for example, at the landward limit or mouth of an estuary, can also influence the spatial distribution and concentrations of nutrients along the length of an estuary. This effect can be considerable since estuaries and coastal waters are often centres of human populations and industry and are, therefore, often the receptacle of the waste produced.

Many of the data sets available were generally not suitable for assessing the extent to which these factors affect nutrient quality in the estuary. However, some of the variability associated with the factors listed above can be reduced within the sampling strategy by requiring nutrient measurements to be made, for example, at a given depth in a given position.

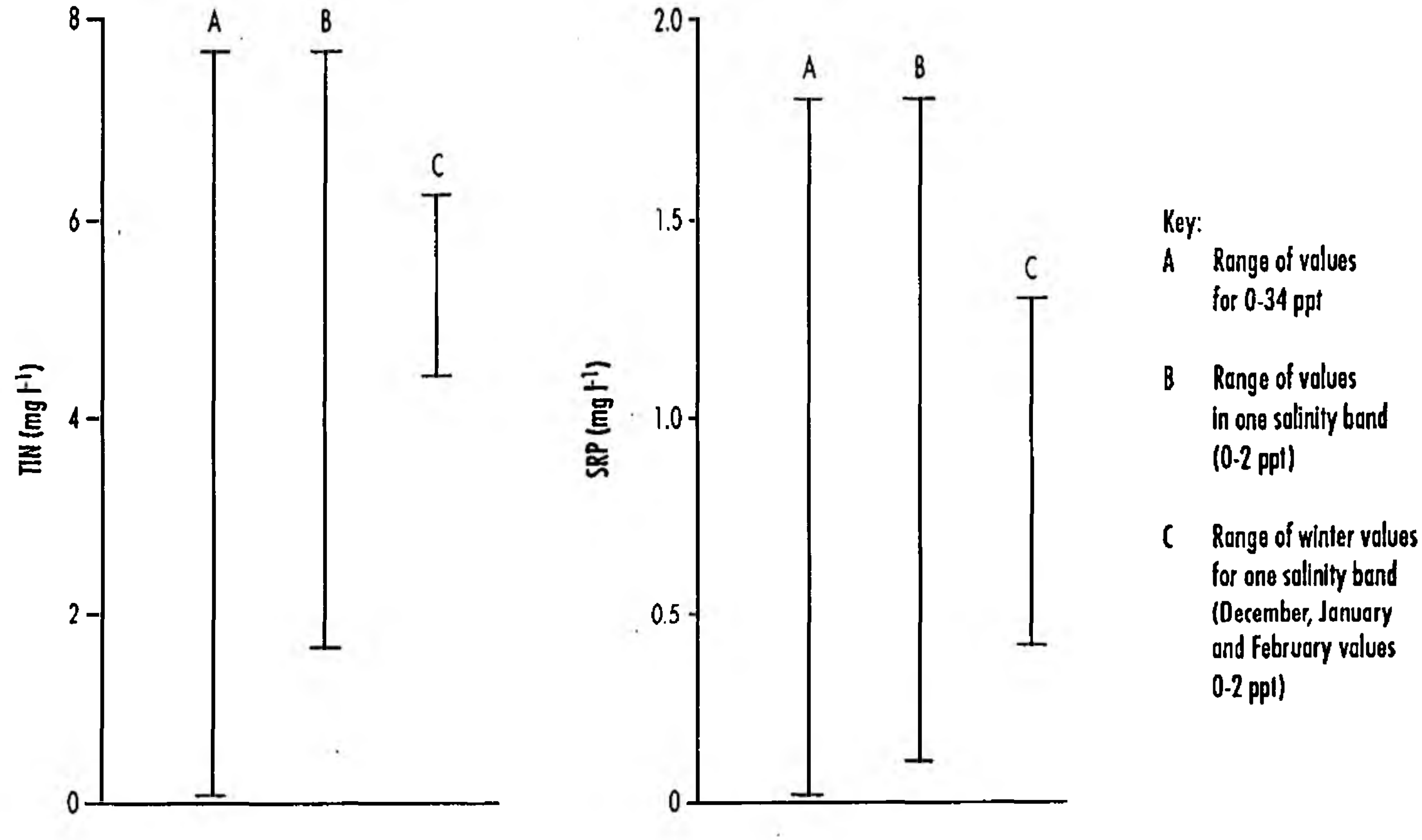

Figure 4.1 **Reducing the variability of TIN and SRP measurement by taking some of the major factors affecting tidal water nutrient concentrations into account – Severn Estuary 1986-1990.**

4.2 Factors associated with temporal variability

Some of the identifiable factors associated with the temporal variability in nutrient levels observed in tidal waters are:

- year;
- season;
- spring/neap tidal cycle;
- daily tidal cycle

On an annual basis, nutrient levels exhibit a strong cycle; nutrient levels are generally higher in the winter than the summer. Temporal variation is also observed over much shorter time periods such as spring/neap and daily tidal cycle, especially in estuarine waters. For example, large tidal flushes associated with spring tides may cause increased mixing of nutrient-rich interstitial sediment water with the water column. In addition, many anthropogenic discharges are linked to the state of the tide, for example, they only discharge when the tide is on the ebb.

Again, some of the variability associated with these factors can be eliminated by restricting the conditions applied in the sampling strategy, for example, by defining a seasonal 'window' for sampling (Figure 4.1, line C and Section 6). However, no data sets were available to determine the importance of these factors fully.

Other sources of temporal variation are more difficult to take account of. For example, high river flows could be associated with increased nutrient loads from the freshwater catchment (e.g. increased runoff from agricultural land and storm discharges), and also with the resuspension of sediment which might be another source of nutrients to the water column. In addition, the amount of freshwater entering an estuary will determine the retention time of nutrients and thereby influence the rate of primary productivity.

5. THE PROPOSED CLASSIFICATION SCHEME

There are two fundamental steps in the development of a classification scheme. Firstly, the appropriate water quality determinands on which to base the scheme must be defined and, secondly, the class determining boundaries based on measurement of the determinands must be established. In addition, to these initial steps, it is necessary to consider approaches to reduce the sizeable variability associated with nutrient concentrations in tidal waters. This is very important as the scheme must be robust and applied with confidence to reduce the change of misclassification so that changes in class are accompanied by real changes in water quality.

The steps in the development of a suitable tidal waters classification scheme for nutrients can be identified as:

- selection of suitable nutrient determinands on which to base the scheme;
- reduction of the variability associated with the measurement of these determinands within the classification scheme;
- consideration of the merits/demerits of a single scheme for tidal waters or separate schemes for coastal and for estuarine waters;
- use of available data to set appropriate class boundaries;
- design of a workable sampling strategy to ensure that in future the variability associated with the measurement of these determinands is reduced to obtain the desired precision in establishing class.

The approach adopted at each of these steps is discussed below.

5.1 Nutrient quality determinands

5.1.1 Chemical measure

Nitrogen is the nutrient most often limiting to phytoplankton growth in UK coastal waters (in contrast to freshwaters where phosphorus is often more important). The situation in estuaries is less clear since a point must occur where the phosphorus-limited freshwater input is countered by the input of nitrogen-limited saline water. It is, therefore, important that monitoring is conducted to establish both nitrogen and phosphorus levels.

It is suggested that the classification scheme is based upon the measurement of midwinter levels of nitrogen as total inorganic nitrogen (TIN, i.e. the sum of the ammoniacal and oxidised nitrogen fractions) and phosphorus as soluble reactive phosphorus (SRP, sometimes referred to as orthophosphate). These fractions were chosen for a number of reasons:

1. Since inorganic nutrient fractions are most commonly monitored, there are more data available on levels found in UK tidal waters. In contrast, there is very little information on total nutrient levels in estuarine and coastal waters making it impossible to set class determining boundaries on this basis.

2. In midwinter the standing crop of phytoplankton is extremely low and levels of organic nitrogen (N) and phosphorus (P) are unlikely to be detected in coastal waters against the much higher background levels of TIN and SRP. Thus measurement of the organic N and P fractions to give an estimate of total nutrient concentration would require additional effort and cost whilst adding little to the result.

3. They are the nutrient species with greatest relevance to primary productivity.

It is also suggested that class boundaries are set separately for TIN and SRP and that the overall class assignment should default to the poorer determinand. This approach is the most suitable if the classification is to represent levels of contamination. However, since it is the limiting nutrient which is more important when assessing eutrophication potential, use of this approach makes it difficult to relate the classification to effects.

5.1.2 Statistical measure

Any summary measure of the levels of nutrients must take account of the highly variable nature of the determinands. In the discussion document on Statutory Water Quality Objectives, the NRA (NRA 1991a) has proposed that class-limiting criteria should be expressed as 95 percentiles rather than a less extreme percentile, such as 80 percentile, or a mean value, in order to prevent a large percentage of values exceeding a standard value set to protect against some detrimental effect. However, since the variability of nutrient concentrations in tidal waters is so great, and the nutrient classification boundaries are not to be based on effect levels, the mean value is considered more appropriate since, statistically, it is more robust. Insufficient data collected for non-parametric estimation of 95 percentiles (at least 19 sampling exercises would be needed for each estuary). Therefore, the arithmetic mean nutrient level is considered the most appropriate measure.

5.2 Relationship of nutrient levels to salinity

It was considered that a significant proportion of the variability observed in tidal water nutrient quality could be accounted for by the use of salinity-related nutrient class boundaries in the range 0-33 ppt salinity. Further reduction in the variability would then be achieved when setting the sampling requirements for the classification scheme which are discussed later (Sections 6.1 and 6.2).

The main process responsible for the reduction of nutrient levels from the freshwater to the tidal end of an estuary is physical dilution, as the generally more contaminated brackish waters mix with the less contaminated, more saline coastal waters. Given that the classification is required to be sufficiently sensitive to detect differences in quality, both temporally and spatially, the change in nutrient levels associated with this process of dilution must be accounted for. This can be achieved by relating nutrient levels to salinity since the level of chloride ions, which act conservatively, can be used as a measure of dilution.

Since the process is one of dilution, the change in nutrient levels per unit of salinity is dependent upon the difference in concentration of the incoming freshwater compared to that of the diluting water. Therefore, the designated class boundaries will necessarily converge at higher salinities.

The use of salinity related boundaries can, therefore, be considered as a way of accounting for the natural change in water quality from the freshwater limit of estuaries (0 ppt salinity) to the coastal water limit (33 ppt salinity). It is also considered that the position of the class boundaries at 0 ppt salinity should ideally correspond to boundaries set in any future freshwater classification and that the class boundaries at 33 ppt salinity should correspond to the class boundaries for any coastal water with salinity ≥ 33 ppt.

The class boundaries used for the classification scheme assume conservative behaviour. Observation of the actual relationship between nutrient levels and salinity for winter data from the estuaries with the most comprehensive monitoring programmes, the Mersey, the Thames and the Severn, show that this, on a very general basis, is a reasonable assumption for winter data. This is to be expected because of reduced biological activity during winter months.

The actual relationship between nutrient levels and salinity is bound to be site-dependent due to the existence of discharges directly to an estuary seaward of the freshwater input and/or the presence of nutrient sinks. For example, the relationship between nitrogen levels and salinity is likely to be less strong in an estuary with numerous nutrient-rich discharges, seaward of the main freshwater input as these would make the freshwater nutrient input less significant.

5.3 One or two schemes?

In the Water Resources Act (Section 104, HMSO 1991) estuaries are considered in the same category as coastal waters. However, an NRA working group (NRA 1991a) recently considered that estuaries require their own classification scheme because they are distinct in terms of their salinity, the patterns of their flow and their biological quality.

It was originally thought that a single classification scheme would lack the sensitivity required to detect changes in nutrient quality. This problem has, to a large extent, been overcome by the use of salinity related boundaries. It is, therefore, proposed that one salinity-related classification system would be sufficiently sensitive. However, the greater complexity of estuarine systems compared to coastal waters is recognised and, therefore, a more sophisticated sampling regime for their classification is proposed. The use of one classification scheme which is salinity-related also overcomes the problem of predefining the point at which estuarine waters become coastal.

5.4 Positioning class boundaries

The position of the class boundaries in any classification scheme which is not based on effects will be somewhat arbitrary and can only be decided by subjective judgements. Three approaches to setting the position of the class boundaries were considered.

The first approach examined was to establish background levels and to base subsequent class boundaries at multiples of this level. However, this approach could not be adopted here because of the paucity of data from uncontaminated areas. In addition, the use of the term background must be viewed with caution as there are very few if any tidal waters (apart perhaps from a very few of the more remote Scottish Lochs, and all the data from these relate to nutrient levels at salinities greater than 22 ppt) which could accurately be deemed 'unaffected by man's activities'. For example, of the data received for estuaries in England and Wales, the Dart appears to have the lowest nutrient levels, but the levels of nitrogen in particular are an order of magnitude greater than the levels observed in the Scottish lochs (see Table 5.1). This reflects the numerous discharges, including some from sewage treatment works, into the Dart. Use of this approach would imply that no estuaries in England and Wales would attain background status and it was not possible, therefore, to proceed on this basis.

Table 5.1 Typical levels of inorganic nitrogen and phosphorus observed in some tidal waters of low nutrient status

Site	Period	Salinity (ppt)	TIN ($\mu g\ l^{-1}$)	SRP ($\mu g\ l^{-1}$)	Ref.
Firth of Lorne	Feb 1979	30.1 - 34.5	100 - 120	20	1
	Feb 1980	31 - 34	100 - 120	20	2
Loch Eil	Feb 1980	22 - 31	70 - 100	10 - 20	2
Loch Linnhe	Feb 1980	26 - 33	70 - 130	12 - 20	2
Loch Fyne	Feb 1986	30 - 34	150 - 250	30 - 80	3
	Feb 1988	-	70 - 280	25 - 60	3
Dart	Dec 1990	28 - 30	410 - 810	10 - 20	4
	Dec 1990	<0.1	1100 - 2000	60 - 120	4

Notes: TIN Total Inorganic Nitrogen measured on a filtered sample
SRP Soluble Reactive Phosphorus measured on a filtered sample
1 Grantham *et al.* (1983a)
2 Grantham *et al.* (1983b)
3 Unpublished data from Clyde RPB
4 Unpublished data from South West NRA

The second approach examined was to set class boundaries so that given percentages of UK estuaries would initially fall into each class (see Figure 5.1). The suitability of this approach is dependent on having a data set which is sufficiently representative of the overall population of tidal water nutrient levels. The lack of comparable data on nutrients in coastal and estuarine waters means that the data sample we have is unlikely to be representative and makes the derivation of class limiting boundaries based on percentages of values falling into a class unrealistic. In particular, there is a bias of data from the more contaminated estuaries, so any nutrient classification scheme based on percentages of these data would itself be flawed.

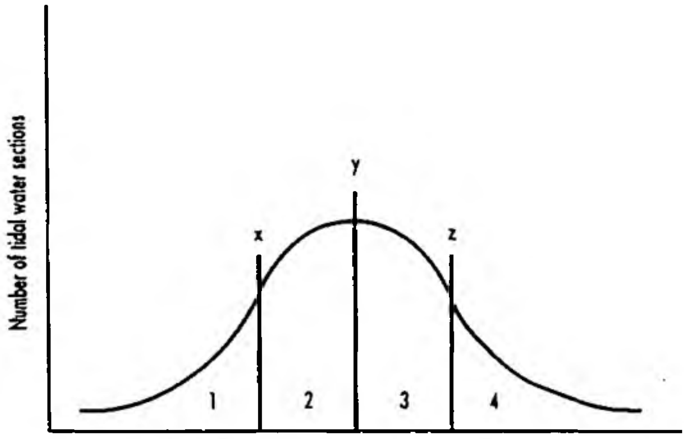

Figure 5.1 Using the population of existing tidal water nutrient concentrations to set class boundaries

The third approach examined was to use the existing data to determine the levels of nutrients at the most contaminated sites available and base the class boundaries on these. This approach could be used with a greater degree of confidence as the data sets available for the more contaminated estuaries such as the Thames, Severn, Mersey and the Nene are more comprehensive.

This last approach was, therefore adopted and the classification boundaries were calculated as a percentage of the maximum nutrient levels found. The maximum TIN and SRP levels observed for UK tidal waters in the period 1986-1990 in the salinity ranges 0-2 ppt and 32-34 ppt (i.e. the low and high salinity ends of the scheme) and the proposed class boundaries are shown in Table 5.2 and illustrated graphically in Figures 5.2 and 5.3. Since this approach has been used it is most appropriate to designate the classes as having low, moderate, elevated and severely contaminated status. It should be noted that the class boundaries proposed are tentative suggestions which should be reviewed in the light of experience and data.

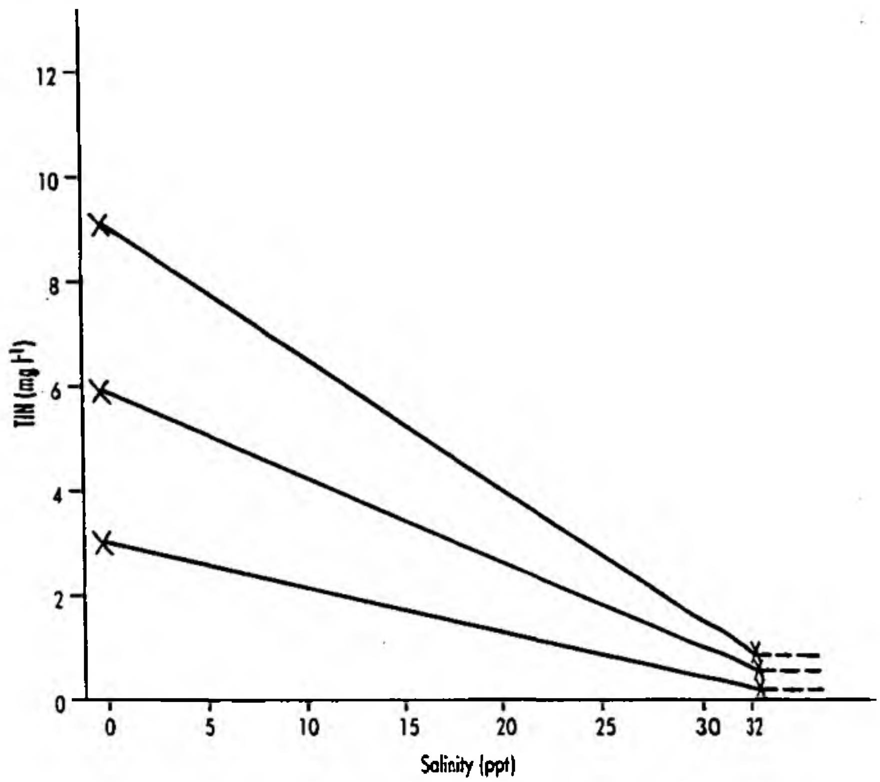

Figure 5.2 Boundaries proposed for the classification of tidal waters according to winter levels of TIN measured on a three year rolling average basis

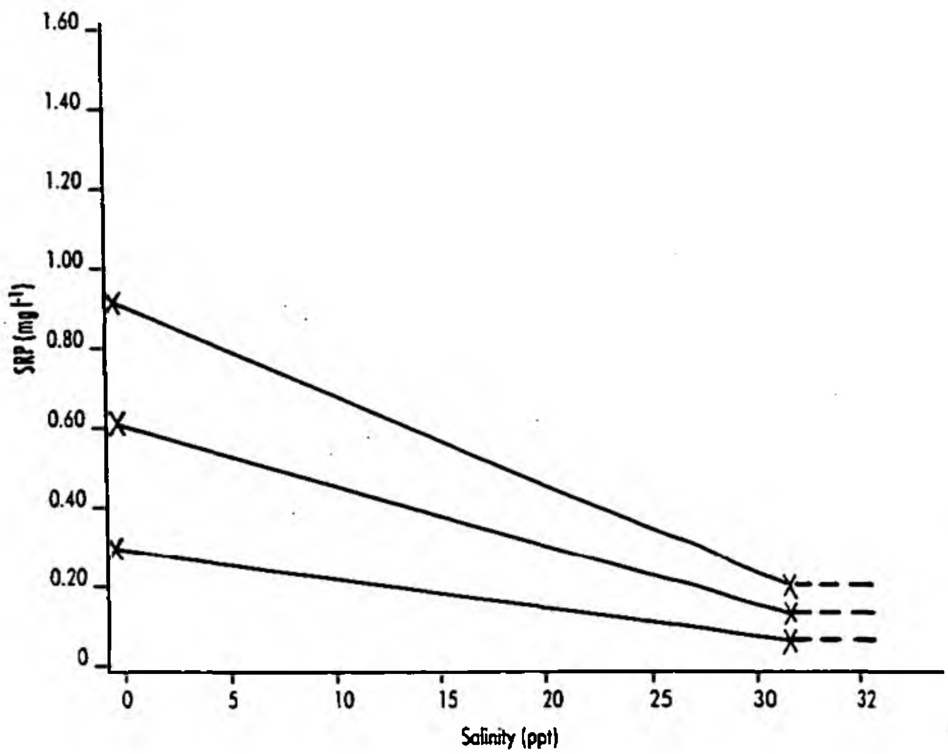

Figure 5.3 Boundaries proposed for the classification of tidal waters according to winter levels of SRP measured on a three year rolling average basis

Table 5.2 Nutrient class boundaries at low and high salinity values

		TIN (mg l^{-1})		SRP (mg l^{-1})	
Class boundary	% of Maximum	0-2 ppt	32-34 ppt	0-2 ppt	32-34 ppt
1/2	≈25%	3.0	0.3	0.3	0.075
2/3	≈50%	6.0	0.6	0.6	0.15
3/4	≈75%	9.0	0.9	0.9	0.225
Maximum		12.37	1.37	1.12	0.33

5.5 Banding tidal waters into classes

The scheme proposed would enable the classification bands to be defined by water quality, either along a stretch of coastline or within an estuary, providing that the sampling requirements for classification are met. Alternatively an estuary 'average' nutrient level at an 'average' salinity might be considered to be more appropriate for some estuaries for a national overview. The banding of estuaries may be particularly useful on local scale to assess the nutrient quality of areas requiring particular attention. For example, where one side of an estuary is more contaminated due to urban or industrial development it may be classified separately from the less contaminated side. Its higher class assignment would target the need to improve the nutrient status in that band but any improvement measures taken would have a more obvious effect in band class than if the estuary were considered as a whole.

The flexibility that this approach provides allows:

1. More intensive sampling to be conducted in those estuaries where more detailed information is required.

2. A greater level of detail, since estuaries can be classified as a whole or as a number of bands.

3. Freedom to apply specialist knowledge of bands of tidal waters to classify these bands separately and to allocate resources most effectively.

6. MONITORING STRATEGY

A common theme throughout this report has been the spatial and temporal variability of nutrient concentrations in tidal waters. Given the scale of this variability, any monitoring approach relying solely on random sampling theory is very likely to produce unacceptably large errors. Two approaches of addressing this difficulty are discussed in this Section: the use of a structured sampling strategy, and the use of predictive mathematical models.

If properly designed, a structured sampling strategy can be used to reduce much of the variability in nutrient levels observed in tidal waters and especially in estuaries. In this way, comparable standardised concentrations would be obtainable for classification purposes. Ideally, the strategy would have been designed by assessing the relative variability associated with the factors affecting nutrient levels. This would require an intensive monitoring programme over a number of years and sites. The programme would need to be designed to study all of the factors likely to affect nutrient concentrations and would attempt to assess the relative size of the effect of season, tidal stage, depth, position in the estuary, sampling position, etc.

Such an assessment of variability could be used to determine the sampling frequency (number of samples) required to achieve a desired precision in classifying tidal waters. For example, in Table 5.2 a class interval of 3 mg l^{-1} TIN has been suggested for low salinity water. Clearly a precision (or margin of error) of ±3 mg l^{-1} would not be acceptable for classification. To obtain an indication of how many samples might be required, some data from the Mersey estuary have been examined. The mean TIN concentration from 12 samples taken over 3 winters (standardised to high water spring tidal conditions) in a salinity range of 0-2 ppt was calculated to be 6.8 ± 2.2 mg l^{-1}. If this mean was required to be estimated with a precision of ±0.6 mg l^{-1} (i.e. one fifth of the band width) at a 90% level of confidence then 44 samples would be required (Ellis 1989). This could be equivalent to approximately 5 samples, taken 3 times a winter, each winter for three years. It will, therefore, be important to assess the scale of the remaining variability associated with the proposed monitoring strategy to establish the level of sampling required to achieve the desired precision. It will be equally important to have a consistent monitoring and class assessment strategy across the NRA regions and the RPBs.

As mentioned previously, limited data were available for the development of a classification scheme or indeed the sampling strategy for a classification scheme, making it difficult to quantify the relative importance of the temporal and spatial factors responsible for the variability in nutrient levels observed in tidal waters. The sampling strategy was, therefore, not designed solely on a statistical basis and a more pragmatic approach was used.

6.1 Estuarine waters

The use of salinity-related class boundaries reduces much of the spatial variability associated with nutrient levels in estuaries. It is important, however, to design the sampling strategy to reduce the variability further by taking account of other factors when deciding the sampling positions and to reduce the temporal variability by restricting sampling periods with respect to season, daily and spring/neap tidal cycles.

6.1.1 Sampling period

The proposed approach to reduce the variability associated with season is to concentrate sampling effort within a limited period. Sampling during the winter months (December to February) is considered to be most appropriate since nutrient levels at this time are at their annual maxima and are less variable because they are least dependent upon phytoplankton production.

The NRA baseline estuary and coastal monitoring programme (NRA 1991b) requires that estuarine sites should be sampled 'on the same day, at or around high water on or around neap tides unless worst-case conditions are expected at other times due to local circumstances or there are sound practical reasons for sampling at other times'. It is suggested that these conditions are complied with when sampling for the nutrient classification scheme.

A great deal of variability can be reduced by restricting the sampling period as mentioned above. However, there may still be variability remaining from other sources. These may include surges in freshwater flow due to storm events, the increase of nutrient loads from storm discharge and runoff events, etc. This is demonstrated by the data on TIN levels in the Mersey estuary (Figure 6.1). All measurements were taken during the winter months 1990/1991 under similar tidal conditions and are expressed in terms of salinity, yet the levels vary considerably between sample periods. In order to 'smooth out' some of the remaining temporal variability a number of sample periods would be required in one winter period to give an average (arithmetic mean) winter figure. As a pragmatic approach, it is suggested that at least for major estuaries (in terms of size and/or contamination status), a minimum of three sample runs should be conducted in each winter season. Furthermore, to help reduce the bias caused by unusually 'wet' or 'dry' years, the estuary class should then be based on a three year rolling average (arithmetic mean).

However, because of these strict sampling requirements, the window for sampling will be limited. Neap tides (defined here as ±10% of the mean neap range) occur on average 6 times between December and February, and last between 2 and 5 days. This would allow around 22 sampling days to complete 3 surveys of all major estuaries in a Region. The actual time window for each survey will further be limited by the requirement to sample around high water. This represents a heavy monitoring requirement which may be achievable with the use of suitable survey boats or helicopters. Alternatively, the use of mathematical models could reduce the requirements for sampling. These are discussed in Section 6.4.

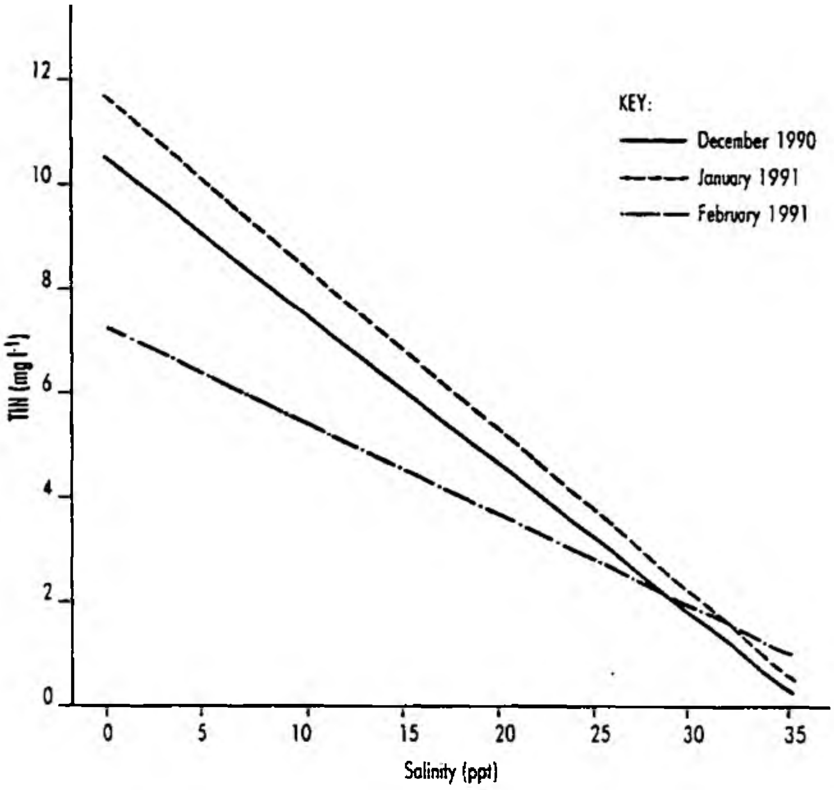

Figure 6.1 Temporal variability of TIN concentrations in the Mersey estuary December 90 - February 91. All samples were taken from the same set of sampling points at high water on spring tides

A different sampling strategy might be more appropriate and justifiable for the smaller, less contaminated estuaries, where there may be less temporal and spatial differences in nutrient concentrations over the sampling season and a 3-year rolling average may, therefore, be an unnecessary requirement. For example, a quinquennial winter survey (3 surveys) might be adequate. Again, it would be important to establish the level of precision required before any sampling strategy was finalised.

6.1.2 Sampling position

In order to reduce some of the spatial variability associated with sampling a band of tidal water a number of sampling points must be chosen. It is not possible to define the number of points required in terms of precision of classification since a detailed statistical analysis of the data would be required. But until further data become available, we suggest that a minimum of 5 sampling points would be required for the classification of any band of tidal water. Further work should be considered to determine whether this number of samples provides adequate precision for the classification of particular estuaries. For example, in estuaries where there is a large spatial variability, smaller sampling bands and/or more samples may be required.

As in the NRA baseline programme (NRA 1991b), we suggest that 'once a sampling site has been chosen, all future sampling should take place at the same site under the same tidal conditions'. A number of requirements should be taken into account when choosing sampling sites so that a representative view of water quality in the relevant band of the estuary is obtained. We suggest that sampling points should:

- be positioned outside the mixing zone of discharge points;
- be at about 1 m below the surface (to avoid potential surface slicks and surface debris). If significant vertical stratification occurs then it may be more appropriate to obtain depth-averaged nutrient levels;
- be spread equally over the salinity range observed for that band of tidal water;
- lie in the middle reaches of the estuary or estuary band unless local conditions dictate otherwise;
- take account of major differences in quality that might occur (e.g. from local knowledge) across the estuary.

6.2 Sampling strategy for coastal waters

6.2.1 Sampling period

As for estuarine waters, sampling for the classification in coastal waters should be conducted in the period December to February. As was described in Section 1 coastal waters will be divided into two zones for classification: a nearshore and an offshore zone. In the nearshore zone there will be potential for temporal tidal effects on nutrient concentrations, particularly if there are nearshore effluent discharges (e.g. storm sewage outfalls). It is recommended, therefore, that samples are taken at, or around, high water, preferably on a neap tide. If the offshore zone sampling is conducted midway between the zone limits (approximately 1.5 nautical miles offshore) then tidal influences are likely to be less significant. In this case it is recommended that sampling of the offshore zone could be undertaken at high water at any stage of the spring/neap tidal cycle. In practice, however, it might be more cost effective to sample the inshore and offshore zones during the same sampling trip.

As for estuarine waters, it is suggested that three sample runs should be made within one winter season and that the results are expressed as a three year rolling average.

6.2.2 Sampling position

For practical reasons, such as cost, and for reasons of continuity or consistency, the NRA will decide upon the spacing of location of sampling points around the coast. Local officers should be given a certain amount of discretion to determine sampling points in view of known physical features and inputs. For example, sites could be located offshore from bathing waters (designated and non-designated) sampled for the microbiological component of the coastal waters classification scheme. Also if there was to be one nutrient classification scheme for saline waters, it would be desirable to obtain contiguous data between estuaries and their adjacent coastal waters. An alternative approach might be to sample at a defined interval around the coast, for example, every 10 km nearshore and every 100 km offshore. In the latter case the desired precision of detecting spatial differences in nutrient levels would have to be considered. Also the acceptability (politically, scientifically or otherwise) of basing the classification on 10 km 'areas' of water or on 100 km 'areas' of water would have to be judged.

However, for whichever strategy is adopted, it is recommended that there is a degree of replication of samples per 'area' of coastal water. In the case of sample 'areas' of 10 km it might be appropriate to take 5 samples, each spaced at 2 km intervals. An average concentration would then be obtained for the derivation of class. As there is relatively little data on the spatial and temporal variability of nutrients in nearshore coastal waters, for example, in relation to tidal state, it is recommended that any monitoring strategy adopted is reviewed in the light of practical experience obtained, perhaps from classification surveys.

We suggest that a number of factors should be taken into account when selecting sampling points in coastal waters, many of which are also stipulated for estuarine waters. Sampling points should:

- be positioned outside the mixing zone of discharge points;
- be at about 1 m below the surface (to avoid potential surface slicks and surface debris). If significant vertical stratification occurs then it may be more appropriate to obtain depth averaged nutrient levels;
- be spread at equal distances over the length of the band to be classified;
- be spread in the nearshore and offshore zone;
- lie at the edge of (rather than in) estuary plumes or influence, where applicable.

6.3 Nutrient analysis

In general there appears to be no standard analytical procedure used at present for measuring nutrients in tidal waters. It is important that this deficiency is addressed if comparable data sets are to be obtained.

Suitable methods for the analysis of nutrients in saline waters are currently being reviewed by ICES (Kirkwood, D. personal communication) and it is not within the scope of this project to discuss analytical details. It is considered more appropriate to define the requirements for analysis in terms of the attainment of set detection limits and a requirement for quality control.

Participation in quality assurance schemes and internal Analytical Quality Control (AQC) procedures must be considered essential if results from different laboratories are to be comparable. But even if such protocols are followed, results will not be comparable unless the samples are analysed shortly after collection or a suitable method of preservation is employed.

The limits of detection cited by individual laboratories which provided data for this project cover a broad range. This is of particular importance in coastal waters where nutrient levels are lower in estuaries. It is a general requirement of analytical techniques that they are capable of achieving appropriate levels of accuracy and precision. This normally implies a limit of detection of no more than one-fifth and, ideally, one-tenth of the lowest concentration required to be measured. For the classification scheme proposed, the one-fifth concentration would be 15 µg l^{-1} for SRP and 60 µg l^{-1} for TIN. Since TIN represents the sum of the ammoniacal and oxidised fractions, this implies detection limits of 10 NH_3-N l^{-1}, 10 µg NO_3-N l^{-1} and 10 µg NO_2-N l^{-1}.

Detection limits quoted for 'blue book' methods suggest that suitable methods are available to obtain the required one-fifth level of accuracy and precision but that, ideally, more sensitive methods should be investigated.

In addition, salinity should be measured at each sample site. If the samples are taken from a boat, simultaneous *in situ* salinity measurements could be taken. If a helicopter was used, salinity measurements would have to be determined retrospectively in the laboratory. In both cases, standard procedures and AQC would be required.

6.4 Use of mathematical models

The difficulty caused by spatial and temporal variability of water quality in tidal waters is not unique to nutrients in estuaries but common with other water quality determinands such as dissolved oxygen (DO) and ammonia which, it is proposed, would also be included in the water quality component of an estuary classification scheme. Monitoring strategies for DO and ammonia in estuary classification schemes were discussed in detail by Nixon *et al.* (1992). They concluded that the approach most likely to produce an accurate and reliable classification of estuaries, based on DO and ammonia, would be through the use of appropriate mathematical models. A suitably calibrated and validated model would then be used to generate standardised data on which compliance with any standard or level associated with a classification scheme would be judged.

Calibration of models involves the quantification of contaminant loads entering the estuary and intensive tidal cycle measurements of water quality determinands in the estuary. The modelled parameters generally include other determinands, such as oxidised nitrogen and SRP, as well as ammonia and DO, and could potentially, therefore, be used for nutrient classification purposes. In the scheme proposed here the generated data from the model would be for the winter months. If an annual average value was required from the model, adequate representation of the primary productivity processes and probably more detailed (and expensive) calibration data would be needed.

Once a model was generated for an estuary there would still be a requirement to monitor for two main reasons:

- to ensure that the classification of the estuary was correct;
- to determine whether discrepancies were due to changes in the loads to the estuary or inadequacies of the model.

The model and its inputs would, therefore, have to be monitored with the aim of reducing the uncertainty with which its outputs were viewed. A cost-effective way of achieving this would be to establish 'Validation Points' (VPs) where relatively inexpensive measurements could be made (probably every winter in larger estuaries) in conjunction with measurement of loads into the estuary. It would make sense to place VPs in positions where the resultant measurements would easily detect major changes in estuary quality. For example, a VP for TIN might be in the part of the estuary receiving the greatest loads and where concentrations were known to vary gently over a tidal cycle. In the case of nitrates (and possibly ammonia) this might be achieved through the periodic deployment of an *in situ* measuring device (see Nixon *et al.* 1992).

As important, for testing the model, would be the monitoring of loads to the estuary for a sufficient length of time before the measurements were made at the VPs. There would be good grounds in any case for measuring the loads frequently since these would have a direct link with the nutrient levels within the estuary and many loads would be under man's control, and could, therefore, be regulated. So it is recommended that Load Measuring Points (LMP) should also be established at the key load addition sites.

One of the main potential advantages of modelling is to provide a substantial increase in knowledge with relatively great economy in comparison with a field measurement programme alone. If a suitable model of an estuary already exists, or was to be produced for DO and ammonia classification or for more general water quality management purposes, then there would be a potential benefit in using such a model for the nutrient component of the estuary classification scheme. The cost of developing a suitable water quality model for an estuary would be dependent upon factors such as physical complexity (e.g. stratification, number of arms and size), the amount of historical data, number of loads entering the estuary and the amount of calibration/validation survey work required. As a guide the cost of developing a fully calibrated and validated 1-D model for a relatively large estuary with many (approximately 16) contributory loads would be around £150 000 at 1992 prices.

It is likely that the cost of developing 1-dimensional (1-D, depth averaged) models for every estuary would be prohibitively expensive and probably unnecessary. Particularly for the smaller and less polluted estuaries, more generalised uncalibrated models may be more appropriate and suitable. These models might be based on existing data and use broad estimates of input loads based, perhaps, on pollution equivalents for sewage discharges and consented limits for other discharges.

In the case of coastal waters, 1-D models would not be adequate and 2 dimensional (2-D, depth averaged) models would be required. Such models have been developed for predicting the dispersion of faecal bacteria from proposed sea outfalls. Coastal models would presumably also have to cover a very much greater spatial area if they are to include all waters that are to be classified. Unless suitable models exist or are required for other purposes, then it would be more appropriate and cost-effective to use properly designed monitoring programmes for classification rather than to develop sophisticated models for the coastal zone.

7. APPLICATION OF THE SCHEME

A number of steps should be followed in order to use the scheme to classify a section of tidal water, these are laid out below:

1. For each sampling point within a tidal water band, establish salinity, TIN and SRP levels according to the monitoring strategy outlined in Section 6.

2. For each sampling point within a tidal water band, calculate the average salinity, TIN and SRP level over three years on a rolling basis.

3. For each tidal water band, calculate the average salinity, TIN and SRP level from the sampling point averages determined in 2.

4. Compare the average levels of TIN and SRP for each tidal water band (as determined in 3) with the classification boundaries for TIN and SRP at the average salinity of the band and classify according to the poorer determinands.

8. DISCUSSION

8.1 Iterations

No estuaries were found with a sufficiently comprehensive data set to fulfil the monitoring requirements of the classification scheme proposed. Therefore, in order to get a best estimate of the proportion of tidal waters falling into each class, each of the available data sets containing information on TIN or SRP levels in winter months over the period 1986 to 1991 was used to give an average salinity-related TIN and SRP value, and hence a class value for that section of tidal water. The factors which were taken into account were:

- salinity (all nutrient levels were related to salinity);
- season (only December - February data used);
- year (only data since 1986 used);
- depth (unless indicated, samples were taken within 1 metre of the surface).

Those factors not taken into account were:

- daily tidal cycle;
- spring/neap tidal cycle;
- position in the estuary;
- the use of a representative selection of salinity sampled points;
- distance from outfalls.

The steps taken to calculate the salinity related TIN and SRP values for each section of tidal water were:

1. For estuarine data, nutrient levels from sample points within each 2 ppt salinity band were averaged to give a maximum of 1 value per 2 ppt salinity band in each estuary. This approach was used to reduce excessive weighting of the average caused by high sampling intensity in some part of the estuary.

2. For each sampling point (or 2 ppt band sampling points in estuaries) data from the last three years were averaged to give three-year averaged salinity and nutrient concentrations. Where data were not available for the last three years then data taken sometime within the last five years were used.

3. The three-year averaged salinity and nutrient levels were then averaged to give one salinity, TIN and SRP value for each tidal water section. The salinity-related average nutrient levels were compared with the classification boundaries.

A summary of the data used in the iteration exercise with comments qualifying its suitability is given in Table 8.1. Table 8.2 compares the resultant class assignments using the boundaries proposed in Section 5 with the NWC class assignment based on the 1990 Water Quality Survey (NRA 1991c).

Some estuaries have areas of different NWC class. Where this occurs the range of classes is given in Table 8.2. It should be noted that any comparison made between NWC class and that from the proposed scheme can only be made on very limited data from relatively few estuaries and even fewer stretches of coastal waters. It is not, therefore, possible to assess how the distribution of classes amongst the examples given in Table 8.2 reflects the distribution of classes in the total population.

However, some general comments can be made. Of the 43 estuaries in Table 8.2 classified under the proposed scheme, 12 were in Class 1, 11 in Class 2 (estuaries in Class 2/3 downgraded to 3), 15 in Class 3 and 5 in Class 4. Some estuaries would be downgraded from their current NWC Class, in particular the Thames would be downgraded from 1/2 to 4, and many of the South West estuaries (e.g. Otter, Gannel and Lynher) would fall by two Classes from 1 to 3. Other estuaries would agree with their current Class. For example, the Mersey varies between Class 2 and 4, and would have an overall class of 3 under the proposed scheme. Under the proposed scheme, 23 of the 43 estuaries would be downgraded on TIN concentration, 2 on SRP and 18 gave the same class for both determinands. No estuaries would be upgraded.

All of the data for coastal waters relate to offshore nutrient concentrations and the limited data available indicate that these would fall into either Class 1 or 2.

8.2 Limitations of the study

The usefulness of the project is limited by the fact that data used in the project were not collected specifically for the development of the classification scheme. The class boundaries are based on a limited number of data sets none of which were entirely compatible with the classification system proposed. It is not possible to ascertain at this stage how many estuaries and coastal waters will fall into each class of the proposed scheme. It is suggested, therefore, that the class boundaries are reviewed in the light of the data collected to meet the requirements of the sampling strategy proposed. These data will more accurately represent the overall quality of UK estuarine and coastal waters.

Similarly, the sampling strategy proposed is limited because there were no suitable studies designed to assess the relative size of the variation associated with factors such as season, spring/neap and tidal cycle, and sampling position. Therefore, the strategy proposed is not designed statistically to optimise the precision with which tidal water bands are classed. It is suggested that the sampling strategy is revised in the light of:

- data gathered for the scheme;
- information on the relative size of the variability associated with factors affecting nutrient levels in tidal waters from a carefully designed field study.

Table 8.1 Summary of data used in the development of the classification scheme for nutrients in tidal waters

Regulatory Authority	Location	Salinity (ppt) Mean	Salinity (ppt) Range	TIN (mg l^{-1}) Mean	TIN (mg l^{-1}) Range	SRP (mg l^{-1}) Mean	SRP (mg l^{-1}) Range	SB	SP	SD	Other
Anglian	Welland	7.2	0.3 - 14.8	7.0	3.7 - 11.0	0.44	0.18 - 0.83	3	3	4-8	High or low water
	Nene	6.0	0.4 - 10.5	8.8	5.4 - 12.4	1.05	0.68 - 1.58	3	6	3-9	High or low water
Thames	Thames	9.1	0.4 - 16.2	7.7	4.0 - 9.8	1.19	0.57 - 1.62	8	29	>9	Modelled to give mid-flow position
Southern	Medway	18.3	0.2 - 32.6	2.9	0.8 - 7.8	0.52	0.33 - 0.72	10	21	2-5	High or low water
	Swale	32.0	31.4 - 32.5	1.4	1.4 - 1.4	0.32	0.32 - 0.34	2	17	5	High or low water
	Ouse	6.0	2.8 - 9.3	3.2	2.3 - 4.1	0.34	0.32 - 0.36	2	2	7-8	High or low water
	South east coast[1]	-	-	0.22	0.06 - 1.40	0.03	0.001 - 0.15	-	21	5	Irrespective of tide
Wessex	Poole H	31.3	29.0 - 33.0	1.2	1.0 - 1.5	0.08	0.05 - 0.15	3	3	1-3	
	Portland H	34.7	-	0.7	-	0.05	-	1	2	2	
	Severn	18.0	0.3 - 32.3	2.7	0.8 - 5.3	0.32	0.08 - 0.79	13	23	3	High water neap, mid-channel
South West	Axe	1	-	9.0	-	0.12	-	1	2	1	Mid-depth, full tidal cycle
	Otter	1	-	6.9	-	0.24	-	1	1	2	Mid-depth, full tidal cycle
	Avon	8.5	1.0 - 16.0	3.1	2.2 - 4.0	0.03	0.02 - 0.03	2	2	1	Mid-depth, full tidal cycle
	Yealm	23.6	3.4 - 32.5	2.1	0.3 - 4.3	0.04	0.02 - 0.06	5	6	1	Mid-depth, full tidal cycle
	Lynher	1.2	0.3 - 2.1	7.8	7.5 - 8.0	0.05	0.05 - 0.05	2	3	1	Mid-depth, full tidal cycle
	Looe	10.0	1.0 - 21.6	5.5	3.1 - 7.9	0.06	0.03 - 0.09	5	5	1-2	Mid-depth, full tidal cycle
	Rest. Creek	11.0	1.2 - 20.8	3.7	2.6 - 4.8	0.01	0.01 - 0.02	2	3	1	Mid-depth, full tidal cycle
	Truro	9.8	4.7 - 15.0	5.8	4.8 - 6.8	0.06	0.04 - 0.08	2	2	1	Mid-depth, full tidal cycle
	Carrick Roads	32.8	-	0.3	-	0.03	-	1	2	1	Mid-depth, full tidal cycle
	Helford	22.6	9.0 - 32.0	2.9	0.5 - 6.6	0.03	0.03 - 0.03	4	5	2	Mid-depth, full tidal cycle
	Hayle	25.7	22.5 - 29.0	1.5	0.4 - 2.6	0.07	0.05 - 0.09	2	2	1	Mid-depth, full tidal cycle
	Gannel	9.3	1.0 - 17.6	5.8	3.7 - 7.9	0.03	0.03 - 0.03	2	2	1	Mid-depth, full tidal cycle
	Camel	16.6	1.0 - 31.6	3.5	1.2 - 6.4	0.03	0.02 - 0.04	6	7	2	Mid-depth, full tidal cycle
	Torridge	9.6	1.0 - 22.9	2.6	0.9 - 4.2	0.62	0.46 - 0.88	3	4	1	Mid-depth, full tidal cycle
	Dart	14.9	1.0 - 28.9	1.1	0.6 - 1.6	0.54	0.16 - 0.91	2	6	1	Mid-depth, full tidal cycle
	Fal	2.5	-	5.7	-	0.77	-	1	1	1	Mid-depth, full tidal cycle
Welsh	Dee[2]	22.5	8.2 - 34.1	2.5	1.6 - 3.8	0.04	0.03 - 0.06	7	24	1	Mid-channel
	Dovey[2]	19.2	1.7 - 33.1	0.5	0.2 - 0.8	0.02	0.01 - 0.03	5	7	1	Mid-channel
	Teifi[2]	21.6	7.0 - 34.6	1.6	0.1 - 3.6	-	-	5	5	1	Mid-channel
	North Coast[2]	32.3	25.2 - 34	0.58	0.09 - 2.30	0.05	0.02 - 0.14	-	12-29	1	1-2 miles from shore
	Cardigan Bay[2]	33.7	29.3 - 34.7	0.20	0.12 - 0.48	0.01	0.004 - 0.019	-	10-32	1	1-2 miles from shore

Table 8.1 continued

Regulatory Authority	Location	Salinity (ppt) Mean	Salinity (ppt) Range	TIN ($mg\ l^{-1}$) Mean	TIN ($mg\ l^{-1}$) Range	SRP ($mg\ l^{-1}$) Mean	SRP ($mg\ l^{-1}$) Range	SB	SP	SD	Other
North West	Mersey	17.0	0.5 - 32.7	4.7	0.8 - 8.3	-	-	14	22	7	Mid-channel
	Mersey[2]	18.7	4.3 - 30.9	4.3	0.5 - 8.0	0.13	0.06 - 0.30	10	18	1	Mid-channel
	Ribble[2]	18.7	1.1 - 30.6	2.3	0.6 - 5.6	0.22	0.03 - 0.50	9	19	1	Mid-channel
	Solway[2]	16.8	13.1 - 20.7	1.2	0.5 - 1.7	0.04	0.04 - 0.04	4	6	1	Mid-channel
	North west coast[2]	30.3	11.0 - 34.0	0.36	0.08 - 7.05	0.055	0.003 - 0.144	-	71-80	1	1-2 miles from shore
	Irish Sea[2]	34.3	33.6 - 35.0	0.21	0.13 - 0.30	0.024	0.001 - 0.057	-	2-27	1	1-2 miles from shore
Clyde	Clyde	6.8	0.6 - 14.4	1.0	0.7 - 1.4	0.06	0.05 - 0.07	3	9	1	Irrespective of tidal state
	Gare Loch	16.5	-	0.9	-	0.08	-	1	2	1	Irrespective of tidal state
	Loch Long	20.9	-	0.6	-	0.07	-	1	2	1	Irrespective of tidal state
	Holy Loch	9.3	-	0.5	-	0.04	-	1	1	1	Irrespective of tidal state
	Loch Goil	22.0	-	0.4	-	0.06	-	1	1	1	Irrespective of tidal state
	Loch Fyne	29.5	28.0 - 31.0	0.2	0.1 - 0.2	0.03	0.03 - 0.03	2	3	2	Irrespective of tidal state
North East	Ythan	5.5	0.1 - 14.3	5.8	4.0 - 6.7	0.09	0.7 - 0.12	3	3	5	Irrespective of tidal state
	Dee/Aberdeen H	6.1	0.6 - 13.7	2.1	1.6 - 2.7	0.03	0.02 - 0.04	4	9	1	Irrespective of tidal state
Forth	Forth Estuary	18.7	0.1 - 30.4	0.4	0.3 - 0.6	0.02	0.01 - 0.03	9	10-12	6	Spring and Neap tides
Tweed	Tweed	11.1	0.1 - 22.0	2.0	1.2 - 2.9	0.04	0.04 - 0.04	2	2	1	Irrespective of tidal state
	Eyemouth	18.5	-	3.5	-	0.04	-	1	1	8	

Notes:
1 Part of the NRA coastal baseline programme
2 Part of the NORSAP programme
SB Number of 2 ppt sample bands for which data were available
SP Number of sample points for which data were available
SD Number of sample dates for which data were available
TIN Total inorganic nitrogen
SRP Soluble reactive phosphorus

Table 8.2 Iterations for existing nutrient levels in estuaries and coastal waters using the class boundaries proposed in Section 5

		Proposed Nutrient Class		
Location	NWC Class*	TIN	SRP	Overall
Estuaries				
Clyde	-	1	1	1
Gare Loch	-	1	1	1
Loch Long	-	1	1	1
Holy Loch	-	1	1	1
Loch Goil	-	1	1	1
Loch Fyne	-	1	1	1
Forth	-	1	1	1
Dart	1	1	1	1
Dovey	1	1	1	1
Solway	1	1	1	1
Dee/Aberdeen	-	1	1	1
Tweed	-	1	1	1
Carrick Roads	-	1/2	1	1/2
Ribble	2	2	2	2
Teifi	1	2	-	2
Dee	1/2	2	1	2
Ouse, Sussex	1/2	2	2	2
Hayle	1	2	1	2
Torridge	1	2	1	2
Avon	1	2	1	2
Rest. Creek	-	2		2
Yealm	1	2	1	2
Severn	1/2	2	2	2
Camel	1	2/3	2	2/3
Fal	1/2	2/3	1	2/3
Portland H	-	3	1	3
Otter	1	3	1	3
Gannel	1	3	1	3
Lynher	1	3	1	3
Helford	-	3	1	3
Looe	-	3	1	3
Truro	-	3	1	3
Eyemouth	-	3	1	3
Ythan	-	3	1	3
Poole H	1/3	3	2	3
Mersey	3/4	3	-	3

Table 8.2 continued

Location	NWC Class*	Proposed Nutrient Class TIN	SRP	Overall
Mersey[1]	3/4	3	1	3
Welland	1	3	2	3
Axe	1	3/4	1	3/4
Medway	1/3	2	4	4
Swale	-	3	4	4
Thames	1/2	4	4	4
Nene	3	4	4	4
Coastal Waters				
Cardigan Bay[1]	-	1	1	1
SE England	-	1	1	1
Irish Sea[1,2]	-	1	1	1
N Wales[1]	-	2	1	2
NW England[1]	-	2	1	2

Notes: 1 Conducted for the Norsap Programme
2 Mersey to Isle of Man
* National Water Council Class, 1990 (NRA 1991c)

8.3 Relevance of the scheme to other nutrient standards

Cartwright and Painter (1991) were unable to propose environmental quality standards (EQSs) to prevent eutrophication in estuarine and coastal waters in the UK. They concluded that eutrophication problems in estuaries appeared to result as much from other factors such as light or topography as the nutrient levels present. Therefore, establishment of an EQS as a general measure to control eutrophication was likely to be of limited value and more research was needed, especially on the role of estuarine sediments in phosphorus and nitrogen cycling. However, they suggested that a sensible approach to reducing eutrophication potential might be to adopt the 30 $\mu g\ l^{-1}$ total phosphorus (annual average) guideline proposed for flowing waters and a 200 $\mu g\ l^{-1}$ total inorganic nitrogen (annual average) guideline which was suggested for coastal waters. These could then be amended on a case by case basis using a modelling approach.

Since the position of class boundaries changes with salinity it is not possible to relate them directly to effects. However, since the class 1/2 boundary levels for TIN and SRP in waters with high salinity are roughly similar to the guideline values for N and P suggested as suitable for the control of eutrophication by Cartwright and Painter (1991), a class 1 tidal water band may be considered to have a low potential for eutrophication.

8.4 The relevance of nutrient contamination to eutrophication effects

Since there are many complex factors affecting eutrophication including light penetration, retention time, weather conditions and nutrient status, increasing the nutrient status of tidal water (nutrification) will only imply a *pro rata* effect on algal growth if nutrients are the growth-limiting resource. It is not clear whether this is often the case particularly in estuaries where light penetration is low, due to high levels of suspended sediment. It is though that light, rather than nutrients, is more likely to be the major factor limiting algal growth as the nutrient levels observed in estuarine waters are much higher than the half-saturation constants for nitrogen uptake, typically 0.1-14 $\mu g\ N\ l^{-1}$ for freshwater and marine phytoplankton (Barnes and Hughes 1988, Reynolds 1984). Phytoplankton blooms have been shown to occur naturally in saline waters of low nutrient status. However, a large body of evidence shows that in saline waters, phytoplankton standing crop is increased following anthropogenic inputs of nutrients to semi-enclosed regions of water, even in some estuaries with high levels of suspended sediment.

The potential of a major bloom occurring increases as nutrient levels increase, and also as the retention or flushing time of an estuary increases. As the doubling times for marine/estuarine phytoplankton are typically in the order of 3-4 days, estuaries with retention times of less than 4 days are likely to have a decreased risk of major algal blooms. The retention time of an estuary is dependent on the freshwater flow. For example, the retention time of the Forth estuary under mean river flows is 12 days, but in summer with reduced river flow it may be as much as 10 weeks (McLusky 1989). This, along with the higher temperatures and higher incident light levels, would increase the potential for an algal bloom.

Whilst a single classification scheme for both coastal and estuarine waters is present in this report, it should be realised that other factors make the two types of environment very different. Water clarity tends to be very much lower in estuaries than coastal waters due to the higher levels of suspended sediment. In addition, the major sources of nutrients are different in estuaries and coastal waters since the freshwater input represents a lower proportion of the total nutrient input into coastal waters. For example, the Atlantic input of nitrogen to the Irish Sea is estimated to be over 13 000 times greater than the river input (ISSG 1990).

Another physical process which makes the biological response to nutrification different within estuaries and coastal waters is that of stratification. Some estuaries and, more notably, sea lochs stratify during warmer months, initially because of a temperature differential which results in less dense surface waters; but the even lower density freshwater input may then mix only with the water above the thermocline, so reducing its density further and stabilising the pycnocline. In coastal and oceanic waters a thermocline may develop during period of calm weather, but this not stabilised by the epilimnion being substantially diluted.

Perhaps the greatest ecological damage that extensive phytoplankton blooms can occur as a result of massive bloom formation under ideal weather conditions in nutrient-rich waters. Algal growth is then limited as nutrients in the surface waters are depleted and the bloom enters a stationary phase. As a result of nutrient stress, some algae divert carbon metabolism to the synthesis of extracellular polysaccharide (Jensen 1984) and subsequently sink to the sea/estuary bed where the resulting microbial degradation results in massive deoxygenation of hypolimnetic waters, causing wide-scale benthic mortality. For other algae, e.g. *Phaeocystis* (Lancelot *et al.* 1987), the factors controlling polysaccharide production/excretion are much less well understood. This alga forms dense colonial blooms which on dying can blanket intertidal and shallow inshore sediments with a slowly decomposing mucilage (Owens *et al.* 1989). Fortunately the resulting damage in UK coastal and estuarine regions has been very much less than that experienced in the Adriatic and off the Scandanavian coast; but blooms of other algae such as non-toxic dinoflagellates which excrete only a fraction of the organic carbon that *Phaeocystis* does, have also been implicated in the wide-scale death of benthic invertebrates (Hepper *et al.* 1974).

8.5 Relevance of the scheme to other nutrients

Silicon is the other major nutrient which affects phytoplankton growth in UK tidal waters. The classification scheme proposed for levels of nitrogen and phosphorus bears little relevance to the presence of silicon since the sources of silicon are very different to those of nitrogen and phosphorus. In addition, the effect the silicon has on eutrophication is distinct from the effect of nitrogen and phosphorus, since its presence is more closely related to the nature of the growth rather than the quantity of growth. Tidal water diatom blooms in spring are usually brought to an end by exhaustion of the bioavailable silicon supply, but since other types of algae have a requirement for only trace amounts of silicon, these diatom blooms are replaced, for example, by microflagellates. Troublesome dinoflagellate blooms, including those species responsible for paralytic shellfish poisoning (PSP) events are therefore far more likely to develop when dissolved silica levels are very low.

Similarly, not all phytoplankton are completely autotrophic. Some algae, including dinoflagellates, are unable to synthesis all of the organic compounds, notably vitamins, which they require, and thus are dependent on an external supply of these compounds. As with silicon and diatoms, if these compounds are not present in large enough concentrations for bloom formation, this will not limit total algal primary productivity; only the growth of certain species will be inhibited.

Whilst the classification scheme is based on SRP as the most suitable approximation of bioavailable phosphorus, some phytoplankton are also known to contain alkaline phosphatases which enable them to use dissolved organic phosphates as a phosphorus supply. This is of little consequence in coastal waters where nitrogen is limiting, but may be of relevance in estuarine waters.

Many algae are also able to use some forms of organic nitrogen (e.g. urea, amino acids, etc.) as a nitrogen supply, but these are believed to account for only a minor part of the phytoplankton nitrogen budget utilised almost exclusively during the summer months when levels of TIN are low.

9. CONCLUSIONS

1. The data available at present on nutrient levels in tidal waters are largely unsuitable for the development of a classification scheme and the scheme proposed must, therefore, be viewed as a 'first attempt' which can provide a basis for further development.

2. Considerable spatial and temporal variability in nutrient quality is observed in all tidal waters, and particularly in estuarine waters. Some of this variability can be reduced by relating nutrient levels to salinity in the range 0-33 ppt. This approach allows one classification scheme for coastal and estuarine waters to be sufficiently sensitive to detect changes in nutrient quality. The class boundaries proposed are:

		TIN (mg l^{-1})		SRP (mg l^{-1})	
Class boundary	% of Maximum	0-2 ppt	32-34 ppt	0-2 ppt	32-34 ppt
1/2	≈25%	3.0	0.3	0.3	0.075
2/3	≈50%	6.0	0.6	0.6	0.15
3/4	≈75%	9.0	0.9	0.9	0.225
Maximum		12.37	1.37	1.12	0.33

3. Further variability can be reduced within the sampling strategy by defining sampling position and sampling period as winter high water neap tides. However, information is not available on the relative importance of the sources of variability making it impossible to design the sampling strategy on a statistical basis to give the required degree of precision.

4. Comparison of classifications which would be achieved under the proposed scheme with NWC classifications in 1990 suggest that some estuaries, notably the Thames, would be downgraded from their present class on the basis of nutrient contamination levels.

10. RECOMMENDATIONS

1. It is recommended that a phased approach is adopted for the further development, testing and implementation of the proposed classification scheme (with its associated sampling and analytical strategy).

2. During the first phase the proposed scheme (with its associated sampling and analytical strategy) should be tested in a number of estuaries and coastal waters covering a range of water quality and physical attributes (e.g. salt wedge and fully mixed estuaries). In particular, the issue of the desired precision of classifying waters with respect to the required frequency of sampling and number of samples should be addressed.

3. During this initial phase the use of different strategies for tidal waters of different contamination status or complexity should also be tested and assessed. For example, mathematical models might be appropriate for the more polluted estuaries whereas less intensive sampling might be adequate for less contaminated or less variable bodies of water.

4. The new data generated and the practical experience gained from 2 and 3 above should be incorporated into the proposed scheme and the scheme modified as necessary.

5. The relationship between the nutrient and other components of the classification schemes should also be considered to ensure that all components are suitably sensitive to changes and differences in water quality. At this stage, the appropriateness of relating nutrient class thresholds to effects should be re-assessed.

6. Once a robust and acceptable scheme has been accepted, detailed protocols for its implementation throughout the NRA and RPBs should be drawn up. This would ensure that a consistent approach and interpretation was adopted so that national differences in class were due to differences in water quality rather than differences in procedures and implementation.

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APPENDIX A

DATA AVAILABILITY
REPORT PROGRESS FORM

Table A.1 Summary of data received in response to the questionnaire

Regulatory Authority	Location	Sampling sites	Frequency per annum	Spring/Neap Tidal Stage
Northumbrian	Blythe	16	4	-
	Tyne	6 (2)[1]	8 (4)	- (N)
	Wear	10 (3)[1]	4 (4)	- (N)
	Tees	13 (3)[1]	4 (4)	- (N)
Yorkshire	Humber	4	6	-
Severn Trent	Humber	No information received		
Anglian[3]	Welland*	3	12	-
	Nene*	6	12	-
Thames	Thames*	30	40	-
Southern[5]	Medway*	14	12	-
	Stour*	8	12	-
	Ouse*	2	12	-
	SE coast[6]*	21	4	-
Wessex	Poole H*	4	V	-
	Portland H*	2	V	-
	Severn*	23	4	N
	SW coast[6]	48	4	-
South West[7]	Axe*	2	4	-
	Otter*	1	4	-
	Teign*	3	4	-
	Avon*	2	4	-
	Erme*	2	4	-
	Yealm*	6	4	-

		Determinands								
Daily Tidal Stage	Depth	NH_3	NO_3	NO_2	TON	TN	SRP	TP	SI	CHL-A
HTC	S,MD,B	X								
- (H)	S,MD,B	X	(X)	(X)	-	(X)[2]	(X)	(X)[2]	(X)	(X)
L (H)	S,MD,B	X	(X)	(X)	-	(X)[2]	(X)	(X)[2]	(X)	(X)
M (H)	S,MD,B	X	(X)	(X)	-	(X)[2]	(X)	(X)[2]	(X)	(X)
-	S	X	-	-	-	-	-	-	-	-
L+H	-	X	X	X	-	-	X	-	X	-
L+H	-	X	X	X	-	-	X	-	X	-
M[4]	S	X	-	-	X	-	X	-	X	X
L+H	-	X	X	X	X	-	X	-	X	-
L+H	-	X	X	X	X	-	X	-	X	-
L+H	-	X	X	X	X	-	X	-	X	-
-	0.5 m	X		X	X	-	X	-	X	X
-	S	X	X	X	X	-	X			
-	S	X	X	X	X	-	X			
H	S	X	X	X	X	-	X		X	
-	0.5 m	X	-	X	X	-	X		X	X
FTC	MD	X	-	-	X	-	X		X	
FTC	MD	X	-	-	X	-	X		X	
FTC	MD	X	-	-	X	-	X		X	
FTC	MD	X	-	-	X	-	X		X	
FTC	MD	X	-	-	X	-	X		X	
FTC	MD	X	-	-	X	-	X		X	

Table A.1 continued

Regulatory Authority	Location	Sampling sites	Frequency per annum	Spring/Neap Tidal Stage
	Lynher*	6	4	-
	Looe*	4	4	-
	Restronguet Creek*	3	4	-
	Truro*	5	4	-
	Carrick Roads*	2	4	-
	Helford*	5	4	-
	Hayle*	2	4	-
	Gannel*	2	4	-
	Camel*	7	4	-
	Torridge*	4	4	-
	Tawe*	4	4	-
	Dart*	6	4	-
Welsh[8]	Severn*	23	4	N
	Teifi*	- (5)[10]	(2)	(-)
	Dovey*	- (7)[10]	(2)	(-)
	Dee*	- (24)[10]	(2)	(-)
	Cardigan* Bay[9]	- (32)[10]	(2)	(-)
	North Wales coast[9]	- (29)[10]	(2)	(-)
North West	Dee*	- (24)[10]	(2)	(-)
	Mersey*	22 (19)[10]	12 (2)	S (-)
	Ribble*	12 (19)[10]	5 (2)	S (-)
	Solway*	- (6)[10]	(2)	(-)
	NW coast[9]	- (80)[10]	(2)	(-)
	Irish Sea[11]* (Mersey to IOM)	- (27)[10]	(2)	(-)

		Determinands								
Daily Tidal Stage	Depth	NH_3	NO_3	NO_2	TON	TN	SRP	TP	SI	CHL-A
FTC	MD	X	-	-	X	-	X		X	
FTC	MD	X	-	-	X	-	X		X	
FTC	MD	X	-	-	X	-	X		X	
FTC	MD	X	-	-	X	-	X		X	
FTC	MD	X	-	-	X	-	X		X	
FTC	MD	X	-	-	X	-	X		X	
FTC	MD	X	-	-	X	-	X		X	
FTC	MD	X	-	-	X	-	X		X	
FTC	MD	X	-	-	X	-	X		X	
FTC	MD	X	-	-	X	-	X		X	
FTC	MD	X	-	-	X	-	X		X	
FTC	MD	X	-	-	X	-	X	-	X	
H	S	X	X	X	X	-	X	X	-	-
(-)	S	X	X	X	X	-	X	X	-	-
(-)	S	X	X	X	X	-	X	X	-	-
(-)	S	X	X	X	X	-	X	X	-	-
(-)	S	X	X	X	X	-	X	X	-	-
(-)	S	X	X	X	X	-	X	X	-	-
(-)	S	X	X	X	X	-	X	X	-	-
H (-)	S	X	X	X	X	-	X	X	-	-
(-)	S	X	X	X	X	-	X	X	-	-
(-)	S	X	X	X	X	-	X	X	-	-
(-)	S	X	X	X	X	-	X	X	-	-
(-)	S	X	X	X	X	-	X	X	-	-

Table A.1 continued

Regulatory Authority	Location	Sampling sites	Frequency per annum	Spring/Neap Tidal Stage
Solway	Solway	No recent data received		
Clyde	Clyde Estuary*	9	6	-
	Clyde Firth*	27	6	-
	Gare Lock*	2	6	-
	Loch Long*	2	6	-
	Holy Loch*	1	6	-
	Loch Goil*	2	6	-
	Loch Striven*	2	6	-
	Loch Fyne*	3	1	-
	Loch Creran	v	v	-
	Irvine/Ayr Bays	47	4	-
	Oban Bay	7	-	-
Highland	Inverness/Beauly Firth	17+10	1/2	-
	Cromarty Firth	10	2	-
North East	Ythan*	3	3-6	-
	Dee/Aberdeen H*	9	<1	-
Tay	Tay	No information received		
Forth	Forth Estuary*	17	24	S+N
	Forth Firth	33	1	-
Tweed	Tweed*	2	3/4	-
	Eyewater*	1	6	-

		Determinands								
Daily Tidal Stage	Depth	NH_3	NO_3	NO_2	TON	TN	SRP	TP	SI	CHL-A
-	DP	X	X	X	X	-	X	-	-	X
-	1	X	X	X	X	-	X	-	X	-
-	DP	X	X	X	X	-	X	-	X	X
-	DP	X	X	X	X	-	X	-	X	X
-	DP	X	X	X	X	-	X	-	X	X
-	DP	X	X	X	X	-	X	-	X	X
-	DP	X	X	X	X	-	X	-	X	X
-	DP	X	X	X	X	-	X	-	X	X
-	DP	X	X	X	-	-	X	-	-	X
-	1	X	X	X	X	-	X	-	X	X
-	DP	X	X	X	-	-	X	-	X	X
-	1	X	X	X	-	-	X	-	-	-
-	1	X	X	X	-	-	X	-	-	X
-	S	X	-	X	X	-	X	X	-	-
H+M+L	S	X	-	X	X	-	X	X	-	-
-	1+B	X	X	X	-	-	X	-	-	X
-	DP	X	X	X	-	-	X	-	X	-
-	S	X	-	-	X	X	X	-	X	-
-	S	X	-	-	X	X	X	-	X	-

Table A.1 continued

Regulatory Authority	Location	Sampling sites	Frequency per annum	Spring/Neap Tidal Stage	Daily Tidal Stage	Depth	Determinands: NH_3	NO_3	NO_2	TON	TN	SRP	TP	SI	CHL-A
Northern Ireland	Larne Lough	5	4-6	-	-	2	X[12]	-	-	X	-	X	-	X[12]	-
	Carlingford Lough	4	4-6	-	-	2	X[12]	-	-	X	-	X	-	X[12]	-
	Strangford Lough	4	4-6	-	-	2	X[12]	-	-	X	-	X	-	X[12]	-
	Belfast Lough	6	4-6	-	-	2	X[12]	-	-	X	-	X	-	X[12]	-
	Lough Foyle	5	4-6	-	-	2	X[12]	-	-	X	-	X	-	X[12]	-
	Coastal sites	4	4-6	-	-	2	X[12]	-	-	X	-	X	-	X[12]	-

Notes:
1 Sampled for the Estuary Baseline Monitoring Programme (NSTF) but data not currently available for the period December to February.
2 Dissolved.
3 Other rivers which are monitored in this region are: Humber, Witham, Great Ouse, Bure, Yare, Waveney, Blythe, Alde/Ore, Deben, Orwell, Stour, Colne, Blackwater, Crouch, Roach, due to data handling difficulties, the information on monitoring in these estuaries was not extracted from disk.
4 A model is applied to the sampling data to calculate the position of the sampled water, and the quality of that water at half tide.
5 Other estuaries monitored in this region are: Rotter, Swale, Milton Creek, Faversham Creek, Beulieu, Hamble, Itchen, Test, Lymington, Solent, Langstone, Portsmouth, Southampton Water, Arun, Adur, Cuckmere, Chichester the information on the monitoring in these estuaries was not used as the data arrived on hardcopy in the late stages of the project.
6 Monitoring was conducted as part of the coastal baseline survey at points 1-2 miles from the shore.
7 Other estuaries monitored in this region are: Kingsbridge, Plym, Plymouth Sound, Tamar, Tavy, Fowey, Penryn, Tresillian, Percuil, Fal, the information was not used because no winter levels were available.
8 Other estuaries which are monitored in this region are: Afan, Ogmore, Loughor, Neath, Tawe, Swansea Bay, Menai Straits, the information on the monitoring in these estuaries was not used because it arrived in the late stages of the project.
9 Monitoring was conducted 1-2 miles from the shoreline.
10 Sampled for the NORSAP programme summer 1990, winter 1990/1991 and summer 1991.
11 Offshore run from the Mersey to the Isle of Man.
12 Will be analysed for 1992 onwards.
* Data used for the iteration exercise.

TON Total oxidised nitrogen
TN Total nitrogen
SRP Soluble Reactive Phosphorus
TP Total phosphorus
CHL-A Chlorophyll-A

Table A.1 continued

Notes continued

Tidal stage

S	Spring tide
N	Neap tide
H	High tide
F	Full tide
L	Low tide
M	Mid-tide
FTC	Full tidal cycle
HTC	Half tidal cycle

Depth

S	Surface
B	Bottom
MD	Mid-depth
DP	Depth profile