MARINE POLLUTION MONITORING MANAGEMENT GROUP

COMPREHENSIVE STUDIES FOR THE PURPOSES OF ARTICLE 6 & 8.5 OF DIR 91/271 EEC, THE URBAN WASTE WATER TREATMENT DIRECTIVE

SECOND EDITION

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FOREWORD

This is the second edition of the report which was first issued by the team on 1st February 1994. In its original form the report was endorsed by both the Group Coordinating Sea Disposal Monitoring and the Marine Pollution Monitoring Management Group before it received approval by the UK Environment Departments. This second edition of the report has the endorsement of the Group Coordinating Sea Disposal Monitoring. It has also been accepted by the Urban Waste Water Treatment Directive Implementation Group and the UK Environment Departments as meeting their requirements for a standard methodology for application throughout the United Kingdom.

The revisions made to this report have been introduced to clarify a number of matters which have caused confusion to users. Details of the main changes are provided in the preface which follows. Simple changes to a few words are not mentioned and it is emphasised that the criteria upon which judgements should be based are unaltered.

The environmental quality issues raised should be addressed in every study. The report specifies standards of environmental quality which are intended as clear guidance. It is not necessary to use the methodology given in the report in evaluating the issues and measures against the standards. The guidance on methodology is not prescriptive, alternatives may be used.

The guidance offered may be subject to review in the light of further experience. In the meantime the secretary to the Task Team can be approached should assistance be required in interpretation.

Comprehensive Studies Task Team,
January, 1996.

PREFACE

In order to assist the reader, this preface lists the major changes which have been made to the first version of the report. Very minor changes, such as single word changes or additions, are not detailed here. The main changes which have been made are:

- it has been stated that the methodologies given in the report apply to Article 6 as well as Article 8.5 studies (section 1.5)

- it has been stated that the degree of confidence which a study must provide should be proportionate to any potential impact a discharge may have (section 1.9)

- draft versions of the certificate to be issued by the regulator, the framework format for the report and the format for the 1-2 page summary have been annexed (section 1.19, annexes 2-4)

- table 1 (Information on sewage effluent) has been removed and it has been stated that the nutrient removal between primary and secondary treatment must be addressed (section 2.5.3)

- it has been clarified that comprehensive studies are designed to examine the relative effect between primary and secondary treatment. The designation of Less Sensitive Areas is a separate issue and needs to be considered apart from comprehensive studies (section 3.1)

- hypernutrification exists when **winter** values of nutrient concentrations, **outwith any area of local effect, significantly** exceed 12 mmol DAIN m^{-3} (sections 3.3.2, 6.2.9). There has previously been confusion over whether summer or winter values were to be used

- reference has been made to winter molar ratios of DAIN to dissolved silica as these may be usefully applied where hypernutrification is suspected (section 3.3.2)

- both nutrients and chlorophyll should be expressed as spatial averages over the area being considered (section 3.3.2)

- the term chlorophyll and methods of extraction have been clarified (section 6.1.5)

- for the yield of phytoplankton from nutrient (q), use of the median value is recommended (sections 6.2.5.1, 6.2.11)

- it is recognised that benthic sampling in hard or mixed substrates is difficult; therefore alternative methodology and proof is permissible, but studies must still be carried out (section 7.1.2)

- the use of a new model (BenOss), which predicts organic carbon deposition on the seabed and associated benthic changes, is recommended (section 7.2.3)

- benthic identification should be carried out to species level wherever possible. Ideally a sieve mesh size of 0.5mm should be used for sampling the benthos (1mm is acceptable under certain circumstances) and the best time to sample the benthos is between February and May (section 7.3.4)

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1. INTRODUCTION

1.1 The Urban Waste Water Treatment Directive (UWWTD) requires the provision of sewerage systems for all agglomerations larger than 2,000 population equivalent (PE) and sewage treatment for agglomerations larger than 2,000 PE discharging to fresh waters and estuaries and for greater than 10,000 PE discharging to coastal waters.

1.2 The objective of the Directive is to protect the environment from being adversely affected by the disposal of insufficiently treated urban waste water. In most cases secondary treatment is the prescribed level of treatment and therefore it follows that secondary treatment is presumed sufficient in most cases to protect the environment from these adverse effects. In the case of Sensitive Areas additional treatment is needed but in Less Sensitive Areas it is recognised that primary treatment can be sufficient to protect the environment from adverse effects. The absence of adverse effects must be demonstrated by a "comprehensive study". The objective of the comprehensive study is to demonstrate that primary treatment, as compared to the norm of secondary treatment, is sufficient in certain circumstances.

1.3 The Directive does not define adverse effects. Neither does it prescribe the context of comprehensive studies. In order to define such effects and the nature of necessary studies the Environment Departments requested that the Marine Pollution Monitoring Management Group (MPMMG) report on this matter. The MPMMG remitted the task to the Group Coordinating Sea Disposal Monitoring (GCSDM). This report has been prepared by the Task Team set up by GCSDM to fulfil the remit. Membership of the Task Team is given at Annex 1.

1.4 In considering the provision of a lesser standard for those discharges made to areas identified as less sensitive it is essential that proper safeguards are established. The Directive provides these through Article 6 and Article 15.3.

(a) Relevant discharges must receive at least primary treatment to specified standards (Art. 6.2)

(b) It must be proven by comprehensive studies that any such discharge will not adversely affect the environment (Art. 6.2)

(c) The identification of Less Sensitive Areas will be reviewed at intervals of not more than four years (Art. 6.4)

(d) Decisions on Less Sensitive Areas will be subject to scrutiny by the Commission who may make appropriate proposals to the Council (Art. 6.2 & 6.3)

(e) Monitoring of Less Sensitive Areas is required (Art. 15.3).

1.5 The guidance and methodologies given in this document apply to Article 6 as well as Article 8.5 studies. The degree of confidence which a study must provide should be proportionate to any potential impact a discharge may have.

1.6 Given that the discharges under consideration are principally of organic matter these are adequate safeguards. The effects of organic discharge in general and sewage in particular are reversed following cessation of discharge. In the absence of irreversible change and with a monitoring regime in place then no long-term damage will arise from organic matter.

1.7 Notwithstanding the security offered by the Directive further safeguards have been incorporated into the United Kingdom approach:

(a) Less Sensitive Areas will only be identified around specified existing and proposed discharges, so that each case will be examined on its merits and comprehensive studies carried out for each discharge.

(b) All relevant discharges will be discharged offshore so that a minimum initial dilution of fifty is achieved at the surface or at a pycnocline for 95% of the time.

1.8 The scope and quality of the comprehensive studies are integral to successful implementation of Articles 6 and 8.5. This report sets out the nature of the studies to be conducted subsequent to the identification of Less Sensitive Areas.

1.9 In considering such studies it is essential that the basic nature of the matter is clearly defined.

Articles 6 and 8.5 allow the discharge of primary treated effluent, as opposed to the norm of secondary treated effluent, to areas identified as less sensitive. Article 6 applies to discharges from agglomerations of between 10,000 and 150,000 PE to coastal waters and those from agglomerations of between 2,000 and 10,000 PE to estuaries. Article 8.5 applies to discharges from agglomerations of greater than 150,000 PE to coastal waters.

Article 6 implies that only the marginal increase in discharge load from primary compared with the normal standard of secondary treament needs to be considered. For example the difference in solids discharged for a PE of 50,000 is only 1.15 tonnes per day (td^{-1}). Studies must therefore be capable of a high degree of discrimination.

Article 8.5 is worded slightly differently than Article 6 and states that it must be demonstrated that "more advanced treatment will not produce any environmental benefits." Due to the larger potential impact of such discharges, a high degree of confidence in the results of the study is required.

1.10 Studies must also have regard to all potential effects in respect of the marginal pollution load differences referred to. There are three main considerations regarding potential effects.

(a) Overall loading to the sea area and its effects including those on adjacent waters.

(b) Far-field but "local" effects such as enhanced phytoplankton growth and solids deposition remote from the outfall.

(c) Local effects in the vicinity of the outlet, e.g. deposition of particulate organic matter.

Studies must take account of all of these considerations.

1.11 Trans-boundary effects on adjacent water masses can be assessed through a knowledge of relative pollutant loads, pollutant transport and the overall quality of the sea area(s) in question. The data necessary for assessment are generally available through PARCOM programmes and previous water and biological quality monitoring. These may be brought together through simple modelling studies. Current studies of particular value are the Continuous Plankton Recorder Programme, the UK National Monitoring Programme and the NRA studies around the English and Welsh coasts utilising remote sensing techniques with ground truth observations.

1.12 In identified Less Sensitive Areas where discharge(s) already receive primary treatment, a relatively simple environmental assessment should establish whether or not "no adverse effects" occur.

1.13 Given the scope of the factors under consideration and also that the discharges in question are unlikely to exist in the desired form at the present time, studies are required to be predictive in the first instance. Only the post discharge monitoring will absolutely establish whether or not primary treatment was sufficient to prevent adverse effects.

1.14 It is also considered that the discharges in question will have little effect and that marginal differences between primary and secondary treatment could be difficult to quantify. Given that in most cases the discharges in question are untreated at present, effects are likely to disappear with primary treatment. Nevertheless studies are required to demonstrate that primary treatment alone is acceptable under the terms of the Directive. Taken overall comprehensive studies will comprise a conceptual framework of fieldwork to establish parameters, one or more predictive models and post-discharge monitoring of predicted effects. A flowchart is given in Figure 1 which asks the most important questions in identifying Less Sensitive Areas and thereafter refers to the methodology necessary to prove that an area will not be adversely affected by a discharge which is subject to treatment less stringent than secondary treatment. Where technical questions are asked, numbers refer to the section in which the appropriate predictive/investigative approach is outlined.

1.15 The approach described at 1.13 has been adopted, recognising that not all of the techniques proposed are fully validated and are subject to development. The methodology proposed will be the subject of continuous review. It is considered that GCSDM should be charged with review and development of the methodology.

1.16 In many instances potential sites will have been the subject of previous studies or there may well be continuing monitoring at such sites. Where the data are suitable for establishing compliance with the standards prescribed in Chapter 3 they may be utilised in the comprehensive study, either substituting for the work proposed here or used in addition to it.

1.17 It is emphasised that application of the lesser treatment standard allowed by Article 6 and 8.5 can only be undertaken within the existing framework of setting discharge control parameters to achieve desired water quality objectives. There is no question of comprehensive studies substituting for current evaluation and control measures aimed at protecting recreational, fisheries or nature conservation uses of receiving waters.

1.18 The technical report which follows describes the nature of the effluents in question, the environmental risks identified and the methods of study.

1.19 In order to try and harmonise reporting for comprehensive studies, a group with representatives from the Department of the Environment (DoE), DoE Northern Ireland, Scottish Office, National Rivers Authority, river purification boards and the Water Services Association has considered standard reporting formats. Annex 2 shows a certificate to be issued by the regulator on completion of a comprehensive study. Annex 3 gives a framework format for the report to be produced by the discharger and Annex 4 is a format for the one to two page summary which is to be produced by the regulator and submitted to the relevant department.

2. NATURE OF EFFECTS REQUIRING PREDICTION

2.1 Introduction

Section 1 makes it clear that, although proper safeguards are required where a lesser standard of sewage treatment is to be permitted, the potential difference in effluent quality between primary and secondary treatment is relatively small, and the parameters concerned are of immediate rather than long-term significance. Of the typical sanitary determinands affected differently by primary and secondary treatment, only biochemical oxygen demand (BOD), suspended solids (SS) and faecal coliforms are substantially reduced after secondary treatment. The differences observed in dissolved nutrients (N and P) occasioned by secondary rather than primary treatment are of a lesser magnitude. Toxicity due to sewage constituents (ammonia, detergents) may be reduced by secondary treatment, while toxicity due to trade discharges should be controlled through normal consenting procedures. Toxicity issues are dealt with in section 2.2 below. Microbial issues are dealt with in section 2.3. Aesthetic criteria are also affected by the degree of treatment, these are discussed at 2.4.

Few sewage discharges are made to waters totally uninfluenced by other, neighbouring discharges. Studies to predict degree of impact will need to define the geographical scope of a candidate discharge and the impact of other discharges within the area. This subject is explored in sections 4 to 7.

Estuarine and coastal receiving environments are physically different in important respects. Salinity ranges, tidal current velocities, dispersion, particulate deposition patterns and hence the nature and complexity of predictive tools required are different. Biological and other aspects are also consequently different: estuaries are a focus for fish migrating between fresh and marine waters and a nursery area for many marine fish species while coastal waters are less physically constraining; the sheltered nature of estuaries encourages a high level of recreational use and intertidal areas have importance for waterside birds.

2.2 Toxicity

For domestic sewage effluents the main toxic component is ammonia. Concentrations of ammonia can be reduced substantially in secondary treated effluent (by up to 90%) by the action of nitrifying bacteria, however the majority of secondary sewage treatment plants do not nitrify unless specifically designed to do so. If, however, such a reduction in ammonia loading is required to meet an Environmental Quality Standard (EQS) in the receiving water, for instance to protect migratory fish passing through an estuary, then this issue is properly dealt with through the normal consenting process. EQSs, available for many persistent or acutely toxic substances, are applied to all relevant controlled waters, and should be met irrespective of Article 6 requirements.

Qualifying sewage discharges containing trade wastes should be subject to a rigorous consenting procedure, but specific toxicity assessment actions in relation to less sensitive candidature need not be undertaken.

2.3 Microbial Contamination

Although faecal coliform bacterial concentrations are reduced by at least an order of magnitude during secondary treatment, the effect on pathogenic bacteria and viruses is less well understood. Bacterial standards are relevant to the quality of bathing waters, shellfish waters and other areas where water contact sports may demand similar standards in the future. Outside these areas *Escherichia coli* and faecal coliform numbers are not relevant. The level of treatment needed to protect bathing waters and/or shellfish waters will be established independently of this Directive and therefore bacterial numbers are not considered in detail in this assessment.

2.4 Aesthetic Considerations

Sewage effluents are less dense than sea water. Unless there is adequate dilution at the point of discharge a surface slick will form which is visual evidence of the discharge. Slicks may also be discoloured, have high bacterial concentrations and give rise to odour problems. The presence of fats in the effluent can enhance slick formation and give rise to floating particulates, (e.g. Newton (1975), SCCWRP (1973)). Once a density slick has formed mixing is inhibited and advection can transport the poorly diluted effluent to recreational or other areas where it can exert an undesirable effect. Whilst secondary treatment does not affect the density of the discharge it produces a less offensive liquid than primary effluent and is unlikely to give rise to nuisance.

The generally accepted initial dilution value preventing density slick formation is 50:1. Although this value is recommended as guidance, local circumstances must always be considered. The objective is to prevent the formation of density slicks and ensure good mixing.

2.5 Water Quality Parameters Relevant to Articles 6 and 8.5

The following parameters are assessed for predictive and monitoring needs:

2.5.1 Biochemical Oxygen Demand

Both particulate and dissolved organic matter contribute to an oxygen demand within the water column. Particulate organic matter settling at the sediment-water interface may also contribute to sediment oxygen demand (see 2.5.2). Secondary treatment removes up to 90% of BOD from primary (settled only) effluent, an improvement of about one order of magnitude. Such a reduction in organic input could be significant and where field data are lacking predictive studies are needed to model the effects on dissolved oxygen concentrations in the receiving water. This is considered in detail in section 5.

2.5.2 Suspended Solids

Suspended solids loading includes particulate carbon, and may be responsible for important effects both in the water column and at the sediment surface. Secondary treatment removes 70 to 80% of SS from primary effluent, but the impact of such a removal will be difficult to assess in the context of an environment receiving substantial particulate input from non-sewage sources. The difference made by secondary treatment is, however, substantial and the impact of SS must be considered.

For smaller individual discharges, the principle cause of change in the benthic macrofauna is likely to be the result of suspended solids settling on the sea bed. There are several ways in which this may affect the benthos:

i) physical: particles in sufficient quantity may induce changes in species composition or relative abundance as a result of physical interference with eg. feeding or tube-building activities;

ii) physico-chemical: at least in stable areas, a build up of organic matter within sediments may, through microbial action, result in an increased oxygen demand. Chemical changes associated with anaerobic metabolism may increase the toxicity of sediments, resulting in the favouring of more tolerant or adaptable taxa over others;

iii) chemical: accumulation within sediments of certain particle-bound contaminants, if present in sufficiently high concentrations in a sewage discharge, may induce a toxic response in "sensitive" species;

iv) organic: inputs of organic matter may provide a direct food source for certain benthic macrofaunal taxa, which may then be favoured over others.

There is a strong likelihood of interaction between some or all of the above. Their relative importance will vary according to the nature of the discharge and the nature of the receiving environment.

2.5.3 Dissolved Nutrients

These are only of interest insofar as they may cause eutrophication. Eutrophication is defined by the Directive as:

> the enrichment of water by nutrients, especially compounds of nitrogen and/or phosphorus, causing an accelerated growth of algae and higher forms of plant life to produce an undesirable disturbance to the balance of organisms present in the water concerned.

Guidance on the identification of eutrophication is given in the second consultation paper "Consultation paper on methodology for identifying Sensitive Areas (Urban Waste Water Treatment Directive) and designating vulnerable zones (Nitrates Directive)". Chlorophyll concentration is a convenient measure of the abundance of planktonic algae. It will be used, in this respect, as the main indicator of the potentially eutrophying effects of a waste water discharge, since it can be measured simply and unambiguously. Establishing the occurrence of significant changes in the balance of planktonic algal species does not seem feasible in the present context.

Dissolved Available Inorganic Nitrogen (DAIN) and Dissolved Available Inorganic Phosphorus (DAIP) play a crucial role in phytoplankton growth in surface waters. Hypernutrification is of potential concern in coastal waters where nuisance blooms of algae would cause aesthetic and possibly toxicity problems.

In considering comprehensive studies the question of relative nutrient removal between primary and secondary treatment must be addressed.

2.6 Administrative Context

Identification of less sensitive status for an area of receiving water, and the demonstration of no adverse environmental effect in relation to a specific discharge, will depend ultimately upon answers to technical questions concerning the impact of BOD, SS and nutrients, nevertheless administrative questions have also to be answered. The necessary sequence of decisions is aided by a flowchart which is shown in **Figure 1**. Where technical questions are asked, numbers refer to the section in which the appropriate predictive/investigative approach is outlined.

3. STANDARDS USED TO DEFINE ADVERSE EFFECTS

3.1 Introduction

The Directive states that comprehensive studies must show that no adverse effects will be caused by discharges, subject to treatment less stringent than secondary (minimum primary), to Less Sensitive Areas. This section outlines what the group considers to be adverse effects in estuaries and coastal waters.

Comprehensive studies are designed to address the impact which a discharge has on the surrounding environment and examine the relative effect of primary and secondary treatment. It is important that this is kept separate from the actual designation of Less Sensitive Areas. The nature of the receiving environment is relevant and must be assessed but, in the context of comprehensive studies, it is only the marginal difference between primary and secondary treatment that is being judged.

In general, the area of interest in which an adverse effect is likely to occur can be defined by one tidal excursion either side of the discharge. Retention time is also important, especially in estuaries and with respect to nutrients.

3.2 Estuaries

Given the small sizes of discharges (2,000 to 10,000 PE) which qualify in estuaries, of the chemical characteristics only dissolved oxygen (DO) is considered an important parameter in these cases.

A median DO concentration of 7 mg/l is considered a safe standard which will allow the passage of all relevant species of migratory fish and will sustain a breeding population of estuarine fishes appropriate to the physical characteristics of the water body. As long as the median DO level is maintained above 7 mg/l, a change of less than 1.0 mg/l in DO level would be acceptable. If the median level falls below 7 mg/l, more study is required and each case must be considered on a local basis. If the difference in DO level would be changed by ≥1.0 mg/l due to the difference in treatment level between primary and secondary, this would be considered an adverse effect and primary treatment alone would be inappropriate. For further details on estuaries see section 4.

Where there are planned improvements in other discharges, affecting the water body in question, to raise the median level above the standard, the discharge under consideration can be viewed in the light of these improvements.

3.3 Coastal Waters

3.3.1 <u>Biochemical Oxygen Demand</u>

It is estimated that in any area where BOD levels deviate <1.5 mg/l from background levels, the resulting impact on DO levels will be <0.5 mg/l. Where the median DO level is maintained above 7.0 mg/l, a change of 0.5 mg/l can be assumed to cause no adverse effect. Section 5.3.1 gives further detail of how to assess an area for impact, i.e. outside the mixing zone.

Where there are planned improvements in other discharges, affecting the water body in question, to raise the median level above the standard, the discharge under consideration can be viewed in the light of these improvements.

3.3.2 Nutrients

An area is considered to be adversely affected if it is hypernutrified and there is evidence or the likelihood of eutrophication; Article 5 would probably apply in this case.

Hypernutrification exists when winter values of nutrient concentrations, outwith any area of local effect, significantly exceed 12 mmol DAIN m^{-3} in the presence of at least 0.2 mmol DAIP m^{-3} (see 6.2.4). This could be affected by any difference between primary and secondary treatment. Hypernutrification should not, however, be seen as a problem in itself. It will cause harmful effects only if a substantial proportion of these nutrients is converted into planktonic algae or into seaweed.

A region is potentially eutrophic only if the relative rate of light-controlled phytoplankton growth is greater than the relative water exchange rate plus the relative loss rate of phytoplankton by grazing; and the predicted summer maximum chlorophyll concentration is greater than 10 mg chl m^{-3} (see 6.2.7). A region is eutrophic if observed chlorophyll concentrations regularly exceed 10 mg m^{-3} during summer.

Recent work on winter molar ratios of DAIN to dissolved silica has increased our understanding and permits a degree of prediction of the trophic status of marine waters. This could usefully be applied where hypernutrification is suspected (Officer & Ryther, 1980, Tett & Walne, 1995). Comprehensive studies carried out to date have raised certain issues regarding the nutrient status of some waters. This matter needs further consideration in terms of long term monitoring, although this is not part of comprehensive studies.

Only treatment-related increases in the predicted maximum chlorophyll levels of >1 mg chl m^{-3} are considered to be significant. Any lesser change would not constitute an adverse effect under Article 6. That is to say, where observed or predicted summer chlorophyll concentrations exceed 10 mg m^{-3}, but less than 1 mg m^{-3} can be ascribed to the discharge under consideration, other factors are likely to be the cause of eutrophication. This would require separate investigation.

Both nutrients and chlorophyll should be expressed as spatial averages over the area being considered. In well mixed areas a depth average to the seabed should be used and in stratified waters the zone above the pycnocline should be taken.

3.3.3 Suspended Solids and Organic Carbon

The effects of suspended solids and associated organic matter are most likely to be seen by examining the benthic community. It is therefore necessary to determine what constitutes an adverse effect on the benthos.

It is proposed that an adverse effect exists when primary treatment induces a significant change in community structure at a distance greater than 100 metres from the outlet which would not have occurred had secondary treatment been installed. Having regard to inherent variability of marine communities, a number of variables should be examined. Levels of acceptable change within the sphere of waste influence compared to a reference site are as follows:

total abundance	: +200% of reference station value
total taxa	: + 50% of reference station value
biomass	: + 50% of reference station value

It is emphasised that the levels of acceptable change given here relate to organic enrichment standards and allow for an early phase in the enrichment process. It is essential to have a clear understanding of the current environmental status and, preferably, history of the site if these guidelines are to be applied effectively.

In the absence of adequate past data for a site, when the guidelines given above cannot be readily applied, the Infaunal Trophic Index (ITI) can be used to determine whether or not a significant change has been induced. An ITI value of less than 30 indicates severely modified communities and a significant change in community structure. Communities which have an ITI value between 30 and 60 may be modified and suffering from an adverse effect. Such areas should be further examined by various univariate and multivariate analyses in order to ensure that only the early phase of organic enrichment is present. This early phase of organic enrichment is not considered an adverse effect. For a more complete interpretation of ITI values WRc (1992) should be consulted.

Section 7 gives methods and guidelines on how to assess benthic communities for impacts from sewage discharge. For a better understanding and application of these guidelines, MAFF (1993) should be consulted.

3.4 The standards proposed must be regarded as guidelines. Only through experience will these be validated. In the meantime the group is confident that they describe a level of no adverse effect.

4. ESTUARIES

4.1 The United Kingdom has adopted two alternative definitions of estuaries for the purposes of this Directive. An estuary is:

(a) an area receiving freshwater inputs where the waters on a depth averaged basis have a salinity of less than 95% of the adjacent local offshore seawater for 95% of the time.

(b) an inlet of the sea bounded by a line between such topographical features as define the seaward boundary of the estuary.

In England and Wales definition (b) is used and in Scotland and Northern Ireland definition (a) is more commonly used to define estuaries.

4.2 Estuaries around the United Kingdom are generally dynamic, well aerated areas, many of which have a high dispersive capacity as a result of limited low water retention and a high exchange between estuarine and coastal water on each tidal cycle. On the other hand fjordic estuaries are common in western Scotland. In some cases their deep waters become isolated from free exchange for weeks or months, and can show substantial oxygen depletion. Residence times of near-surface waters range from a few days to a few weeks. Rias (drowned river valleys), found in SW Wales and England, may have vigorous local dispersion because of strong tidal currents, but only weak exchange with adjacent coastal waters.

4.3 A significant number of UK estuaries have been modelled by either 1-dimensional or 2-dimensional modelling techniques in association with discharge consenting and civil engineering schemes. Where such models exist, their application to comprehensive studies in order to show 'no adverse effect' is encouraged. In such circumstances their use is considered fully justified and will represent one of the most technically valid and cost effective means of undertaking the comprehensive study. Where no previous hydrodynamic model exists, guidelines for suitable alternatives are given in 4.6.

4.4 Discharges to estuaries which may be subject to treatment less stringent than that prescribed in Article 4 only range between 2,000 and 10,000 PE. The difference in loading between primary and secondary treated discharges from works of this size is very small. In the context of the parameters controlled by the Directive only dissolved oxygen (DO) levels will be significantly affected and need to be taken into account when dealing with estuarine discharges.

4.5 A median DO of 7 mg/l will allow the passage of all relevant species of migratory fish, support a residential fish population and will sustain breeding populations appropriate to the physical and hydrographical conditions of the water body.

As long as the median DO level is maintained above 7 mg/l, a change of less than 1.0 mg/l in DO level would be acceptable. If the level is predicted to fall below 7 mg/l, more study is required and each case must be considered on a local basis.

If the difference between primary and secondary treatment is predicted to cause a ≥1.0 mg/l DO level change of the surrounding water, this will be considered an adverse effect and primary treatment will be inappropriate.

Where there are planned improvements in other discharges, affecting the water body in question, to raise the median level above the standard, the discharge under consideration can be viewed in the light of these improvements.

4.6 In general the application of state of the art 2-dimensional models is considered unnecessary. Most, if not all, circumstances can be adequately considered by using 1-dimensional modelling.

Intermediate levels of technology such as steady state or time dependent box models exist for estuaries, however the heavy reliance on field data makes them somewhat cumbersome to use with no overall benefit.

These guidelines therefore recommend the use of the modern 1-dimensional PC series of models produced by the main modelling houses (eg. WENDY, MIKE II, TIDEFLOW TD).

4.7 It is expected that authorities will already monitor DO levels in all significant estuaries to a standard acceptable for the purposes of Article 6. Should this not be the case, any less sensitive estuarine waters must be monitored not less than monthly. Sampling stations should allow depth averaging and be of a sufficient number to permit validation of the predictive model employed.

5. COASTAL WATERS

5.1 Introduction

In the context of areas identified as less sensitive, there is a responsibility to prove that a given outfall/discharge regime will show no overall environmental disadvantage if treatment of that specific discharge is primary rather than secondary.

- The task group believes evaluation of this impact should utilise appropriate predictive modelling technologies. In the context of this Directive specific requirements extend to the prediction of BOD, dissolved available inorganic nutrients and suspended solids. The rationale behind these particular parameters is given in section 2.

- Matters related to other substances such as complex organic compounds and heavy metals, or to specific impacts upon marine shellfisheries and bathing water compliance are adequately covered by respective directives, legislation and guidelines and are not specifically considered here.

5.2 Modelling of Coastal Waters

Coastal waters around the UK are generally dynamic and characterised by large tidal range, large tidal excursion and high dispersive properties. In contrast there are some waters, including semi-enclosed bays and some Scottish sea lochs, where wind driven circulation and stratification can be important.

A significant proportion of the UK's coastline has been covered by sophisticated 2-dimensional hydrodynamic models which have been calibrated and verified for use in optimising major outfall designs, waste strategies and civil engineering schemes. Where such models exist, their application is encouraged. In complex circumstances their use will be fully justified and will represent one of the most technical and cost effective means of undertaking a 'comprehensive study'.

In general, however, the application of state of the art predictive models, usually a 2-dimensional plan view model of hydrodynamics and effluent dispersion at fine grid resolution (~200m) is considered unnecessary.

Very few techniques have been developed representing an intermediate technology between field experimentation assisted by simple calculations and the more sophisticated 2-dimensional high resolution models currently available.

These guidelines promote the use of simpler assessment tools capable of identifying the 'no impact' case. Options fall into two generic categories.

5.2.1 <u>Intermediate Models</u>

An appropriate alternative promoted in this guideline is FLOWSUM (FLOWSUM was developed by YARD, a member of the SEMA-GROUP and is commercially available). This model offers a fundamentally different approach to predictive modelling. The model is based upon field data and establishes a continuity flow field; the model does not rely on numerical analysis of the equations of motion and convective diffusion in the normal manner. It uses available field data, whether from current meters, drogues, dye floats or remote sensing. From this potentially sparse data it is capable of creating a high resolution 2-dimensional flow field whilst ensuring continuity of current flow and allowing for bed friction.

The model can also accommodate vertical profiles of tide and wind driven circulation in creating a 3-dimensional random walk simulation describing effluent dispersion and decay in the usual manner. The model is at this stage similar to more sophisticated techniques and incorporates colour graphic outputs and other familiar presentation of results.

The technique is specifically designed to provide quick application to a new site, to allow rapid compilation, good local prediction of transport and dispersion process. This is achieved by making maximum use of field data.

Whilst this model is recommended others may be used or better alternatives might be developed.

5.2.2 Screening Models

The second option is to use a simplified version of conventional 2-dimensional modelling. By making certain simplifying assumptions it is possible to maintain adequate predictive accuracy with much reduced effort. Major modelling institutions differ in how this can be achieved but the following example illustrates this generic level of modelling.

The technique developed by Delft Hydraulics involves the application of a standard preconstructed 2-dimensional model grid with a simplified coastline and boundaries. The model can be layered and requires background flow velocities at boundaries and background polluting loads. The transport equation is solved for steady state and tide averaged conditions, allowing the prediction of both decaying and persistent materials. This standard of model would be acceptable.

5.2.3 Field Data

All models require a basic suite of supporting data derived from field observations. The observations and supporting data necessary for the studies described are listed at Annex 5.

5.3 Application and Assessment of Impact

5.3.1 Biochemical Oxygen Demand

The biochemical oxygen demand pattern arising from the proposed outfalls can be generated from either of the predictive techniques described above.

In general terms the discharge of primary settled effluent will be at a strength of some 150 mg/l. When effluent of this strength is discharged through an appropriate port or diffuser system designed to achieve 50 initial dilutions, the resulting buoyant plume concentration at the sea surface will have an initial strength of 3 mg/l BOD above background.

Thereafter, the effluent will disperse away from the outfall, its concentration reducing as a result of biochemical decay and entrainment of background water. With a typical decay of 0.3 day^{-1}, steady state conditions will be approached after three days and well established after five. The model should be used to predict the build up of BOD over this period or to predict its steady state concentration directly.

In terms of identifying an adverse effect, any area of BOD not exceeding 1.5 mg/l deviation of background will generate less than 0.5 mg/l estimated impact on dissolved oxygen. Where this level of change is sustained above a 7.0 mg/l threshold, it can safely be assumed that there will be no significant impact. This will in most situations correspond to an area away from the point of discharge where effluent will have received at least ten secondary dilutions, a process which will be achieved over a period of six hours or less. BOD concentrations nearer to the outfall may exceed 1.5 mg/l. The impact in this zone will depend upon travel time from the outfall within which the kinetic process can take effect. In general the short duration is unlikely to provide opportunity for impact >0.5 mg/l, this can be checked by a simple calculation in the form of a point source plume model.

Where there are planned improvements in other discharges, affecting the water body in question, to raise the median level above the standard, the discharge under consideration can be viewed in the light of these improvements.

5.3.2 Nutrients

In the medium and wider field the impact of hypernutrification from either DAIN or DAIP can be assessed by those empirical relationships set out in section 6. The critical factor affecting both hypernutrification and subsequent eutrophication is the clean water exchange rate of water in any given study section.

This exchange rate can be simulated using the model technique described here. The exact method will depend upon local circumstance. A first task is to establish a meaningful 'box' within which nutrient enrichment and phytoplankton growth can be calculated. In an open coastal area the definition would be somewhat arbitrary and the sensitivity of box size to predicted impact should be established.

The exchange rate E can be estimated by a variety of methods. One approach is to model the building of DAIN and DAIP based on measured loadings. The prediction should be run to a steady state condition over a timescale which will depend upon local circumstances. The mass of nutrients contained within this box can be estimated and the model run continued with zero inputs. The rate at which material is lost from the defined box will then be predicted giving a direct estimate of E.

In certain cases an estimate of E may be obtained from knowledge of the residual current, measured by drogues or by a self-recording current meter. The residual current will indicate the net rate of transport away from the release point.

Of these methods, the model assisted approach incorporates a greater number of local processes and is favoured on the basis of greatest accuracy.

The value of E can be used in procedures set out in section 6.

5.3.3 Suspended Solids

Predicting the fate of suspended solids discharged from a marine outfall is a highly complex subject. Prediction involves all of the problems of dissolved pollutant modelling but with the added problems of variable particle size, particle density and colloidal and flocculant properties. Even assuming that the settling velocity of the particles can be estimated, their subsequent fate will depend upon the bed stress created by current structure in the bottom ½ to 1m of the water column, the bed form, the extent of consolidation with natural bed sediment (a time dependent process) and the ability of water current to erode the sediment at high tidal velocities or storm events.

It is worth recognising that primary settled effluent discharged through a correctly designed sea outfall will have a maximum surface concentration of 3 mg/l suspended solids near the outfall. The particles present in this discharge will be those which were not settled in the primary treatment phase. The settling velocity of these particles will therefore be extremely low and even allowing for flocculation it is unlikely that these solids will rapidly deposit around the outfall.

Given the levels of technical difficulty and uncertainty involved in predicting suspended solids behaviour and the large number of physical and physico-chemical co-efficients which need to be derived locally, we believe that the costs of sophisticated modelling are not justified by the marginal benefits which may be obtained.

Our guideline is therefore based upon a new model developed (BenOss) which predicts quantitative changes in the benthic fauna (see section 7).

5.4 Monitoring

5.4.1 The basic data gathering necessary for physical studies is described at Annex 5. These studies need not be repeated unless there are changes in the environment liable to alter the hydraulic regime.

5.4.2 The monitoring necessary in respect of eutrophication and the benthic impact of solids is described elsewhere in this report.

5.4.3 The monitoring of DO levels is also required, preferably before and after the discharge commences. It is recommended that a targeted set of observations designed to test the predictions of the model are carried out during the year in which the model is first used and then every four years after that.

6. PREDICTION AND MONITORING OF EFFECTS DUE TO NUTRIENTS

6.1 Definitions

6.1.1 'Nutrients' are substances needed for the growth of phytoplankton and benthic plants, and which are often scarce, in relation to demand, in seawater. For present purposes, they are compounds of nitrogen and phosphorus. Enrichment can lead to extra plant growth and algal blooms. In designing studies to demonstrate the lack of adverse effects of a relevant discharge it is necessary to establish (a) whether hydrography allows the local build up of a significant nutrient enrichment ('hypernutrification'), and (b) whether local hydrographic and biological conditions allow the conversion of this enrichment into plant production ('eutrophication'). The outcome of eutrophication may be beneficial or harmful, but it is not possible to predict this with the present state of knowledge. Instead, it will be assumed that eutrophication, as defined at 2.5.3 in this report, should as far as possible be avoided.

6.1.2 As elsewhere in this report it is useful to consider nested zones of potential effect.

A: a small inner zone in which discharged dissolved nutrients have a residence time of 10^1 to 10^3 seconds, in which particulates may accumulate in the absence of sufficient tidal stirring, and which can be recognized by the presence of discharged nutrients at concentrations close to the minimum initial dilution. Only in this zone could the growth of attached macrophytes be visibly increased.

B: a zone in which discharged dissolved nutrients have residence times of 10^5s or a few days, the timescale of phytoplankton growth in favourable circumstances. Nutrients are dispersed through this zone mainly (in UK waters) by tidal movements.

C: a larger region in which the residence time of water is 10^6 to 10^7s (10 to 100d), sufficiently long for its dissolved nutrient concentration to be increased by mineralization of particulates. Dispersion on this larger scale results from residual circulation as well as tidal movements.

6.1.3 This section deals mainly with the potential for growth of phytoplankton in Zone B. Zone B must be at least the size of the tidal excursion about the discharge point. In some circumstances it will be necessary to take account also of dispersion brought about by other water movements. Finally, the zone is in fact a volume, Vm^3. Where stratification is persistent, the depth of the zone should extend only to the pycnocline. The criterion, that the residence time of a typical water packet should be a few days, sets a lower limit to the dimensions.

6.1.4 The zone's dilution, or relative exchange rate is defined (on the assumption of perfect internal mixing) as:

6.1.4.1 $E = (\Delta V/\Delta t).(1/V)$ d^{-1}

where

$\Delta V/\Delta t$ is the mean rate of volume exchange with adjacent [seawards] areas

E should be estimated, using salt budgets or numerical models (see 5.2) for worst case dilution conditions. In the absence of detailed hydrographic data, E=0.1 d^{-1} can be used.

6.1.5 The research work that led to the setting of phytoplankton chlorophyll concentrations and phytoplankton yield involved measurements of photosynthetic pigments by methods that were standard for marine scientists in the 1970s and 1980s (viz: extraction of pigments into 90% acetone and measurement of fluorescence before and after acidification using a bench fluorometer equipped for chlorophyll measurement and calibrated against a standard solution of pure chlorophyll *a*). The resulting estimates may include errors resulting from the presence of other photosynthetic pigments. This is also the case for concentrations calculated by spectrophotometric measurement of optical density at several wavelengths.

The label "chlorophyll *a*" should probably only be used when the pure pigment has been prepared by chromatographic separation, a method that is not yet suitable for routine use in water quality laboratories. The use of the more vague label "chlorophyll", or the fuller version "chlorophyll *a* and related pigments" should be used as it will be less misleading in most cases.

Both nutrients and chlorophyll should be expressed as spatial averages over the area being considered. In well mixed areas a depth average to the seabed should be used and in stratified waters the zone above the pycnocline should be taken.

6.2 Prediction of the Trophic State

6.2.1 There are many models available which predict the trophic state. The use of these is encouraged but close attention should be paid to the assumptions made. Care needs to be taken when the results are compared with the averaged standards recommended in this report.

6.2.2 Since any model will assume homogeneity within zone B, the dimensions should not be taken as larger than the minimum, ie. a residence time of a few days. In the absence of detailed hydrographic data, the zone can be taken as an ellipse defined by twice the amplitude of the neap tidal excursion about the discharge point. The area of any land (down to mid-tide) should be subtracted. The volume is obtained by multiplying the average depth (below MTL) of the water area. In fjordic sea-lochs, 10m may be taken as the typical depth of a persistent pycnocline.

6.2.3 Potential, steady-state, nutrient concentrations can be estimated using a 'mixed-box' model:

6.2.3.1 $$S = S_o + ((s_i + s_d)/(E.V)) \quad \text{mmol m}^{-3}$$

where

S_o is the nutrient concentration in adjacent seawater (generally the background zone C concentration);

s_i is the total of local inputs from sources other than the discharge under consideration, in mmol d^{-1};

s_d is the nutrient input from the discharge under consideration, in mmol d^{-1}.

The calculation should be carried out for conditions in late winter (with S_o measured in

February before the spring phytoplankton bloom has depleted nutrients) and in mid-summer (July to August) and for present and future values of s_d with and without secondary treatment. Consideration should be restricted to 'Dissolved Available Inorganic' nutrients. DAIN is ammonium + nitrite + nitrate. DAIP is reactive phosphate.

6.2.4 Nutrient predictions are best tested by sampling in late winter, before the assimilation of DAIN and DAIP by phytoplankton. Hypernutrification may be considered to exist when predicted winter values of **S** exceed 12 mmol DAIN m^{-3} in the presence of at least 0.2 mmol DAIP m^{-3}. The condition may be termed anthropogenic if at least 5 mmol DAIN m^{-3} of the concentration observed at any time can be ascribed to human action.

6.2.5 The "mixed-box" approach can also be used to estimate the maximum biomass of phytoplankton that can be supported by nutrient enrichment. Biomass is specified as chlorophyll concentration **X**, mg m^{-3}. Under conditions that are ideal for microalgal growth, and thus "worst-case" for potential eutrophication, maximum biomass can be predicted by assuming that all available nutrient is converted into phytoplankton:

6.2.5.1 $$X_{max} = X_o + q.S \text{ mg m}^{-3}$$

where

X_o is the concentration of phytoplankton chlorophyll in the surrounding water;

q is the yield of phytoplankton from nutrient, 1.1 to 2.8 mg chl (mmol DAIN)$^{-1}$, 50 to 100 mg chl (mmol DAIP)$^{-1}$; (A study has shown a median value of 1.1 for q and a 90%ile value of 2.8 (Gowen *et al.*, 1992). We recommend use of the median value.)

S is given by 6.2.3.1.

The calculation should be done for early spring (March to April, high S_o and low X_o) and mid-summer (July to August, minimum S_o) conditions and for the proposed waste water treatment options. It should be made for phosphorus as well as for nitrogen; the limiting nutrient is the one that predicts the smallest biomass increase q.S. In most marine cases nitrogen will be found to be limiting.

6.2.6 Circumstances might not be suitable for phytoplankton growth. Compute the relative rate of light-controlled growth:

6.2.6.1 $\mu = \alpha(m_2.I_o/(\lambda.h) - I_c)$ d^{-1}

where

α and I_c are properties of the phytoplankton and the other parameters describe local environmental conditions;

α is a photosynthetic efficiency with a spring value of 0.030 and a summer value of 0.015 d^{-1} $(\mu E\ m^{-2}\ s^{-1})^{-1}$;

m_2 = 0.37 allows for extra attenuation of polychromatic PAR near the sea-surface;

I_o is 24-hour mean sea-surface photosynthetically available radiation (PAR);

h is the mean depth of the defined volume;

I_c = 12 $\mu E\ m^{-2}\ s^{-1}$ is the compensation irradiance, the minimum allowing phytoplankton growth.

The most critical parameter is the diffuse attenuation coefficient λ (m^{-1}) for most penetrating downwards PAR. This must be measured locally under a range of conditions; it is especially influenced by suspended particulate matter, which may in turn depend on tidal stirring or river flow. Table 1 gives example solutions of equation 6.2.6.1.

Table 1. Example solutions to equation 6.2.6.1

symbol	units			
		Milford Haven, outer part		
		March (av sun)	June (av sun)	June (full sun)
α	/d.(µE/m^2.s)	0.030	0.015	0.015
m_2		0.37	0.37	0.37
I_o	µE/m^2.s	204	456	640
λ	/m	0.3	0.3	0.3
h	m	20	20	20
I_c	/d	12	12	12
μ	/d	**0.02**	**0.24**	**0.41**
		Milford Haven, inner part		
		March (av sun)	June (av sun)	June (full sun)
α	/d.(µE/m^2.s)	0.030	0.015	0.015
m_2		0.37	0.37	0.37
I_o	µE/m^2.s	204	456	640
λ	/m	1.0	1.0	1.0
h	m	8	8	8
I_c	/d	12	12	12
μ	/d	**-0.08**	**0.14**	0.26

Data source: Tett (1992)

6.2.7 The potential maximum biomass will be realised only if $\mu > (E + L)$ where L is the relative loss rate of phytoplankton due to grazing by zooplankton and by benthic filter feeders. It would be unusual for data to be available allowing estimation of L, and a conservative approach is to take $L = 0.0\ d^{-1}$.

- A region is potentially eutrophic only if $\mu > (E + L)$ and

  Summer $X_{max} > 10$ mg chl m^{-3}

As with nutrients, the maximum potential chlorophyll concentration can be partitioned into natural and man-made components, the latter including a contribution that will be reduced by secondary treatment.

6.2.8 Predicted chlorophyll concentrations should be compared with observations made during the spring bloom and in mid-summer. The bloom occurs between March and May, depending on water depth and turbidity. Without continuous monitoring it is difficult to sample the maximum of the bloom. An alternative is to measure chlorophyll X_{obs} and DAIN S_{obs} concentrations (in zone B) during the growth phase of the bloom, and to calculate $X_{max} = X_{obs} + q.S_{obs}$. This procedure can validate the predictions only when $X_{obs} >> X_o$ and $S_{obs} >> S_o$.

The purpose of observations during the spring bloom is to better understand the algal cycle in the receiving water and to check the chlorophyll predictions. In the absence of substantial anthropogenic perturbation, the spring bloom of phytoplankton in UK coastal waters is typically dominated by diatoms and usually does not exceed 10 mg chl m^{-3}. Spring concentrations exceeding 10 mg chl m^{-3} are not, however, deemed evidence of eutrophication unless there is a substantial shift away from diatoms in the phytoplankton species balance. That is to say, the standard of 10 mg chl m^{-3} applies absolutely only to the summer concentrations.

6.2.9 A specified coastal water is deemed not to be adversely affected if, for zone B:

a) there are no observations showing winter DAIN > 12 mmol m^{-3} (in the presence of at least 0.2 mmol m^{-3} DAIP), nor does the equation 6.2.3.1 predict such concentrations; that is, there is no evidence, or likelihood, of hypernutrification;
or if, when hypernutrification has been demonstrated or predicted,

b) there are no observations showing summer chlorophyll > 10 mg m^{-3}, nor does the procedure described in 6.2.5 to 6.2.7 predict such concentrations when conditions allow phytoplankton growth to exceed losses; that is, there is no evidence, or likelihood, of eutrophication;
or if, eutrophication having been demonstrated or predicted,

c) the application of secondary treatment will reduce the predicted maximum chlorophyll by less than 1 mg chl m^{-3}.

6.2.10 Next, the contribution of nutrients to zone C must be considered. The zone is best defined in terms of hydrographically realistic management units, such as an estuary or coastal segment. Then:

a) Rank the N and P contribution (including particulate and dissolved organic forms of these elements) of all waste waters to the management unit;

b) If the discharge under consideration contributes more than 5% of the total anthropogenic nutrient, use regional hydrographic models and nutrient budgets to predict the results of secondary (as opposed to primary) treatment.

To set this in context, sewage discharges contribute about 15% of the total dissolved nitrogen load and 11% of the total phosphorus load of UK input to the North Sea. The qualifying discharges probably contribute less than 10% of that load.

6.2.11 The procedures given here should be considered tentative. Parameter values have been chosen according to the "precautionary principle", with the aim of minimizing environmental impact if the values are wrong. Assumptions involved in the simple box model could be tested by comparing its predictions with those from more sophisticated models for a few well chosen sites. The value of q (Gowen *et al.*, 1992) needs further study in a range of coastal waters, but in the meantime the team recommends the use of the median value (see 6.2.5.1). Finally, the task of providing optical data for the simple model would be eased if it were possible to use Secchi disc estimates of λ. This might be investigated in appropriate coastal waters.

6.3 Field Observations and Monitoring

6.3.1 Initial studies can be designed either:

a) to demonstrate, observationally, the absence of hypernutrification and eutrophication, or,

b) to obtain data for use in the simple numerical model described in 6.2.3 through 6.2.8.

Observational studies should desirably last two years, with nutrients sampled monthly, and phytoplankton chlorophyll concentration measured weekly during March through October. It is likely to be more cost-efficient to use the modelling approach first. If the model predicts eutrophication, the region may either be accepted as eutrophic, or an observational program carried out.

6.3.2 Monitoring should be carried out to assess the effects of discharges into regions identified as less sensitive. This can be either:

a) an observational programme designed to show the continued absence of hypernutrification and eutrophication, with nutrients sampled monthly and chlorophyll weekly (March to October) during one year, repeated every four years, or,

b) a targeted set of observations designed to test the predictions of the model, carried out during the year in which the model is first used and then every four years after that.

Targeted observations are likely to be more cost-effective. They are described in 6.2.4 and 6.2.8.

6.3.3 Concentration data must be averages over the defined volume. This is often best achieved by sampling at one site throughout a tidal cycle, paying attention to the existence of water column stratification. Optical conditions are sensitive to the amount of suspended particulate matter, including phytoplankton itself. Values of λ should be obtained at a number of sites within the defined volume, ideally under a range of weather and tidal conditions, by measuring submarine downwelling PAR I_z at several depths and calculating $\lambda = \Delta \ln(I_z)/\Delta z$ for depths greater than $1/\lambda$.

7. SEWAGE DISCHARGES: EFFECTS ON BENTHIC COMMUNITIES

7.1 Choice of Benthic Communities as Indicators of Discharge Effects

7.1.1 The benthos comprise animals or plants living in, on or in close association with the sea bed. The macrofauna (ie, animals retained on 0.5 to 1mm mesh sieves) are a common target in many investigations of marine pollution for the following reasons:

i. seabed sediments represent the ultimate sink for most contaminants discharged to sea;

ii. most macrofauna species are relatively long-lived (>1 year) and sedentary, and so can provide an indication of the integrated effects of discharges over time;

iii. they are relatively easy to sample quantitatively. Generally, plankton or fish populations are less amenable to quantitative study on a scale appropriate to the delineation of localised effects of most discharges and in the latter case, they also have the ability to avoid contaminated areas. No such option is available for sedentary benthic species;

iv. they are well-studied scientifically, compared with other sediment-dwelling components (e.g. meio- and micro-fauna) and taxonomic keys are available for most groups;

v. there may be direct links with valued resources, e.g. fish (via feeding) and edible molluscs;

vi. macrofauna community structure has been shown to respond to pollutants in a predictable manner (thus, the results of changes can be interpreted with some degree of confidence).

The comprehensive studies need to consider two main objectives with respect to the benthos. Studies must provide a means for predicting changes which are likely to occur if discharge treatment levels are changed and must also provide a means for assessing the acceptability of such changes. Relevant factors are discussed in section 2.5.2.

7.1.2 Benthic studies are most easily carried out in areas of deposition with fine grained sediments. This is helpful insofar as these are most at risk from deposition of discharged solids. The methodology described in this report is best suited to such soft sediments.

In hard or mixed sediments sampling is difficult. Because of this, alternative methodology and proof is permissible. This should be discussed with the assessor of the study prior to the investigation. Even in the absence of deposition the increase in dissolved organic carbon and particulate organic carbon may result in effects on the trophic status of benthic communities.

7.2 Determining Detrimental Effects and Predicting Changes

7.2.1 <u>Organic Enrichment</u>

Accurate estimates of carbon flux at the sea bed, along with an assessment of the consequences for benthic organisms, for each locality of interest, would represent a major resource commitment and would be difficult to justify given the small spatial scales of effect which are likely to be encountered. However, some useful generic relationships may be revealed from an appropriate desk study which may then have predictive value and this is to be recommended (see 7.2.3).

Given that it is not simple to measure carbon fluxes, other approaches may be more useful in establishing the necessary relationships. Empirical models have been developed which describe the responses of the benthic macrofauna along enrichment gradients. A good example is the work of Pearson and Rosenberg (1978), which is summarised in Figure 2. From such a model, the status of benthic populations at varying distances from an organically rich discharge can be assessed, at least in areas subject to low turbulent energy, and a judgement both as to the acceptability of observed changes and the likely consequences of future increases or decreases in effluent load may be arrived at (e.g. Swartz *et al.*, 1986 for a US sewage discharge, Rees and Pearson, 1992, MAFF, 1992 and 1993, for UK sewage-sludge disposal sites). This approach has the advantage that there is no absolute necessity to establish quantitative links with carbon inputs.

An assessment (by a GCSDM Benthos Task Team) was made of the performance of a range of measures and methods for the identification of change in benthic communities using a range of specimen data sets (MAFF, 1993). Measures presently considered to be suitable for routine use in EQS derivation included total abundance (A), total taxa (T) and total biomass (B) as ash-free dry weight, along with ratios of these measures (A/T, B/A) which had interpretative value. (The Shannon-Wiener diversity index H' ($\log_2$): Shannon and Weaver, 1949, and Multidimensional Scaling Ordination: see, e.g. Field *et al.*, 1982 were also identified for complementary use).

By comparing impacted areas with reference sites further away from affected areas, one can test for the acceptability of change at certain sites relative to others by applying the criteria given in Annex 6. These criteria allow for an early phase in the enrichment process.

Using this method of comparison, one can also monitor unimpacted reference sites to ensure that the environment outside the zone of immediate effect is preserved (see Annex 6 for guideline values). Care should be taken in choosing a suitable reference site to ensure that the area is demonstrably unimpacted; for example, that it is typical of the local sea area, or, for coastal areas only, that the United Kingdom Infaunal Trophic Index value (WRc plc, 1992) is greater than 60, indicative of normal conditions. For further guidelines on the selection of reference stations see Annex 7.

7.2.2 Benthic Changes related to Mass Emission Rates

Mearns and Word (1982) have established convincing relationships between mass emission rates of suspended solids from larger sewage discharges off the Californian coast and changes in the benthic fauna.

Working on deep water (20 to 60m) Californian sewage discharges, they derived a series of equations relating effects on benthic communities (intensity and spatial extent) with mass emission rates of suspended solids (see Figures 3 to 5). The authors noted that benthos changes were well correlated with the latter, but poorly correlated with concentrations of suspended solids or other contaminants. They also estimated that about 10 to 20% of suspended solids settled to the sea-floor, creating elliptical zones of contamination; further, that suspended solids contained 'much' of the BOD, COD, nitrogen and phosphorus load. The key measure of biological effect used was the 'Infaunal Trophic Index' (e.g. Word, 1979).

This index has been the subject of recent investigation in a UK context by the Water Research Centre, (WRc, 1992).

Using these relationships, consequences for the benthic fauna can be predicted for different levels of sewage treatment (see Table 2 for several predictions). The validity of extrapolating from a relationship established for large US discharges to such low levels of suspended solids inputs may be questionable. Points in favour and against wider application are given in Annex 8. Further recommendations are also given in Annex 8.

	Untreated		Primary		Secondary	
	< 10,000 pe	<150,000 pe	< 10,000 pe	<150,000 pe	<10,000 pe	<150,000 pe
Total excess standing crop of infauna (metric tonnes wet wt.)	0.12	13.16	0.03	3.91	0.003	0.306
Area occupied by total excess standing crop of infauna (km^2)	0.08	1.01	0.04	0.52	0.01	0.129
Area occupied by infauna dominated by sub-surface deposit-feeders (esp Capitella) ITI<30; (m^2)	1	532	0.1	90.8	0.002	2.22
Area occupied by infauna dominated by surface and sub-surface deposit-feeding organisms,ITI<60; (m^2)	97	33461	21.6	7478.2	0.94	322.85

Table 2 : Predicted Consequences for the Benthic Fauna of Different Sewage Treatment Levels

Since the first version of the CSTT report, these empirical relationships between benthos changes and mass emission rates of suspended solids have been tested on some UK sewage discharges. It has been found that the relationships have overpredicted the benthic effects. Although this approach could still be used to predict the worst case scenario, a new model recently developed is likely to give more realistic predictions (see section 7.2.3).

7.2.3 Organic Carbon Deposition Model and Benthic Effects

A model has been developed which predicts organic carbon deposition on the seabed and associated changes in soft sediment benthic communities. This model is called BenOss (biological effects and organic solids sedimentation) and has been published by UK Water Industry Research Limited (UKWIR, 1996). BenOss will be reviewed and improved as further data from comprehensive studies become available. The model has been developed to the point where it may be used with some confidence to assess the need for large investments in effluent treatment. As it is one of the few quantitative predictive methods available for benthic communities, its use is recommended as part of comprehensive studies.

The suite of models developed predicts the amount of suspended solids (organic carbon) accumulating in the near vicinity of domestic sewage outfalls in terms of (mass of carbon) (unit area)$^{-1}$ (time)$^{-1}$. Figure 6 shows the overall structure of the model. A grid generation sub-programme allows the user to generate an area of interest from a master grid of a given site. A Lagrangian particle tracking model has been used to simulate settling of the sewage particles and their movement through the water column. For this part of the model site specific information is required, such as sewage effluent information and current velocities in the area. The model then simulates resuspension and carbon degradation once a particle has been deposited on the bed. The effect of the organic carbon on the benthic communities is then predicted by a benthic module.

The model has been developed so that it is not site specific and has a variety of features which can be used depending on the site in question. The long sea outfall of Edinburgh sewage treatment works has been used as a study site during model development. As part of the model validation a fluorescent tracer study was carried out. Even though the Edinburgh sewage outfall has no or very little effect on the benthic communities, the tracer study showed incorporation of particles into the sediment. Long term accumulation or cyclical effects may therefore occur and monitoring of the benthos should be carried out.

This predictive tool should be used to complement, rather than replace, other methods currently being used to assess benthic communities. This model will not replace the need for sampling the benthos, but should aid in assessing the likely differences resulting from primary and secondary treated effluent.

7.3 Monitoring

7.3.1 The ability to sample benthic communities effectively and to quantify their pollution status is strongly dependent on local environmental conditions. It is not possible to provide a general blueprint for the conduct of such surveys, since substrate types may vary from rock to mud and dispersive properties (along with the proximity of other discharges) may dictate widely varying geographical scales for the distribution of sampling effort.

7.3.2 Site-specific considerations will therefore be essential in the planning of impact studies. Guidelines for the conduct of surveys covering a wide range of habitat types can be found in Holme and McIntyre (1984), Baker and Wolff (1987) and Rumohr (1990) while recent pollution-orientated advice is given in Rees *et al.* (1990, 1991) and Gray *et al.* (1992).

Sampling design should:

i. be closely linked to predictions of effluent dispersion and especially the settling of particulates at the sea bed. The outcome of field surveys employing tracers of sewage contamination at the sea bed, such as faecal bacteria and plant remains (including tomato pips), will also be valuable in this respect;

ii. include any 'far-field' depositional areas likely to be influenced by the discharge, if identified;

iii. include stations within and outside the sphere of waste influence; stations should, as far as possible, be selected for similarity in environmental conditions;

iv. along with sampling methodology, be tailored to local requirements including, where necessary, allowance for the influence of multiple waste inputs;

v. recognise that quantification of changes will in general be easiest for soft sediments in quiescent areas and the most difficult in areas of mixed or hard substrates in 'high-energy' areas.

7.3.3 An initial survey is required in order to establish suitable sites for continued monitoring, unless existing knowledge of an area is adequate. A grid survey covering a broad enough area is recommended in order to obtain general information on substrate type and the type and distribution of the benthos. From this more general information several sites should be chosen and sampled in more detail.

After the initial survey has been conducted, it is recommended that the chosen sites be monitored annually until there are sufficient data to allow determination of the monitoring frequency necessary to demonstrate whether or not significant change is occurring. In the case of less significant discharges a reduced frequency may be acceptable. Recognising the need to review every four years there is likely to be a requirement for at least a four yearly cycle until the statistical validity of the observations is clearly demonstrable. Section 3.3.3 gives guideline values and criteria of acceptable change which can be used to determine whether or not a discharge is causing any adverse effect.

7.3.4 The benthic standards given in this report are based on samples which were identified down to species level. Therefore it is recommended that samples are identified to species level wherever possible. The differences between primary and secondary treatment may be quite small so sensitivity in distinguishing between these is required.

In the majority of cases, a sieve size of 0.5mm should be used in order to further enhance the likelihood of detecting subtle effects of discharges at regularly monitored stations. However, in some cases a 1mm mesh may be acceptable, e.g. where substrates are gravelly or where there is much supporting historical data for a site. A 1mm mesh sieve may also be employed in an initial descriptive survey of an area, i.e. prior to selection of representative stations, but for subsequent trend monitoring a 0.5mm sieve is to be recommended.

The best time to sample the benthos is between February and May, i.e. before the main summer recruitment period.

7.4 Conclusion and Recommendations

It is clear that there is no well-tested quantitative technique for the prediction of change in benthic fauna through inputs of additional organic carbon. Nevertheless a decision must be made in the context of the Directive.

The evidence from Table 2 suggests that the zone of impact from a primary discharge will be minimal, even under worst case conditions. This is borne out by monitoring studies of large, well dispersed primary effluent discharges, e.g. Edinburgh STW (500,000 PE), where only minimal change in the benthos occurs.

It is recommended that:

1. The model BenOss is used to compare predictions of the impact of primary and secondary treated sewage effluent on soft sediment benthic communities.

2. A biological study fulfilling the requirements of Annex 6 be carried out. This will be conclusive in circumstances where an existing primary discharge is under examination.

3. In circumstances when there is not an existing primary discharge then a judgement must be made based upon 1 and 2, together with the results of modelling studies and having regard to known effects (e.g. Pearson and Rosenberg, 1978).

4. In both circumstances the application of the ITI is recommended as a means of achieving further insight.

5. An effective monitoring programme must be established.

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ANNEX 1

COMPREHENSIVE STUDIES TASK TEAM MEMBERS

W. Halcrow (Chairman)	Scottish Environment Protection Agency Clearwater House Heriot Watt Research Park Avenue North Riccarton Edinburgh EH14 4AP
I.A. Jack (Secretary)	Scottish Environment Protection Agency Clearwater House Heriot Watt Research Park Avenue North Riccarton Edinburgh EH14 4AP
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H. Rees	Ministry of Agriculture, Fisheries and Food Fisheries Laboratory Remembrance Avenue Burnham-upon-Crouch Essex CM0 8HA (marine biology)
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P.W. Lai

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West Riding House
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(hydrodynamic modelling)

ANNEX 2

URBAN WASTE WATER TREATMENT DIRECTIVE (91/271/EEC)

FORMAT OF CERTIFICATE TO BE ISSUED BY REGULATOR ON COMPLETION BY DISCHARGER OF AN ACCEPTABLE COMPREHENSIVE STUDY

For items in square brackets, the relevant details will need to be inserted
For items in curved brackets, the relevant option, from those shown, will need to be selected

---

CERTIFICATE FOR THE PURPOSES OF REGULATION [*Regulation No*] OF THE URBAN WASTE WATER TREATMENT ({*Country*}) REGULATIONS [*year*]

The [*name of regulatory authority*] hereby certifies that [*name of discharger*] has completed a comprehensive study[1] in accordance with the standard United Kingdom methodology[2] in respect of {*a discharge/discharges*} which {*is proposed to/are proposed to*} receive at least primary treatment as defined in Regulation 5(8)(b) from an agglomeration with a population equivalent of {*2,000-10,000/10,000-150,000/>150,000*} from [*STW name*] into {*estuarial/coastal*} waters within the [*HNDA name*] High Natural Dispersion Area at [*two letter and 8 figure NGR and latitude/longitude*] and the [*name of regulatory authority*] is satisfied that the study indicates that the {*discharge/discharges*} if so treated will not adversely affect the environment.

Signed.............

[*name of regulatory authority*]

Dated.............

1 A report of the study, entitled "[*Report title*]" and dated "[*Report date*]" has been deposited at the [*name of regulatory authority*]'s offices at [*address of regulator's regional office*] and is available for inspection at all reasonable times.

2 Comprehensive Studies For The Purposes of Article 6 of DIR 91/271 EEC, The Urban Waste Water Treatment Directive. Report prepared for the United Kingdom Environment Departments and the Marine Pollution Monitoring Management Group by the Group Coordinating Sea Disposal Monitoring. Initially issued 18 November 1993 and published by Forth River Purification Board, Edinburgh, 1 February 1994, subsequently revised by 2nd Edition, issued January 1997 and published by the Department of the Environment for Northern Ireland, the Environment Agency, the Scottish Environment Protection Agency and the Water Services Association.

ANNEX 3

URBAN WASTE WATER TREATMENT DIRECTIVE (91/271/EEC)

FRAMEWORK FORMAT FOR REPORT TO BE PRODUCED BY UK DISCHARGER ON COMPLETION OF A COMPREHENSIVE STUDY

INTRODUCTORY NOTES

The UK Urban Waste Water Treatment Directive Implementation Group agreed that a consistent UK format was desirable for the report which is to be produced in relation to each comprehensive study undertaken pursuant to Article 6 or Article 8.5 of the Directive and the relevant UK regulations.

A framework format for comprehensive study reports is attached to these notes. It comprises a set of headings defining the various sections required in the report, together with a brief explanation as to the content required for each section. The precise level/depth of information within each comprehensive study report cannot be prescribed since it will be dependent on local circumstances and is a matter for resolution between the regulator and the discharger. In addition, given the wide range of circumstances and techniques catered for within the comprehensive study exercise, it is recognised that the framework format may not be applicable in certain cases. However, conformity with the standard format is recommended wherever possible.

The report is to be produced by the discharger, liaising as throughout the comprehensive study procedure, with the local regulator.

The report will form the basis for the regulator's decision to certify (or be unable to certify) that the study indicates that the discharge will not adversely affect the environment. It is therefore in the interests of the discharger to ensure that the report, as well as the study, is comprehensive.

The comprehensive study report, together with any associated certificate issued by the regulator pursuant to the UK regulations, will be deposited at the regulator's regional office and be available for public inspection at all reasonable times. The report will form supporting information in respect of any consent application for the primary treated discharge to which the study relates.

URBAN WASTE WATER TREATMENT DIRECTIVE (91/271/EEC)

FRAMEWORK FORMAT FOR REPORT TO BE PRODUCED BY UK DISCHARGER ON COMPLETION OF A COMPREHENSIVE STUDY

The items not marked with an asterisk are required in all cases. Items marked with an asterisk will not normally be required for studies relating to estuarine discharges, unless required by the regulator.

CONTENTS

EXECUTIVE SUMMARY (1-2 sides)

1. INTRODUCTION

1.1 Relevance to the UWWT Directive

Outline the objectives of the study and the report. Include a statement as to whether the study is for the purposes of Article 6 or Article 8.5 and whether the discharge is to coastal or estuarial waters (as defined for the purposes of the Directive). Briefly describe the relevant Directive requirements, the formulation of the CSTT report and refer to the parameters and standards used to define adverse effects in coastal and estuarine waters. Comment on the overall approach followed in undertaking this particular comprehensive study.

1.2 Description of the receiving waters (HNDA)

Describe the overall water regime of the area to which the discharge will be or is made, including the depth and the substrate type. Mention the uses of the waters, including any particular sensitivities. Explain whether there are other discharges which influence the HNDA and whether any of these are subject to comprehensive studies.

1.3 Description of the discharge(s) and the discharge point(s)

Provide details of the proposed (or existing) discharge to which the study relates. This should include the size (design population equivalent and flow rates), level of treatment, composition (any analyses plus comment on domestic, trade contribution), location of discharge point (NGR and lat/long plus a map), depth below surface at low water, diffuser arrangements etc. The history of the discharge, including any past pollution problems should be described with comments on whether the installation of primary treatment and/or outfall relocation is intended to address those problems.

1.4 Relevance to other Directives and other water quality interests

Mention any designations under other Directives within the HNDA eg Bathing Waters, Shellfish Waters. Although not part of the comprehensive study itself (other than the UWWTD requirement to choose, as far as possible, discharge *points to minimise effects on receiving waters) explain how any change to the current discharge point or level of treatment will affect these other interests.*

2. HYDROGRAPHIC ASSESSMENT OF THE RECEIVING WATERS

2.1 Introduction and methods

Describe the sources of information drawn upon.
Explain in detail the approach followed, including any predictive modelling work and field surveys undertaken.

2.2 Results and discussion

Describe the findings/results of the assessment and discuss these. Include comments on the degree of confidence which can be ascribed to the findings.

2.3 Conclusions

Outline the conclusions drawn from the findings, about the hydrographic regime of the area to which the discharge is or will be made. Include comments on the stability of the receiving hydrographic environment.

3. ASSESSMENT OF INITIAL DILUTION

3.1 Introduction and methods

Describe the sources of information drawn upon.
Explain in detail the approach followed, including any predictive modelling work and field surveys undertaken.

3.2 Results and discussion

Describe and discuss the findings of the assessment. Include comments on the degree of confidence which can be ascribed to the findings.

3.3 Conclusions

Outline the conclusions drawn from the findings. Include comments in particular on compliance with the CSTT standards i.e. whether an initial dilution of 50 at the surface or a pycnocline is or will be achieved for at least 95% of the time.

4. ASSESSMENT OF EFFECTS UPON DISSOLVED OXYGEN AND B.O.D.

4.1 Introduction and methods

Describe the sources of information drawn upon.
Explain in detail the approach followed, including any predictive modelling work and field surveys undertaken. Include details of sampling protocols and analytical quality.

4.2 Results and discussion

Describe and discuss the findings, including results from any previous work (modelling and/or field measurements) and from new modelling and/or fieldwork undertaken for the comprehensive study. Include comments on the degree of confidence which can be ascribed to the findings.

4.3 Conclusions

Outline the conclusions drawn from the findings. Include comments in particular on compliance with the CSTT standards i.e. whether the median DO level will be maintained above 7 mg/l and whether DO will deviate by less than 0.5 mg/l compared to background levels in the area (COASTAL WATERS).

Outline the conclusions drawn from the findings. Include comments in particular on compliance with the CSTT standards i.e. whether the median DO level will be maintained above 7 mg/l and whether DO will deviate by less than 1.0 mg/l compared to background levels in the area (ESTUARINE WATERS).

5. ASSESSMENT OF EFFECTS UPON NUTRIENTS AND CHLOROPHYLL*

5.1 Introduction and methods

Describe the sources of information drawn upon and the approach followed, including any predictive modelling work and field surveys undertaken. Explain any assumptions made as to the level of nutrient removal during treatment. Explain in detail how hypernutrification and eutrophication were assessed (sampling, box model or more sophisticated model) and how the zones of potential effect were defined. Include details of sampling protocols and analytical quality.

5.2 Results and discussion

Discuss the findings, including results from any previous work (modelling and/or field measurements) and from new modelling and/or fieldwork undertaken for the comprehensive study. Comment on phytoplankton community structure/successions (if studied). Include comments on the degree of confidence which can be ascribed to the findings.

5.3 Nutrient contribution from the discharge(s) in comparison to other inputs

Contrast the contribution from the discharge(s) in question to those from other inputs in the area, including other discharges and riverine contributions. Discuss the nutrient contribution to Zone C.

5.4 Conclusions

Outline the conclusions drawn from the findings. Include comments in *particular on compliance with the CSTT standards i.e. whether for Zone B:*

(a) *there is evidence, or likelihood of hypernutrification in the receiving waters (where observed or predicted summer nutrient concentrations exceed 12 mmol DAIN m^{-3} in the presence of at least 0.2 mmol DAIP m^{-3});*

(b) *there is evidence, or likelihood of eutrophication in the receiving waters (where observed or predicted chlorophyll concentrations regularly exceed 10 mg/m^3 in summer);*

(c) *if the area is demonstrated or predicted to be eutrophic, the application of secondary treatment would reduce the predicted maximum chlorophyll by more than 1 mg/m^3.*

6. THE BENTHIC COMMUNITY AND FACTORS AFFECTING IT*

6.1 Introduction and methods

Describe the sources of information drawn upon and explain in detail the approach followed, including any modelling work and field surveys undertaken, for both near field and far field (but local) areas. Include details of sampling protocols and analytical quality.

6.2 Results and discussion

Discuss the findings, including results from any previous work (modelling and/or field measurements) and from new modelling and/or fieldwork undertaken for the comprehensive study. Include comments on the degree of confidence which can be ascribed to the findings.

6.3 Conclusions

Outline the conclusions drawn from the findings, regarding the impact of suspended solids and organic carbon deposition on the benthic community. Include comments in particular on compliance with the CSTT standards in section 3.3.3 of the CSTT report.

7. RECOMMENDATIONS FOR FUTURE MONITORING

Make recommendations on future monitoring (required under Article 15(3) of the Directive) of the impact of the (primary treated) discharge, following the guidance in the CSTT report and building on the work carried out for the comprehensive study.

8. SUMMARY OF CONCLUSIONS

Summarise the conclusions of the study, addressing the various components assessed and then drawing overall conclusions as to whether the discharge of primary treated effluent would adversely affect the environment.

9. REFERENCES

FIGURES

TABLES

APPENDICES

These, together with the figures and tables, should be used to present supporting information such as details of the standards used to define adverse effects, the position of sampling stations, the results of surveys, information about models used in the study, modelling results and additional oceanographic, chemical and biological data.

ANNEX 4

URBAN WASTE WATER TREATMENT DIRECTIVE (91/271/EEC)

FORMAT FOR THE 1-2 PAGE SUMMARY REQUIRED FOR EACH COMPREHENSIVE STUDY REPORT

INTRODUCTORY NOTES

The UK Government requires a summary of each report of the outcome of a comprehensive study pursuant to Article 6 or Article 8.5 of the Directive and the relevant UK regulations.

In order to provide national guidance as to the format of the report summary, this document has been drafted, taking the form of an example report summary (see attached three sheets). The headings and level of detail in the document are intended to be indicative of what will be expected as the norm for this exercise. The items not marked with an asterisk are required in all cases. Items marked with an asterisk will not normally be required for studies relating to estuarine discharges, unless required by the regulator.

An Explanatory Note is included in the document, being a standard piece of text intended to summarise the relevant requirements of the Directive, the Regulations and the relevance of the standard methodology, thereby putting the report summary into context so that it can be used a stand alone document in responding to enquiries about the studies.

The items in square brackets and italics in the Explanatory Note will need to be tailored to the needs of individual countries and regulatory authorities.

It is proposed that the Report Summary be prepared by the local regulator, liaising as necessary with the discharger.

URBAN WASTE WATER TREATMENT DIRECTIVE (91/271/EEC)

SUMMARY OF A COMPREHENSIVE STUDY REPORT

DISCHARGE(S): WHIFFYSBURGH SEWAGE OUTFALL

RECEIVING HNDA: Number 59 on the Index Map for England & Wales (DoE 1994)

An explanatory note on the Comprehensive Studies procedure is appended to this summary.

1. INTRODUCTION

During 1994 and 1995, a comprehensive marine scientific study was carried out on the environment around the Whiffysburgh sewage outfall (125,000 population equivalent) in order to assess whether or not primary treatment of the effluent would be sufficient to protect the area from adverse effects. The discharge, which currently receives only coarse screening, is made via a long sea outfall into the Gazen Straits at (NGR and lat/long), within the Whiffysburgh HNDA, defined as coastal waters for the purposes of Directive 91/271/EEC. This study was undertaken for the purposes of Article 6 of the Directive.

The study assessed the consequences of the discharge of primary as compared to secondary treated effluent in terms of particle deposition, dissolved oxygen concentrations, nutrient concentrations and the effects of suspended solids and organic carbon on the benthos at and around the discharge site.

2. HYDROGRAPHIC ASSESSMENT

A hydrographic survey was undertaken, involving current meter measurements at four locations around the outfall, drogue tracking on spring and neap tides and two dye release experiments under differing tide and weather conditions. The data from the hydrographic survey were used in a particle tracking model of the receiving waters, to describe the water movements and predict the distribution of settled sewage particles in the vicinity of the outfall. The model results and the survey data showed good agreement, indicating a highly dispersive, high-energy environment with strong offshore currents. Evidence of sedimentation in the area of the outfall was minimal.

3. INITIAL DILUTION

The discharge is made from a 20 port diffuser via a 1.2 km outfall and the outlet is always covered to a minimum depth of 10 metres. Dye release experiments were undertaken in February and May 1995, under worst case tidal conditions, to assess dilution at the boil point above the outlet and at other locations within 200 metres of the outlet. The dilution values achieved ranged from 350-700. It is therefore concluded that the minimum initial dilution value of 50 at the surface for >95% of the time, specified in the CSTT guidance, will be comfortably achieved at all tidal states and all effluent flows.

4. DISSOLVED OXYGEN

Dissolved oxygen concentrations in the vicinity of and at some distance from the outfall appear to be unaffected by the existing discharge. A comprehensive field survey was undertaken and no depression in DO concentrations was detected. Primary treatment would reduce the organic load compared to the current discharge and would not give rise to any adverse effects on dissolved oxygen concentrations.

5. NUTRIENTS AND CHLOROPHYLL*

The predicted steady-state dissolved available inorganic nitrogen (DAIN) concentration, determined using a sophisticated water quality model, was found to be 15 mmol m^{-3} with dissolved inorganic available phosphorus of 2 mmol m^{-3}. This is supported by field data taken over many years. The area is therefore considered to be slightly hypernutrified. However, summer maximum chlorophyll concentrations are neither predicted nor found to exceed 10 mg/m^3 and no abnormal algal blooms have been recorded in the area. The waters are therefore considered not to be eutrophic and the existing discharge does not have an adverse effect on the surrounding area with respect to nutrient enrichment. Primary treatment would therefore be sufficient. The contribution of the discharge to the North Sea is negligible.

6. BENTHOS*

The sediments and benthic community within 1000 metres of the outfall were examined. The presence of organic debris, tomato seeds and fibres in the sediments adjacent to the outfall indicated that there was some settlement of sewage debris in the immediate vicinity of the outlet. However, the Infaunal Trophic Index (ITI) values and various univariate and multivariate analyses performed on the benthic data indicated no significant change in community structure at any of the stations sampled. Given that the present discharge has no adverse effect on the benthos, primary treatment would reduce any minor impact and would therefore be fully acceptable.

7. RECOMMENDATIONS FOR FUTURE MONITORING

Proposals for continued monitoring of the receiving waters after the installation of primary treatment have been formulated. These include periodic assessment, at a range of sampling stations, of dissolved oxygen, biochemical oxygen demand, nutrient and chlorophyll concentrations and the benthos.

8. OVERALL CONCLUSIONS

The study provides extensive evidence, from existing field data, newly commissioned sophisticated modelling and further field validation and monitoring, indicating that the current preliminary treated discharge has no adverse effects on the environment (assessed against the guidelines set out in the standard UK methodology - see footnote to the attached Explanatory Note). The study predicts that provision of primary treatment would reduce further the current minimal environmental impact.

EXPLANATORY NOTE

This document summarises, in the preceding sections, the content and findings of a report on a comprehensive study undertaken for the purposes of Regulation [*Regulation No*] of the Urban Waste Water Treatment ([*Country*]) Regulations [*year*]. The Regulations implement, as respects [*Country*], Council Directive 91/271/EEC concerning urban waste water treatment. Under the Regulations, certain discharges of urban waste water to estuarine and coastal waters may be permitted a minimum level of primary treatment (rather than the norm of secondary), providing the discharge is made into waters identified as a High Natural Dispersion Area (HNDA) and subject to comprehensive studies having indicated that the discharge will not adversely affect the environment.

Under the Regulations (and the Directive), the discharges for which a minimum of primary treatment may be permitted, subject to the provisos outlined above, are those from agglomerations with population equivalents of:

(i) 2,000-10,000 into estuaries (for the purposes of Article 6 of the Directive);
(ii) 10,000-150,000 into coastal waters (for the purposes of Article 6 of the Directive) ;
(iii) >150,000 into coastal waters, in exceptional cases with the agreement of the European Commission pursuant to Article 8(5) of the Directive.

In the UK, a standard methodology for Comprehensive Studies was published in February 1994[1] (2nd Edition published January 1997). This was agreed by the UK Environment Departments and the Urban Waste Water Treatment Directive Implementation Group as the standard methodology for application throughout the UK. The studies have been commissioned and/or carried out by the dischargers, with the work being audited and the outcome determined by the relevant regulatory authority (the Environment Agency in England and Wales, the Scottish Environment Protection Agency in Scotland and the DoE in Northern Ireland).

In cases where the regulatory authority is satisfied that comprehensive studies indicate that the discharge will not adversely affect the environment (and, in England, Wales and Scotland has certified that this is the case), the discharge will, for the purposes and within the deadlines of the Directive and the Regulations, require a minimum of primary treatment, subject to the approval of an application for consent to discharge and any other relevant statutory authorisations. Determination of adverse effects has been undertaken in accordance with the standard methodology[1]. In cases where the studies indicate that the discharge may cause an adverse environmental impact and no acceptable alternative discharge arrangement is possible, then HNDA status may be reviewed.

A full report of the comprehensive study from which this summary is derived, entitled "[*Report title*]" and dated "[*Report date*]", has been deposited at the [*name of regulatory authority*]'s offices at [*address of regulator's regional office*] and is available for inspection at all reasonable times.

1 Comprehensive Studies For The Purposes of Article 6 of DIR 91/271 EEC, The Urban Waste Water Treatment Directive. Report prepared for the United Kingdom Environment Departments and the Marine Pollution Monitoring Management Group by the Group Coordinating Sea Disposal Monitoring. Initially issued 18 November 1993 and published by Forth River Purification Board, Edinburgh, 1 February 1994,

subsequently revised by 2nd Edition, issued January 1997 and published by the Department of the Environment for Northern Ireland, the Environment Agency, the Scottish Environment Protection Agency and the Water Services Association.

ANNEX 5

SUPPORTING DATA REQUIRED

The validity of any modelling assisted study is dependent upon the quality and quantity of field data and the care with which sampling programmes are defined.

The following list is intended to indicate, in general, the scale of data support appropriate to this comprehensive study.

Effluent Loading	-	The discharger is required to demonstrate good knowledge of pollutant loading through simultaneous monitoring of discharge flow and effluent quality at two hour intervals covering at least one representative 24 hour period, representative of normal conditions.
Initial Dilution	-	The discharger is required to design an outfall and port diffuser arrangement which is hydrodynamically balanced and can achieve 50 dilutions of effluent in the buoyant plume prior to that plume reaching the air/water or stratified water interface. An alternative to this initial dilution criterion is proof of conditions preventing the formation of a stable density field.
		The discharger is required to support this calculation with data describing vertical profiles of water velocity and density at the site of any proposed outfall. Such profiles should be collected at 30 minute intervals along with associated tide levels on a neap or intermediate tide condition.
Water Movement	-	Water currents and density should be measured at two additional fixed stations within the study grid on neap tide.
	-	Drogues should be released from the proposed outfall on the same, or similar intermediate tides, at one hourly intervals and tracked for at least one hour. At least two drogues should be used to measure the full tide excursion.
	-	Dispersion data should be provided through two discrete dye releases, typically high and low slack water, or otherwise, depending upon the intended effluent release pattern.

- At least one independent fixed station measuring water current should be used for verification.

- A sparse water quality grid should be designed and used to provide information on background levels of contaminants.

- The discharger is also required to demonstrate to the satisfaction of the regulator, reasonable understanding of all surrounding discharges and sources of polluting materials which can reasonably be assumed to significantly effect the predictions carried out.

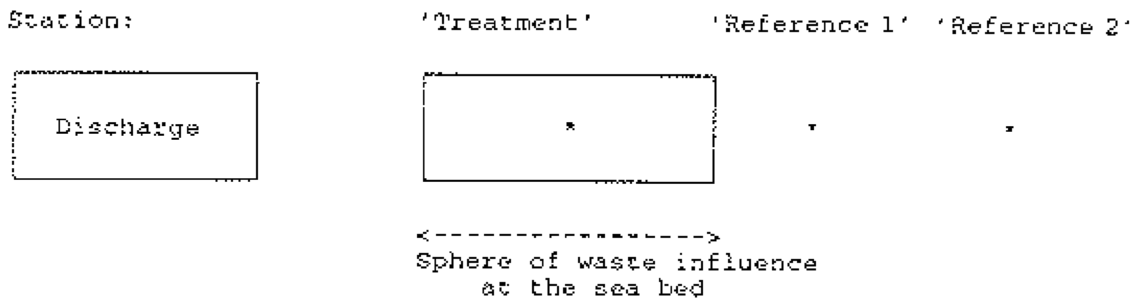
ANNEX 6

APPROACHES TO EQS DERIVATION

(The following account is adapted from: Rees, H.L. and Pearson, T.H., 1992, An approach to the setting of Environmental Quality Standards at marine waste disposal sites. ICES C.M. 1992/E:33, 10pp, mimeo).

The guideline values and criteria of acceptable change given in this section are derived largely from experience at the Garroch Head sewage-sludge disposal site, western Scotland (see eg. Pearson, 1987), where well-defined gradients of effects are present. The criteria of acceptable change given here allow for an early phase in the enrichment process, and if lesser standards were used a significant structural change in the marine communities would be the likely result.

The proposed approach to compliance monitoring can best be illustrated by a hypothetical example:



The 'Treatment' station is located within the sphere of waste influence, but outside any 'mixing zone', if one has been defined. 'Reference 1' is located just outside the known sphere of waste influence, while 'Reference 2' is some distance away.

In most cases it will be very difficult to establish the precise boundary of waste influence and to select for identical environmental conditions at both reference stations. Because of the natural variance that is present in the communities, it will be necessary to establish an initial 'baseline' which can be derived from pairwise comparisons between the reference stations. The significance of any future differences between reference stations can then be assessed against this baseline. Certain variables need to be measured for all stations in order to establish baseline values and assess an area for possible change. These variables are total abundance (A) as numbers of individuals, total taxa (T) and biomass (B) as ash-free dry weight.

Baseline Values

Baseline values would ideally consist of the mean of pairwise comparisons from at least three annual sampling periods before the discharge commences and should be calculated as follows:

[(Reference 1/Reference 2) - 1] x 100

As such pre-disposal data are not usually available, the best possible baseline should be determined, bearing in mind that the locations being compared should ideally be subject to identical natural environmental influences.

Ensuring Preservation of the Environment outside the Zone of Effect

Once a baseline value has been established, one can monitor the unimpacted reference sites to ensure that the environment outside the zone of immediate effect is preserved. Guideline values designed for the preservation of unimpacted sites are as follows:

Primary variables

A	:baseline value (%) +/-50
T	:baseline value (%) +/-20
B	:baseline value (%) +/-20

Derived variables

A/T	:baseline value (%) +/-50
B/A	:baseline value (%) +/-50

These percentage changes from the baseline value would be acceptable and would indicate no significant change at the reference stations. Action of an appropriate nature would generally follow only when the guideline values of all three primary variables were exceeded.

Levels of Acceptable Change within the Sphere of Waste Influence

Within the sphere of waste influence a certain amount of change would be allowed relative to the reference stations. Acceptable change allows for an early phase in the enrichment process and the following guideline values are as follows:

Primary variables

A	:+200% of reference station value
T	:+ 50% of reference station value
B	:+ 50% of reference station value

Derived variables

A/T	:+100% of reference station value
B/A	:- 50% of reference station value

Compliance-testing will involve pairwise comparisons of annual measures, as follows:

[(Treatment/Reference 1 or 2) - 1] x 100

These percentage changes from the reference stations would be considered to be acceptable.

It will be clear that careful selection of stations will be critical to the success of this approach. The primary variables are presently considered to be of first importance in compliance monitoring, and action of an appropriate nature would generally follow only when the guideline values of all three were exceeded. In addition, annually sampled stations may be marginally in breach of guideline values for up to three successive years, to allow for any anomalous changes attributable to natural causes. This allowance would be over-ridden during the three year period if complementary analyses - using a variety of measures of community structure - provided conclusive evidence of adverse effects attributable to the discharge.

ANNEX 7

SELECTION OF "REFERENCE" STATIONS FOR MONITORING THE EFFECTS OF DISCHARGES

INTRODUCTION

In principle, these should be identical in all respects to the "treatment" station(s), save for the influence of the discharge under investigation. In practice, it is highly improbable that all conditions governing equality could be satisfied, or that "pristine" stations (ie uninfluenced by anthropogenic activity) could be found at most locations, particularly those within estuaries. In general, the greater the distance separating paired stations, the less likely it is that they will be subject to similar natural environmental forces.

The reality of field conditions will therefore dictate that the choice of monitoring stations will often fall some way short of the ideal and, given this, both a degree of expert scientific judgement and an in-built element of flexibility in the regular sampling programme will be required. **Personnel with a high level of scientific expertise must be involved in the planning and conduct of field surveys of this nature.** Some of the factors that such personnel should take into account are listed below. These complement guidelines for monitoring around point-source discharges referred to elsewhere, which should also be consulted.

FACTORS TO BE CONSIDERED

(a) **Similarities to "treatment" station(s)**

(i) Similar depths. In many cases where tidal currents run parallel to depth contours, this would tend to place the reference stations along the same tidal axis as for the discharge stations (or "upstream" or "downstream" of the discharge point in the case of estuaries). The precise distance between the treatment and reference stations will depend on site-specific predictions regarding the short and long-term transport pathways for contaminants at the sea bed;

(ii) Similar "exposure". This would largely relate to the effects of wave action at the sea bed, but conceivably might include a consideration of bottom turbulence arising from the movement of large ships in narrow shipping lanes, or of the effects of regular commercial trawling activity;

(iii) Similar tidal current regime. As with wave action, equality in the degree to which sediments are disturbed (if at all) will be an important factor in determining the nature and dynamics of the colonising fauna. Clearly, tidal disturbance will - unlike wave action - be predictable in occurrence;

(iv) Similar substrate type. The preferences of different benthic species for different substrates are well known, and hence this factor will be critical to effective site selection. Similar substrates are also, to a degree, likely to reflect similarity in prevailing hydrographic conditions. However, it is important to bear in mind that one or more of the "treatment" stations near to a long-standing outfall may already show signs of modification arising from the settling of particulates. In the absence of prior information, the extent to which substrates in the outfall vicinity are modified can only be established through an initial "pilot" survey at several stations encompassing the area of interest;

(v) Similar salinities. This consideration will usually only be important at locations within estuaries;

(vi) Similar "diffuse" anthropogenic influences (save for the discharge itself). An example would be a consideration of variability in water quality along the length of an urbanised estuary. In most circumstances, this would probably also establish that no location could be defined as "pristine".

(b) **Differences from "treatment" station(s)**

(i) Not subject to influence by the discharge to be monitored. This criterion may be satisfied by predictions of effluent dispersion, although a "pilot" survey may be more revealing, as an aid to site selection;

(ii) Not subject to influences by other discharges in the vicinity, or of other known anthropogenic activity, excepting where it is necessary to establish "equality" in such influences across all sampling stations (see (a)(vi) above).

The likelihood is that nearby stations will have the greatest chance of satisfying these criteria and, in general, the distance should rarely exceed a few km. Knowledge gained through prior sampling of the chosen locations is the most desirable basis for site selection (see below).

An important exception to the above approach to selection of station locations would be in the case where a depositional area (which may be distant from the discharge) has been identified as the likely long-term recipient of significant quantities of waste products from the discharge under investigation. Such a location should be sampled as an "entity", irrespective of similarities with the station(s) at or near the discharge point.

COMPROMISES (or degree of permissible departure)

Particular circumstances may dictate that it is very difficult to match environmental conditions at the outfall site with reference stations. Given this, expert scientific judgement as to the degree of permissible departure in certain characteristics will be required. The more dissimilar the sites in the above respects, the more likelihood there is that the fauna may be responding to different stimuli which will be reflected (*inter alia*) in a lack of synchrony in year-to-year fluctuations unrelated to the discharge, and the more this will place demands on prior knowledge of site characteristics before the programme can be set up. In this respect, there is simply no substitute for site-specific experience. One sensible approach would be to incorporate an element of "redundancy" into the initial sampling programme, ie by sampling a number of reference stations, not all of which will ultimately require analysis. In areas where little prior knowledge exists of conditions around an outfall to be studied, a "pilot" benthic survey is to be strongly recommended.

ANNEX 8

BENTHIC CHANGES AND MASS EMISSION RATES OF US DISCHARGES; POINTS FOR AND AGAINST WIDER APPLICATION

Points in favour of wider (including UK) application:

i. effects on the US benthos appear to be primarily attributable to organic enrichment (rather than effects of toxic components) with one exception: see Mearns and Word (1982);

ii. US sewage discharges are mainly urban in origin;

iii. the authors were able to draw from a comprehensive background of information (though only a few surveys were geared to clearly resolving the size and shape of affected areas);

iv. the precise nature of the relationship with organic carbon is bypassed by a consideration of mass emission rates;

v. the predictive relationship looks convincing for US data;

vi. the authors list a number of limitations relevant to wider application, eg. the assumption about constancy in mass emission rates, and recommend that 'relationships and equations be tailored to individual situations'. However, the deeper-water US discharges suggest more quiescent (ie. depositional) conditions than typically shallow-water (even intertidal) UK discharges. Therefore, there might be a case for treating US discharge effects as 'worst cases'.

Points against wider (including UK) application:

i. the data relate to Southern California (USA);

ii. discharges are to relatively deep water (typically 60m, though one is at 20m); in addition, one discharge was of waste-activated sludge;

iii. it is clear that extrapolating from the relatively large US discharges to very small (<10,000pe) discharges begin to look fanciful, especially for ITI-related measures (Table 2; note that the area affected is expressed per m^2). These estimates could be taken to indicate no effect but, in reality, what biological effects are to be expected around such small UK discharges? (see below);

iv. because the ITI measure was developed for California marine waters, its predictive use for UK waters can, at best, only be taken as generally indicative of the scale of likely effects. It cannot be expected to describe the precise nature of the effect; for example, in the case of UK estuarine fauna, values >60 are likely to be only rarely encountered even in pristine environments;

v. a general problem regarding predictions of the impacts of future UK waste-water treatment is that appraisals of current status may frequently relate to low intertidal discharges. Future mitigation of impact (if any) arising from secondary treatment also needs to be assessed against the probability of new 'long-sea' outfalls discharging subtidally.

Recommendations

1. US experience could be used to define 'worst case' effects. However, the quantities of suspended solids present in small discharges under present consideration (especially following treatment) are much below those used in defining the above relationships. Therefore, in order to validate the above models for smaller-sized UK discharges, it will be essential to conduct site-specific surveys (or compile data from existing surveys if such exist), designed to identify the spatial extent of benthic impacts in response to discharges differing in quantity and level of treatment. It would seem reasonable to select for more quiescent locations in order to establish 'worst case' relationships.

2. For model validation, or development of monitoring programmes, predictions concerning settling and dispersion of solids should allow targeted (rather than widespread) sampling, for example, a line transect in the direction of the residual flow. Further rationalisation may be permissible for assessment of 'EQS' compliance.

3. Key determinands for benthos surveys would include;

   i. biomass;

   ii. assessment of feeding habits of the range of taxa encountered, with a view to applications of a UK-adapted Trophic Index (subject to consultation with WRc on the scope for immediate application);

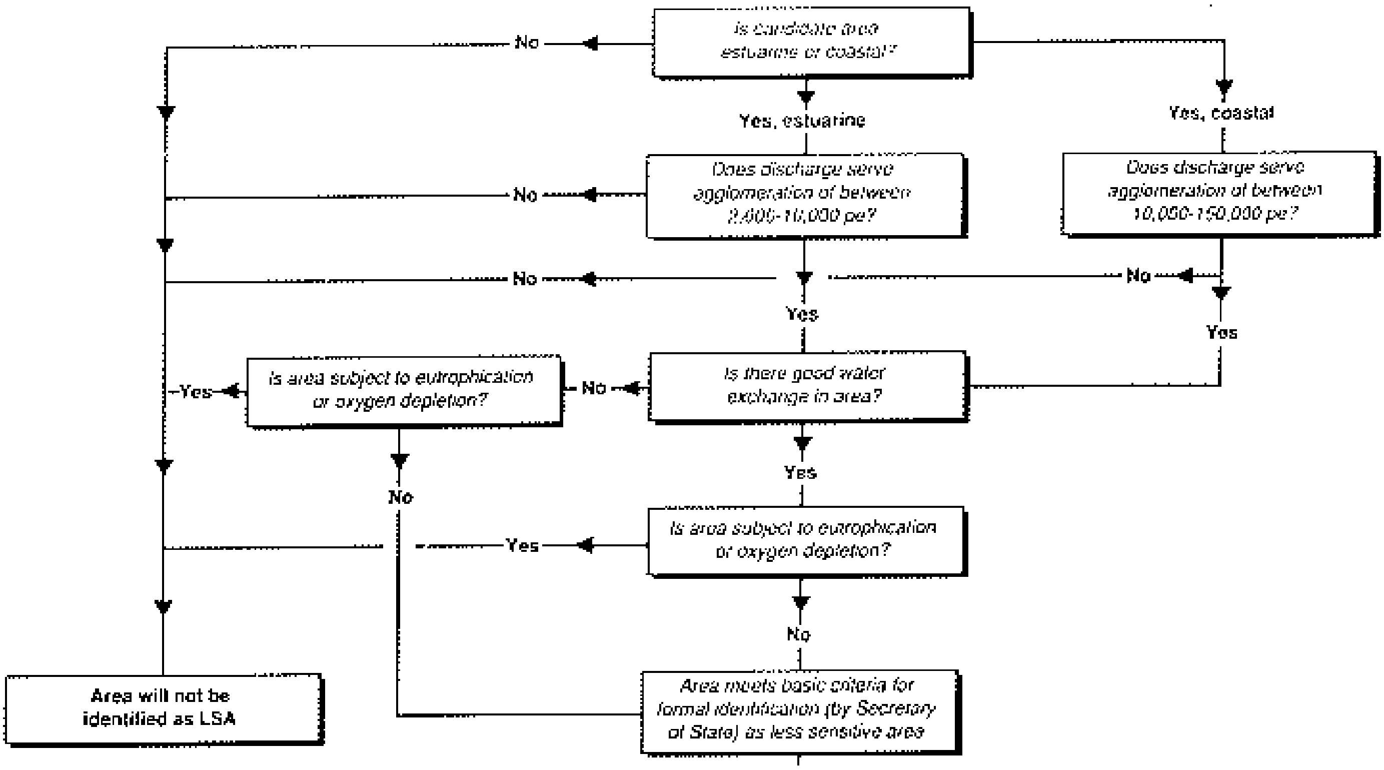
   iii. identification of enrichment indicator organisms (eg. *Capitella*) wherever possible.

FIGURES

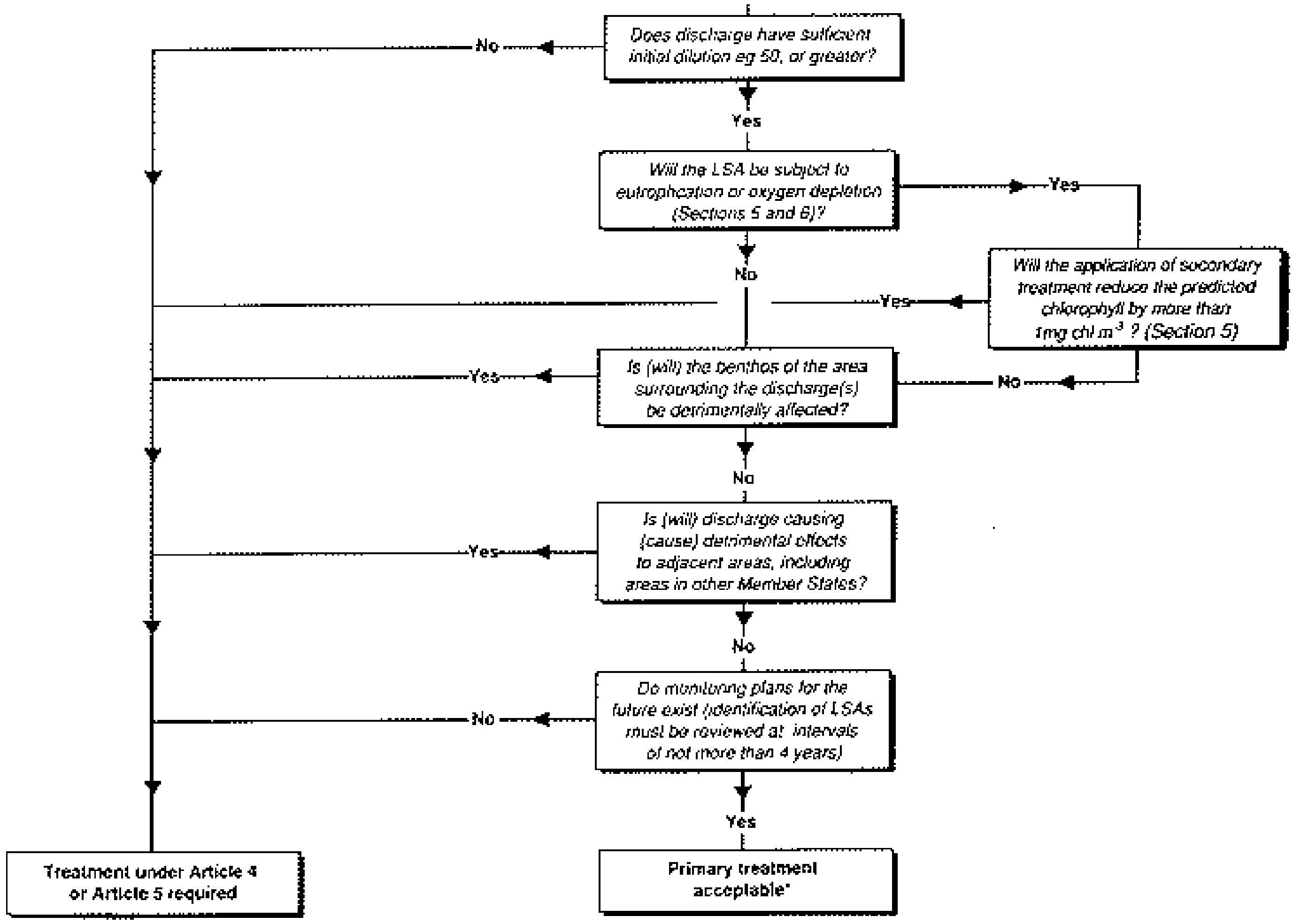
Figure 1

Identification of Less Sensitive Areas and Confirmation of Level of Treatment (Article 6)

Part A - Identification of Less Sensitive Area (LSA)



Part B - Confirmation of Level of Treatment of Discharge to LSA by use of Comprehensive Studies



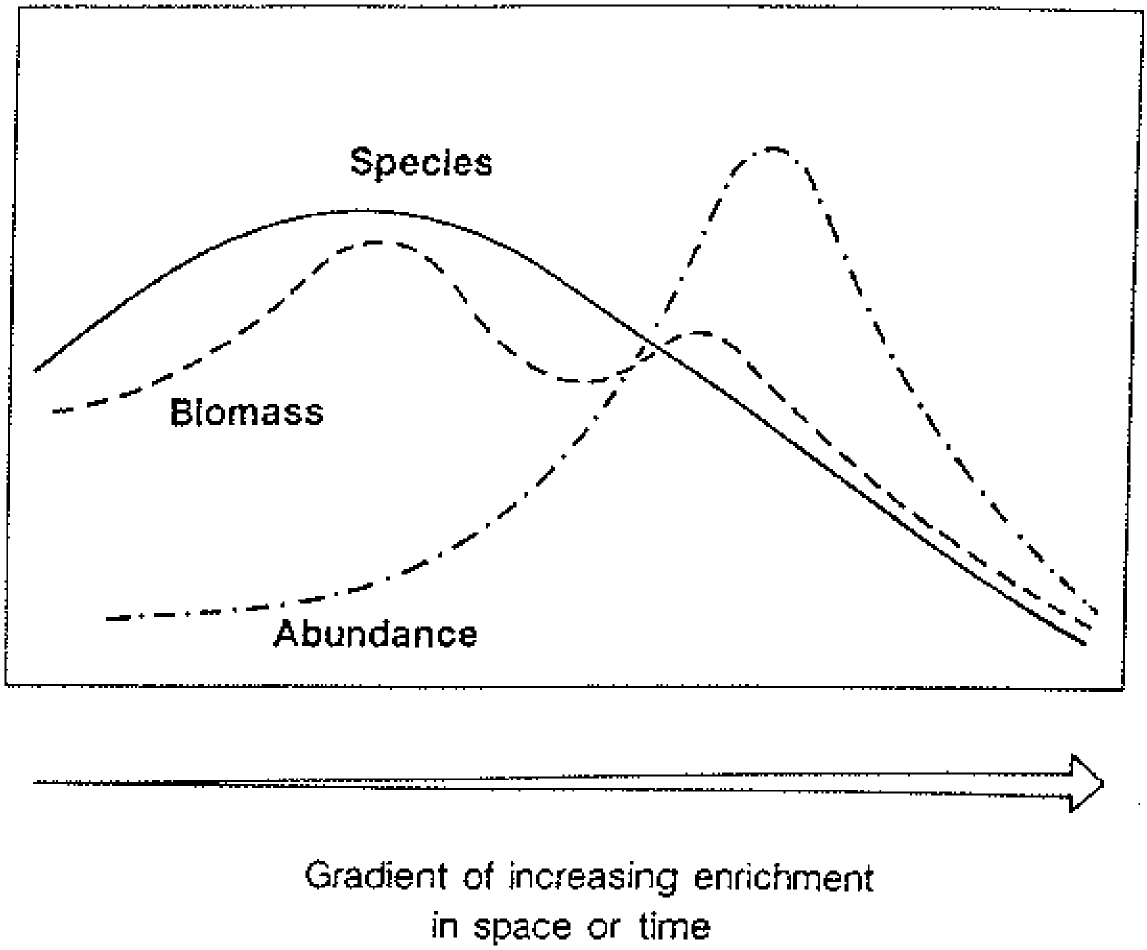


Figure 2. Empirical model for changes in the macrobenthos in response to organic enrichment (after Pearson and Rosenberg,1978)

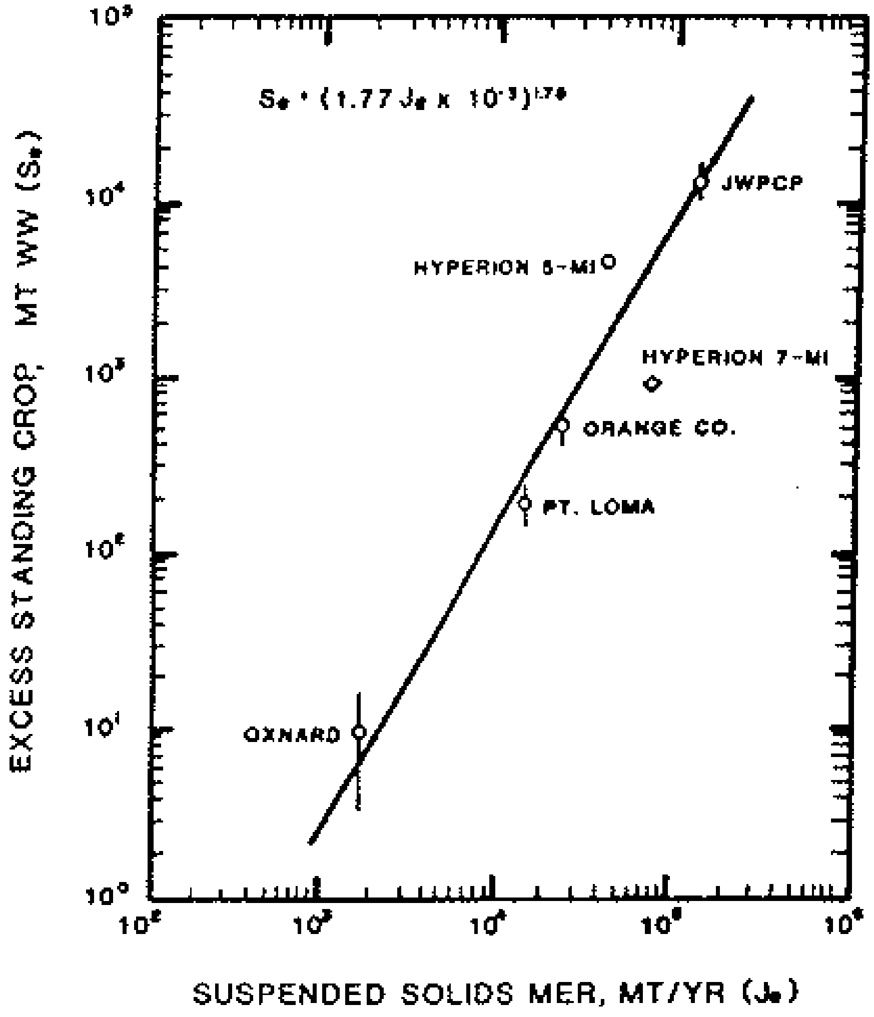


Figure 3. Relation between suspended solids mass emission rates (J_e, mt/yr) and total excess standing crop of benthic infauna (S_e, mt wet wt) surrounding six outfalls on the southern California mainland shelf. Hyperion 8-km (5-mi) effluent and 11-km (7-mi) sludge outfalls plotted separately. Circles and diamond indicate average excess standing crop; bars indicate range of standing crops for each location.
Data from Mearns and Word (1982).

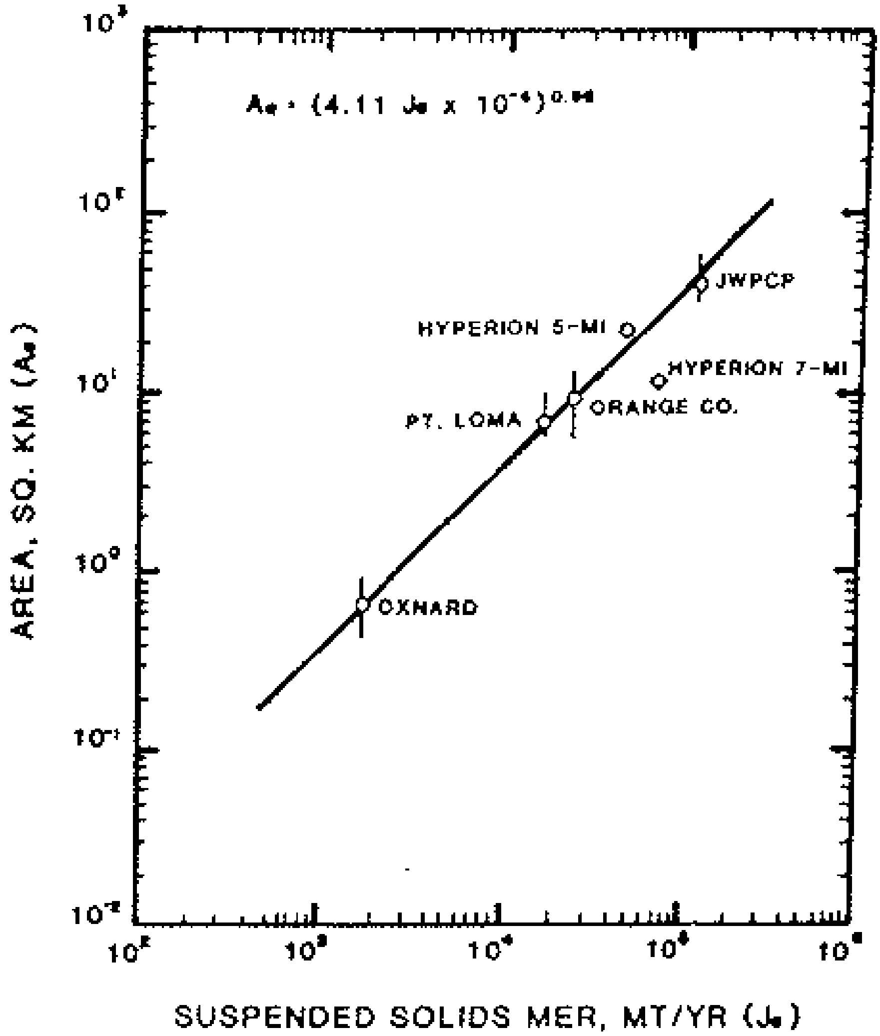


Figure 4. Relation between suspended solids mass emission rates (J_e, mt/yr) and size of areas (km^2) occupied by total excess standing crop (A_e) of infauna surrounding six outfalls on the southern California mainland shelf. Circles and diamond indicate average of area occupied by excess standing crops; bars indicate ranges for each location.
Data from Mearns and Word (1982).

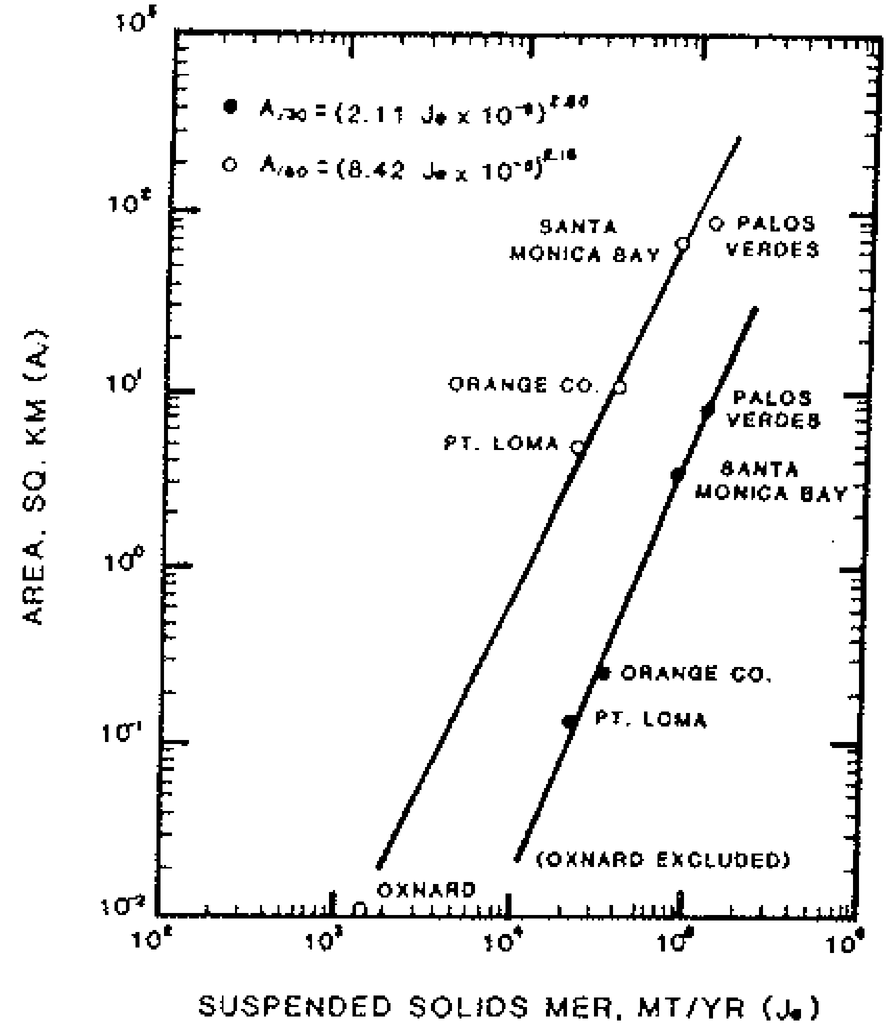


Figure 5. Relation between suspended solids mass emission rates (J_e, mt/yr) and size of areas (A_i, km^2) occupied by macrobenthic fauna dominated by subsurface deposit-feeding organisms (i < 30) and by surface and subsurface deposit-feeding organisms (i < 60); calculations based on the Infaunal Trophic Index (ITI).
Data from Mearns and Word (1982).

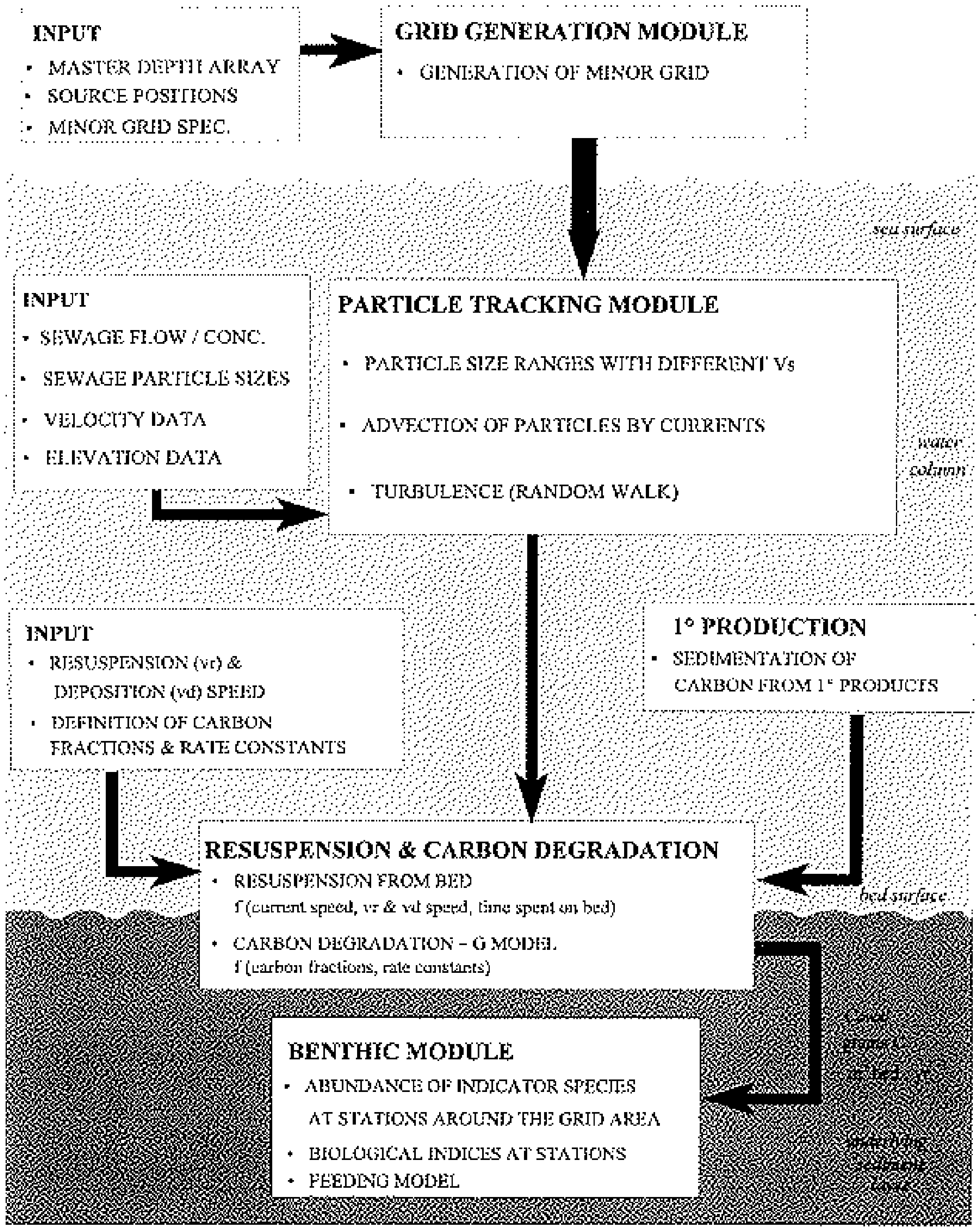


Figure 6. Modules for forecasting the effects of organic carbon from a sewage discharge. The arrows indicate the general flow of information through the modules.