# Review of Eutrophication-Related R&D

R&D Technical Report P408

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**Tel: 01793 865138/012 Fax: 01793 514562 E-Mail: publications@wrcplc.co.uk**
**URL:** www.wrcplc.co.uk/rdbookshop

**Publishing Organisation:**
Environment Agency
Rio House
Waterside Drive
Aztec West
Almondsbury
Bristol BS32 4UD

Tel: 01454 624400 Fax: 01454 624409

ISBN 1 85705 429 6



**Dissemination status**
Internal: Released to Regions
External: Released to Public Domain

**Statement of use**
The aim of this project was to review and produce a synopsis of recently completed, ongoing and proposed eutrophication-related R&D in order to provide a clear framework for the Environment Agency's future R&D programme in this area.

**Keywords**
Eutrophication; Nutrient enrichment; Phosphorus; Nitrogen; Research and Development; Prioritisation.

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# FOREWORD

The control of aquatic eutrophication is a priority for the Environment Agency, with its commitment clearly stated in the 'Environmental Strategy for the Millenium and Beyond'(Environment Agency, 1997) and the publication in December 1998 of proposals for a national strategy in this area (Environment Agency, 1998). The success of the Agency in achieving its goals is critically dependent on a sound scientific understanding of the issues/processes involved.

Because the nature and extent of eutrophication problems vary considerably, both temporally and spatially, related research has at times proceeded in an uncoordinated fashion. Consequently, there was an urgent need for a review of recently completed, current and proposed eutrophication-related R&D to identify specific areas where knowledge is lacking. This review will be used to direct future R&D in a co-ordinated way, in line with the Agency's proposed national strategy for eutrophication.

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# EXECUTIVE SUMMARY

This report is the result of work undertaken by WRc and the Centre for Ecology and Hydrology (CEH) to review eutrophication-related R&D and to make recommendations on areas of priority research that should be considered by the Environment Agency. The principal objectives of the work were:

1. To review completed, ongoing and proposed eutrophication R&D reports;

2. To identify areas requiring future R&D investment and to develop a cost-benefit framework to prioritise these areas in terms of the Agency's business needs over a five year horizon;

3. To investigate the relevance of European and non-European eutrophication-related R&D to the Agency;

4. To identify potential areas for collaborative research nationally and internationally.

R&D reports and research programmes have been reviewed with particular emphasis on recommendations made for further studies (Appendix A). These recommendations have been carefully evaluated by the project team in light of the team's knowledge, expertise and opinion on future needs and with consideration of the Agency's business and regulatory needs.

To assist in the prioritisation of R&D activities, a clear, simple and transparent process has been developed by combining a simple scoring and weighting exercise with a cost-effectiveness analysis. The adopted approach comprises eight steps. The starting point is the proposed management strategy of the EA for aquatic eutrophication (Step 1) from which focus areas have been identified which are directly related to the delivery of the management strategy (Step 2). In addition to the management strategy for eutrophication, the EA has a set of broader environmental themes identified in its Environmental Strategy and a set of R&D criteria (Step 3). The focus areas, environmental themes and R&D criteria are then weighted (Step 4) and projects are then scored (Step 5) against each criterion and weighted scores calculated. The projects are then given a priority score by dividing the weighted score by the estimated cost (Step 6). Each of the projects generated from the review is put through this procedure (Step 7) to produce a database of projects.

The majority of this prioritisation process (Steps 1 to 6) has been implemented in a spreadsheet system - the Eutrophication R&D Prioritisation System (ERDPS). It is recommended that the Agency use this system in the prioritisation of any subsequent eutrophication-related research projects identified. The Agency may wish to modify the spreadsheet (e.g. change some of the weighting factors used) in the light of their evolving business needs.

A priority list of cost-weighted recommended projects has been derived and the selected projects have been entered onto a template that has been constructed by the Agency for the development of its national R&D strategy.

As part of the review process, the relevance of overseas eutrophication-related R&D has been identified, in particular, where scientific studies into the understanding and the management science of eutrophication are relatively advanced and are of relevance to the business needs of the Agency. Potential areas of research identified from this review considered worthy of further investigation by the Agency through contact and/or collaboration with overseas researchers and research organisations are discussed. Projects identified through this review have been included within the ERDPS prioritisation process.

Potential areas for national collaboration have been identified, and contact names and addresses of potential overseas collaborators identified from the network of contacts available to the project team are provided.

# 1. INTRODUCTION

The Environment Agency have commissioned this project to carry out a review of eutrophication-related R&D with the following objectives:

1. To review completed, ongoing and proposed eutrophication R&D reports;

2. To identify areas requiring future R&D investment and to develop a cost-benefit framework to prioritise these areas in terms of the Agency's business needs over a five year horizon;

3. To investigate the relevance of European and non-European eutrophication-related R&D to the Agency;

4. To identify potential areas for collaborative research nationally and internationally.

This report is the final output of the project team addressing these objectives. R&D reports have been reviewed with particular emphasis on recommendations made for further studies. These recommendations have been carefully evaluated by the project team in light of the team's knowledge, expertise and opinion on future needs and with consideration of the Agency's business needs. The prioritisation framework presented in Section 3 has been used to facilitate this process. Recommendations for future R&D have subsequently been provided in accordance with the template currently being used by the Agency to develop its national R&D strategy.

# 2. REVIEW OF EUTROPHICATION-RELATED R&D REPORTS

## 2.1 Funding of eutrophication-related R&D

A range of organisations in the UK commission eutrophication-related R&D. The nature of the research commissioned in relation to the eutrophication problem is governed by the regulatory responsibilities and business needs of the organisation.

In England and Wales, the main funders of eutrophication-related R&D are the Ministry of Agriculture, Fisheries and Food (MAFF), the Environment Agency, Department of the Environment, Transport and the Regions (DETR), the research councils (Natural Environment Research Council (NERC) and the Biotechnology and Biological Sciences Research Council (BBSRC)), English Nature (EN), Countryside Council for Wales (CCW), UK Water Industry Research (UKWIR) and the Foundation for Water Research (FWR).

In Scotland and Northern Ireland, eutrophication-related R&D is funded by the Scotland and Northern Ireland Forum for Environmental Research (SNIFFER)[1], some of the individual member organisations of SNIFFER (e.g. Scottish Executive Rural Affairs Department (SERAD)) and the Department of Agriculture and Rural Development (DARD) in Northern Ireland (formerly Department of Agriculture (DANI)).

## 2.2 Review of eutrophication-related R&D

The review of UK eutrophication-related R&D undertaken for this project has concentrated on the research programmes of the environmental regulatory bodies supplemented, where possible, with readily available information on grant funding by NERC and BBSRC. Generally speaking, research commissioned by the regulatory bodies (with the exception of MAFF) is published in research reports while research commissioned by the research councils (and MAFF) is published in the primary scientific literature. Complete listings of R&D reports published by the FWR and SNIFFER are available from FWR (www.atlas.co.uk/listons), by the Environment Agency from the R&D Dissemination Centre (www.wrcplc.com/ea/rdreport.nsf) and by UKWIR from UKWIR Publications (www.ukwir.co.uk).

DETR (and previously DoE) has sponsored some eutrophication-related R&D for several years (including large collaborative programmes such as the Joint Nutrient Study (JoNuS, JoNuS II) and the Southern Nutrient Study (SoNuS)). DETR currently sponsors research under the Marine and Land-based Inputs to Sea (MLIS) programme in support of OSPAR initiatives including the Strategy to Combat Eutrophication (OSPAR, 1998). DETR publishes

[1] SNIFFER commissions environmental research of common interest to its members: Scottish Environmental Protection Agency (SEPA), the Environment and Heritage Service (EHS) in Northern Ireland, the Scottish Executive Rural Affairs Department (SERAD), Scottish Natural Heritage (SNH) and the Forestry Commission.

Research Newsletters (www.detr.gov.uk) containing details of past publications and new projects each year.

Research commissioned by NERC and BBSRC is organised into thematic programmes and details of current and recent programmes are available at the research council websites (www.nerc.ac.uk and www.bbsrc.ac.uk).

NERC has one current research theme that is directly relevant to eutrophication – Global Nitrogen Enrichment (GANE) (www.ncl.ac.uk/gane/). The first round of awards has been announced and contains several projects related to eutrophication. Details of awards under other thematic programmes and of projects undertaken by NERC institutes (including CEH and the Centre for Coastal and Marine Studies (CCMS)) as part of their core, or collaborative, programmes are less easy to identify. However, reviews of eutrophication-related R&D in relation to lakes and rivers have been commissioned from CEH as part of this project (see Section 4).

BBSRC maintains a database of awards called Oasis (www.bbsrc.ac.uk) enabling recent projects to be identified (some with summaries). Searches of this database using 'eutrophication', 'nutrient', 'phosphorus' and 'nitrogen' as search terms identified several recently completed and ongoing projects related to eutrophication.

In addition to these main sources of information, several key publications from the primary scientific literature have been identified and used in the review.

The purpose of the review of eutrophication-related R&D was 'to review completed, ongoing and proposed eutrophication R&D reports' with a view to identifying 'areas requiring R&D investment' (see Section 3). The approach adopted has been to identify as many completed, ongoing and proposed projects as possible from main funders of eutrophication-related R&D and from this list to identify key references (particularly review documents) in order to identify areas requiring R&D investment. In addition to this, reviews of the primary scientific literature have been undertaken in relation to lakes and rivers (see Section 4).

The main findings and recommendations of the key references are summarised in Appendix A, which is organised in relation to the Eutrophication Focus Areas (see Section 3) and sub-divided, where appropriate, into waterbody type (lakes and reservoirs, rivers, estuaries and coastal waters, and wetlands):

**A2** Nuisance Attenuation;

**A3** Chemical targets;

**A4** Ecological targets;

**A5** Source measures;

**A6** Impact Assessment;

**A7** Eutrophication Control Action Plans (ECAPs);

**A7.1** Source apportionment;

**A7.2** Cause-effect relationships;

**A7.3** Cost-benefit and effectiveness;

**A7.4** Collaboration mechanisms;

**A7.5** Control techniques;

**A7.6** Monitoring framework.

From each of these summaries the project team has identified areas requiring further R&D investment and has translated these into projects. Table 3.1 summarises the projects identified from the review. These projects have then been subjected to the prioritisation process.

### 2.2.1 Eutrophication modelling

One of the greatest challenges in the management of aquatic eutrophication is to develop modelling tools that can simulate the eutrophication process from nutrient sources to eutrophication effects in all water body types and can include a range of management options.

Indeed, the Environment Agency's National Centre for Risk Analysis and Options Appraisal is presently undertaking an exercise to compare the needs for modelling of eutrophication against the availability of models in the context of the EA's Strategy for Aquatic Eutrophication (Robert Willows pers. comm). This review is using Mainstone *et al.* (1998) (see Section A7.2 for further details) as a starting point but aims to expand on this limited assessment of the availability of suitable models.

The review of projects in Appendix A reveals a number of models that have, or are being, developed for various stages of the eutrophication process.

Modelling of nutrient supply from catchments has received much attention. Two recently developed models not covered by Mainstone *et al*. (1998) are MAGPIE and INCA. MAFF funded R&D on nitrates has resulted in the MAGPIE model (see Section A7.1 for further details) that predicts the export nitrogen to surface and groundwater on a catchment or a national basis. The INCA (Integrated Nitrogen in Catchments) model has been developed, by the University of Reading with NERC and university funding, for assessing multiple sources of nitrogen in catchments (Whitehead *et al.,* 1998a and b). It is a daily simulation model with model results produced at every reach boundary in the simulated system. The model can simulate up to six different land uses, with sources of nitrogen from atmospheric deposition, from point and distribute sources or from natural organic sources.

Both the MAGPIE and INCA models are being adapted to predict the export of phosphorus from catchments.

Modelling nutrient supply to estuaries and coastal waters has required further understanding of the transformation processes involved and the results of the LOIS, JoNuS and SoNuS programmes have contributed significantly to this. Further research is underway to understand the role of some of the processes of nutrient cycles in estuaries (see Section A7.2).

Modelling of nutrient transport and transformations in receiving waters is undertaken more routinely using a variety of approaches (see Section A7.2 for further details).

Mainstone *et al*. (1998) describe some of the models available for predicting eutrophication responses in all water body types and ongoing research in the UK (see Section 4 and A7.2) and abroad (see Section 5) is addressing this issue.

# 3. PRIORITISATION OF AREAS REQUIRING FUTURE R&D INVESTMENT

## 3.1 Introduction

Objective 2 as outlined in the Terms of Reference was to identify areas requiring future R&D investment, and to develop a cost-benefit framework to prioritise these areas in terms of the Agency's business needs with regard to eutrophication. The following section outlines the approach to prioritisation.

## 3.2 Prioritisation of eutrophication-related R&D projects

A range of procedures is available to assist in the prioritisation of R&D activities. A clear, simple and transparent process is achieved by combining a simple scoring and weighting exercise with a cost-effectiveness analysis.

The adopted approach comprises eight steps. The starting point is the Environment Agency's proposed management strategy for aquatic eutrophication (Environment Agency, 1998) (Step 1) from which focus areas have been identified that are directly related to the delivery of the management strategy (Step 2). In addition to the proposed management strategy for eutrophication, the Environment Agency has a set of broader environmental themes identified in its Environmental Strategy (Environment Agency, 1997) and a set of R&D criteria (Step 3). The focus areas, environmental themes and R&D criteria are then weighted (Step 4) and projects are then scored (Step 5) against each criterion and weighted scores are calculated. The projects are then given a priority score by dividing the weighted score by the estimated cost (Step 6). Each of the projects generated from the review is subjected to this procedure (Step 7) to produce a database of projects. High priority projects are then summarised in an agreed format (Step 8).

The majority of this prioritisation process (Steps 1 to 6) has been implemented in a spreadsheet system - the Eutrophication R&D Prioritisation System (ERDPS).

The following sections describe each of the steps in more detail.

### 3.2.1 Step 1 - the proposed Management Strategy of the EA for aquatic eutrophication

The proposed Management Strategy for Aquatic Eutrophication in England and Wales is set out in the EA's Consultative Report published in December 1998 (Environment Agency, 1998). The overall aims of the strategy are to address the management of the environment in an integrated way, to form an overview of the state of the environment at any one time, to identify the pressures which affect that state, to determine the management responses, and to work in partnership with and through others to achieve agreed objectives.

The key elements of the strategy are:

- Promotion of a partnership approach at local and national level (with other environmental regulators such as DETR, MAFF/CEFAS, English Nature and SEPA);

- Use of regulatory and other mechanisms (voluntary, collaborative, educational and economic) to reduce nutrient inputs;

- Review of how to measure the extent of the eutrophication problem in different waters, the impact of point source discharges, and the impact of land use and management (diffuse sources);

- Use of risk assessment as a tool to target monitoring and protective measures;

- Development of the priorities for action based on:

  - where there are statutory requirements (see below);
  - the strength of the evidence on cause and effect;
  - where uses are adversely affected;
  - where there is special conservation interest;
  - where benefits can be delivered and deterioration prevented at reasonable cost.

- Development of interim targets for eutrophication control in freshwaters;

- Application of statutory and/or international standards to marine waters;

- Development of catchment-based action plans for specific sites;

- Promotion of a programme of R&D to improve scientific understanding.

The direct policy drivers for eutrophication control are:

- Urban Waste Water Treatment (UWWT) Directive (91/271/EEC);

- Nitrate Directive (91/676/EEC);

- Proposed Water Framework Directive (WFD);

- OSPAR Convention.

The indirect policy drivers for eutrophication control are:

- Habitats Directive (92/43/EEC) (through Special Areas of Conservation, SACs);

- Wild Birds Directive (79/409/EEC) (through Special Protection Areas, SPAs);

- Rio Conference 1992 (through UK Biodiversity Action Plan, UKBAP, and more specifically the Mesotrophic Lakes and Eutrophic Standing Waters Habitat Action Plans);

- Freshwater Fish Directive (78/659/EEC) and Surface Water Abstraction Directive (75/440/EEC) (these may be subsumed by the WFD if it is implemented);

- Directive on Integrated Pollution Prevention and Control (IPPC) (96/61/EEC) (through controlling discharges from large intensive livestock (pig and poultry) units);

- Common Agricultural Policy (through environmentally sustainable agricultural practices; Agenda 2000; Countryside Stewardship (with MAFF); Environmentally Sensitive Areas; and Codes of Good Agricultural Practice (through MAFF and NAWAD)).

### 3.2.2 Step 2 - R&D Project Assessment Criteria- Focus Areas

The Management Strategy provides the framework for future R&D investment in eutrophication, and from this, six Focus Areas have been identified which are directly related to the delivery of the Management Strategy. These Focus Areas form part of the set of Project Assessment Criteria (PAC) and are used in the ERDPS to judge the extent to which R&D projects meet the requirements of the Management Strategy. Some Focus Areas were sub-divided into the following water body types: lakes and reservoirs, rivers, estuaries and coastal waters, and wetlands (Table 3.1)

**Table 3.1 Focus Areas sub-divided into water body types**

| Focus Areas | Sub-divided into Waterbody type? (Y = Yes and N= No) |
|---|---|
| PAC 1 Attenuating nuisance impact | Y |
| PAC 2 Chemical targets | Y |
| PAC 3 Ecological targets | Y |
| PAC 4 Source measures | N |
| PAC 5 Impact assessment | Y |
| PAC 6.1 ECAP tool: Source apportionment | N |
| PAC 6.2 ECAP tool: Cause-effect relationships | Y |
| PAC 6.3 ECAP tool: Cost-benefit and effectiveness | N |
| PAC 6.4 ECAP tool: Collaboration mechanisms | N |
| PAC 6.5 ECAP tool: Control techniques | N |
| PAC 6.6 ECAP tool: Monitoring framework | N |

**PAC 1. Attenuating nuisance impact**

This Focus Area incorporates R&D projects into methods addressing the nuisance impacts, rather than the fundamental causes, of eutrophication. Thus, for example, projects on algal inhibition by chemical or physical means, physical control of macrophytes, and methods to enhance phytoplankton grazing would all fall into this Area.

**PAC 2. Chemical targets**

This Focus Area incorporates R&D projects into the definition of chemical targets - quality objectives and standards - for nutrients. Thus, any project addressing the definition or further development of such targets, in any type of water body, would fall into this Focus Area. It should be noted, however, that quality objectives and standards are less well developed for estuarine and coastal waters, for which action will be required by legislation (e.g. UWWT Directive, proposed Water Framework Directive, OSPAR Convention).

**PAC 3. Ecological targets**

Ecological targets based on reference conditions for different eco-regions are an important element in the proposed Water Framework Directive. This Focus Area incorporates R&D projects into the derivation of ecological targets for use in the control of eutrophication, including work on the estimation or determination of relevant reference conditions.

**PAC 4. Source measures**

This Focus Area incorporates R&D projects into measures for minimising nutrient inputs from point and diffuse sources, relevant either to load reduction targeting or to the application of Best Available Techniques (BAT) or Best Environmental Practice (BEP), and supporting application of the Precautionary Principle in the absence of specific environmental targets.

**PAC 5. Impact assessment**

This Focus Area incorporates R&D projects into methods for assessing and predicting the impacts of eutrophication, including relevant monitoring, classification and risk assessment activities.

**PAC 6. Eutrophication Control Action Plans (ECAPs) tools**

Where eutrophication is a local environmental problem, catchment-based planning and control is important, and this Focus Area is divided into 6 sub-Areas addressing specific ECAP requirements.

**PAC 6.1 Source apportionment**

This Focus sub-Area incorporates R&D projects into methods for identifying nutrient sources (point and diffuse) within a catchment, and for estimating their relative contributions to overall nutrient loads and eutrophication impacts.

**PAC 6.2 Cause-effect relationships**

This Focus sub-Area incorporates R&D projects into tools - including predictive models - to address the interactions within water bodies between nutrients, the biota and other relevant factors affecting nutrient chemistry and algal growth, and the consequences of that growth. Understanding of such interactions is best developed for standing waters, and least developed for estuarine and saline waters.

**PAC 6.3 Cost-benefit and effectiveness**

This Focus sub-Area incorporates R&D projects into methods for assessing the costs, benefits and overall effectiveness of different options for the control and management of eutrophication and relevant causative factors. Such options may include effluent and run-off treatment, improved farming practices, land use changes, and economic instruments.

**PAC 6.4 Collaboration mechanisms**

This Focus sub-Area incorporates R&D projects into mechanisms to promote consultation on, and collaborative implementation of, ECAPS. For example, relevant projects could address such areas as procedures for the establishment of local groups of interested parties, and evaluating the most cost-effective methods of encouraging the adoption of environmental auditing by farmers.

**PAC 6.5 Control techniques**

This Focus sub-Area incorporates R&D projects into techniques for local eutrophication control. The scope of the sub-Area is therefore as large as the scope for such techniques - covering source controls (e.g. improved sewage treatment, improved farm waste management, agricultural buffer zones), wetland creation and river engineering, *in situ* control of nutrient loads (e.g. destratification, removal/isolation of sediments, changes in fish communities to reduce sediment disturbance). It should also be noted that research and development into assessing the wider environmental impact of applying the control measures is included.

**PAC 6.6 Monitoring framework**

This Focus sub-Area incorporates R&D projects into methodologies for monitoring and reviewing the implementation of ECAPs. It potentially includes both techniques for monitoring and assessing ECAPs in general, and techniques for monitoring and assessing specific eutrophication control and management measures.

### 3.2.3 Step 3 - R&D Project Assessment Criteria - broader EA Environmental Themes and R&D criteria

In addition to the set of Focus Areas identified in Step 2, there are five broader EA environmental themes identified in the EA Environmental Strategy (Environment Agency, 1997) and three R&D criteria that all projects should meet. The environmental themes and R&D criteria complete the set of fourteen Project Assessment Criteria and are used in the ERDPS to judge the extent to which R&D projects contribute to the delivery of these themes and criteria.

**Environmental themes**

These are broader Agency goals, described in its Environmental Strategy and reiterated in its "Corporate Plan 1999~2000. Our forward look to 2002" (Environment Agency, 1999). The weighting given to each of these themes should reflect the fact that eutrophication is only one of many issues which impinge upon a particular theme. Thus, a project should still score 100 points against a theme if it would answer all the information needs regarding that theme in respect of eutrophication, but a low weighting would be assigned to the theme (e.g. in comparison with that for a Eutrophication Focus Area) because eutrophication is only a small "contributor" to the theme. In the ERDPS spreadsheet NONE of the themes are sub-divided by water body type.

**PAC 7. Biodiversity enhancement**

This addresses the extent to which proposed projects are likely to contribute to the Agency's goal of protecting and enhancing biodiversity, through reducing or eliminating the impairment of biodiversity caused by the proliferation of nutrient tolerant species and consequent changes to community structures.

**PAC 8. Integrated river basin management (IRBM)**

This addresses the extent to which proposed projects are likely to contribute to the development and practice of integrated river basin management, by which the Agency endeavours to ensure a sustainable water environment (in which all waters are suitable for their uses, without prejudice to the needs of future generations), and seeks to improve overall water quality continuously.

**PAC 9. Industrial regulation**

This addresses the extent to which proposed projects are likely to contribute to the regulation of major industries by the Agency, to its general aims of achieving firm, fair and consistent regulation and using its resources to achieve maximum environmental benefits, and to its specific need to ensure improvement in the quality of discharges, in relation to the UWWT Directive.

**PAC 10. Partnership opportunities**

This addresses the extent to which proposed projects are likely to offer opportunities for partnerships at local, national and international levels.

**PAC 11. Information**

This addresses the extent to which proposed projects are likely to provide information that is timely, accurate and relevant, in a cost-effective manner. Factors to consider include the time that is likely to be required to achieve project objectives, the extent to which the information gained will be case-specific and how widely applicable the results will be.

**R&D Criteria**

These are general Agency R&D criteria. The "Value for money" criterion is not included, as the division of "Weighted Score" for each project by its estimated total cost to give a "Priority Score" addresses this aspect.

**PAC 12. Seriousness**

This addresses the following issues:

- what would happen to the environment if the project were not carried out?
- is the business rationale for the Agency's involvement clearly established?
- to what extent is the Agency responsible for the issue concerned?
- will the Agency be able to respond effectively to external influences?
- will the Agency be able to forecast its future needs?
- will the Agency be able to account for the consequences of its actions and decisions, over different time scales and across the environment as a whole?
- will the Agency be in a position to influence other people and what other people want?

**PAC 13. Timeliness**

This addresses the following issues:

- how urgently is the R&D needed?
- will the need or magnitude of the problem expand if the R&D is delayed?
- is it an issue of high profile political or public concern?

**PAC 14. Delivery**

This addresses the following issues:

- is it clear how the R&D should be carried out and managed?
- how is the quality and effectiveness of the R&D to be assessed?
- how will risks, constraints and dependencies affect delivery?
- who will benefit from the output of the R&D, and is it clear how this will be implemented and used?
- will the Agency be able to make better decisions and act more effectively?

### 3.2.4 Step 4 - Weighting of Project Assessment Criteria

Weighting of the Project Assessment Criteria allows the relative importance of each to be included in the assessment of R&D projects. The ERDPS has a facility for weighting factors to be applied (totalling 100) to the Focus Areas, sub-divided, where appropriate, into waterbody type, environmental themes and R&D criteria. Weighting factors have been applied in the ERDPS such that the greatest emphasis has been placed on the Focus Areas, followed by the R&D criteria with least emphasis on the environmental themes.

### 3.2.5 Step 5 - Scoring of R&D projects

R&D projects identified from the review have been allocated scores out of 100 according to the extent to which they satisfy the Project Assessment Criteria.

A particular R&D project may address a number of different Focus Areas and environmental themes and should be scored against those it addresses. All projects should be scored against each of the R&D criteria.

The Weighted Score for each project (the sum of the project scores multiplied by the weighting factor) provides an indication of the extent to which the project contributes to the Focus Areas and environmental themes it addresses and to the R&D criteria. The greater the Weighted Score, the more relevant the project.

### 3.2.6 Step 6 - Prioritisation of R&D projects

Prioritisation of R&D projects is to be made on the basis of cost effectiveness. The measure of cost effectiveness is the Priority Score which is calculated by dividing the Weighted Score by the estimated cost in £K. R&D projects with the higher Priority Score are those that are considered most relevant with respect to the Project Assessment Criteria with a lower estimated cost.

### 3.2.7 Step 7 - Analysis of R&D projects by Focus Area and cost-effectiveness measure

All R&D projects gleaned from the review and personal knowledge have been subjected to the scoring/weighting process described above. These have been summarised by title, source and cost and arranged within each of the Focus Areas described in Step 2 (Table 3.1). Details of the priority score assigned by the project team for each project is given in the ERDPS output provided with this report. A summary of the prioritised list of cost-weighted projects is provided in Table 3.2.

### 3.2.8 Step 8 - Template for entry into National R&D Strategy

The cost-weighted projects will then need to be entered into the template that has been constructed by the EA for the proposals submitted to the EA's national R&D programme. Following discussions on the prioritised list of projects provided, nine priority projects have been entered onto the EA's template. These are presented in Tables 3.3 to 3.11.

**Table 3.2 Analysis of R&D projects by Focus Area**

| Ref Title of Project | Background and Overall Objectives | Source[2] | Estimated Cost (£k) | Potential collaborators |
|---|---|---|---|---|
| Focus Area 1: Attentuation of the nuisance impact of eutrophication | | | | |
| 1.1 Phosphorus retention in buffer zones. | To undertake research to accurately predict the short-term and long-term retention of phosphorus and nitrogen in buffer zones under typical loading conditions in arable and livestock areas. | Mainstone *et al.,* 1994 | 150 | MAFF/NAWAD |
| 1.2 Further investigation of ionic absorbents as a treatment for removal of phosphate ions | To undertake a desk study to further investigate the use of ionic absorbents as a treatment for removal of phosphate ions in lake systems. | This report (see Section 4) | 40 | UKWIR, Statutory Conservation bodies. |
| Focus Area 2: Definition of chemical targets (quality objectives /standards, especially for estuarine and coastal waters) - linked to statutory drivers | | | | |
| 2.1 Nutrient levels in surface waters equating to high, good and moderate ecological status. | To define and quantify nutrient levels in rivers, lakes, estuaries and coastal waters equating to high, good and moderate ecological status as defined in the proposed Water Framework Directive. | Proposed Water Framework Directive | 100 | DETR, SNIFFER, European Regulatory Authorities |
| 2.2 Evaluation of estuary classification procedures and monitoring protocols. | To evaluate estuary classification procedures and monitoring protocols for classification of nutrient impacts. | Scott *et al.,* 1999 | 50 | DETR, SNIFFER, Statutory Conservation bodies. |

[2] Sources for these projects incude those arising from this report and from information reviewed in Appendix A (see References in Appendix A)

| Ref Title of Project | Background and Overall Objectives | Source[2] | Estimated Cost (£k) | Potential collaborators |
|---|---|---|---|---|
| 2.3 Desk study to evaluate the current P index scheme to classify the phosphorus status of UK soils. | The current soil P index scheme is considered too coarse with P indices 2 and 3 considered to cover the critical range of P concentrations for most soils. This project would investigate the likely effects of further divisions of soil P indices including the likely effects of long-term water quality of changing fertiliser applications rates based on knowledge of critical soil P levels and corresponding crop N requirements. | Parr *et al.,* 1999a | 30 | MAFF/ NAWAD |
| Focus Area 3: Definition of ecological targets and reference conditions – linked to the proposed Water Framework Directive | | | | |
| 3.1 Development of a viable approach to a national assessment of background nutrient concentrations in estuaries. | To determine background concentrations in estuaries in order to provide a baseline against which contemporary nutrient loading to estuaries can be assessed. | Scott *et al.,* 1999 | 50 . | DETR, SNIFFER, Statutory Conservation bodies, NERC |
| Focus Area 4: Source orientated measures for minimising nutrient discharges (BAT, BEP, PP), point and diffuse – linked to statutory drivers and OSPAR | | | | |
| 4.1 Review of agricultural nutrient balances for different crop and soil types. | To consolidate and assess information on nutrient balances for different crop and soil types in the light of recommended fertiliser application rates and likely crop yields. | Parr *et al.,* 1999a | 40 | MAFF/ NAWAD |
| 4.2 Decision-support system for slurry spreading. | To undertake a study to produce decision-support systems for optimal slurry spreading (to include consideration of topography, soil type, proximity to watercourse, rainfall, timing of application, rate and method of application and nutrient budgeting). Such systems would be operated either by the farmer or independent advisors and used to plan farm management according to local conditions. (This project would need to take account of relevant work funded by MAFF including the MANNER (MANure Nitrogen Evaluation Routine) decision-support system). | Mainstone *et al.,* 1994 | 80 | MAFF/ NAWAD |

| Ref Title of Project | Background and Overall Objectives | Source[2] | Estimated Cost (£k) | Potential collaborators |
|---|---|---|---|---|
| 4.3 Agronomically and environmentally acceptable soil phosphorus levels. | To review the use and efficacy of maintenance dressings, the implications of reducing soil phosphorus reserves for different crops, and the availability of crops and crop varieties that can efficiently utilise low levels of available soil phosphorus. | Mainstone *et al.,* 1996 | 35 | MAFF/ NAWAD |
| 4.4 Agricultural best management practices to reduce non-point sources of nutrients. | To investigate the applicability and cost-effectiveness of agricultural management practices for reducing non-point source nutrient loads. Includes:<br>techniques such as contour ploughing and contour strip cropping;<br>machinery to target inorganic fertiliser application at the crop root;<br>avoiding compaction of sensitive soils. | Mainstone *et al.,* 1996 | 60 | MAFF/ NAWAD |
| 4.5 Livestock control in riparian areas. | To estimate phosphorus loading from direct defecation by livestock with streambed access, in order to assess the likely benefits of livestock control. | Mainstone *et al.,* 1996 | 30 | MAFF/ NAWAD |
| Focus Area 5: Methods for assessing and predicting impacts | | | | |
| 5.1 Development of a catchment scale eutrophication risk tool. | To further develop existing catchment scale delivery models to provide a high-resolution tool for assessing and predicting phosphorus loads to high priority rivers and targeting control measures. | Mainstone *et al.,* 1996 and NERI, 1997 | 200 . | MAFF/ NAWAD DETR, Statutory Conservation bodies |
| 5.2 Further development of the Trophic Diatom Index (TDI). | To further develop protocols for use of Trophic Diatom Index (TDI) as an operational diagnostic tool in different types of water body. | Kelly, 1996 | 150 | DETR, SNIFFER, Statutory Conservation bodies |

| Ref Title of Project | Background and Overall Objectives | Source[2] | Estimated Cost (£k) | Potential collaborators |
|---|---|---|---|---|
| 5.3 Alternative methods for monitoring estuarine trophic status. | To explore the potential alternative/supplementary monitoring methods to chemical monitoring in the operational assessment of the trophic status of estuaries. | Parr *et al.,* 1999a | 40 | DETR, SNIFFER, EU/EEA, Statutory Conservation bodies, NERC. |
| 5.4 Development of a national nutrient export model. | To develop a national nutrient export model building on national expertise, possibly including modelling approaches developed as part of MAFF funded R&D on phosphorus and nitrogen (i.e. MAGPIE). The model would be GIS-based and have a modular format such that advances made in nutrient modelling techniques in the future can be retrofitted by replacing a single module. The initial phase of the study would be to determine which organisations would use such a model and what the model would be used for. | Parr *et al.,* 1999a and MAFF, 1999b. | 130 . | MAFF/ NAWAD/ SERAD |
| 5.5 Further development of algal bioassays. | To continue the development of algal bioassays (e.g. in vitro microplate assays) for water quality management purposes (fresh and marine waters). Standard methods should be developed with guidelines on appropriate modifications which can be made to improve the ecological relevance of the results to individual waters. (Once the standards methods are developed, the bioassays would be used to determine a statistical relationship between bioassay results and other indicators of trophic status such as chlorophyll *a* and nutrient levels). | Parr, 1993 | 120 | DETR, NERC, Statutory Conservation bodies, SNIFFER |

| Ref Title of Project | Background and Overall Objectives | Source[2] | Estimated Cost (£k) | Potential collaborators |
|---|---|---|---|---|
| 5.6 Demonstration of the benefits of the artificial enrichment of gravel pits as a fishery management tool. | A recent review undertaken on behalf of the Environment Agency has identified a need for the benefits of artificial enrichment to be more clearly demonstrated. A monitoring study would be undertaken on gravel pits which are currently, or are scheduled to become, artificially enriched, to obtain "before" and "after" data that may be used to assess the effects of the fertilisation programme. The monitoring programme would include monitoring "improvements" to phytoplankton and fish populations as well as nutrient levels. | Barnard *et al.,* 1999 | 80 | Statutory Conservation bodies, NERC, Gravel extraction industry |
| 5.7 Strategy for wetlands eutrophication modelling. | To assess the need for an operational modelling tool to predict the effects of nutrient enrichment on wetlands, and to review the applicability of existing wetlands models (mainly European) to the Agency's requirements. The project would recommend a strategy for wetlands eutrophication modelling. | Mainstone *et al.,* 1998 | 40 | Statutory Conservation bodies, Wildlife and Wetlands Trust, RSPB, NERC. |
| 5.8 Estuarine diatom index feasibility study. | To undertake a survey of basic diatom taxonomy in intertidal sediments combined with a water and sediment quality monitoring programme, to assess whether the development of an estuarine episammic diatom trophic index is practicable. | Parr *et al.,* 1999b | 80 | DETR, Statutory Conservation bodies, NERC |
| 5.9 Applicability of models for estuaries and coastal waters. | To undertake a further investigation of the applicability and usefulness of models relating to, or with elements of, nutrient cycling or impacts in estuaries and coastal waters. | Mainstone *et al.,* 1998 | 60 | MAFF/ NAWAD, NERC, Statutory Conservation bodies, EU/EEA. |

| Ref Title of Project | Background and Overall Objectives | Source[2] | Estimated Cost (£k) | Potential collaborators |
|---|---|---|---|---|
| 5.10 Role of nutrients in the formation of water quality barriers to fish migration. | To assess the role of nutrient enrichment in promoting dissolved oxygen sags in estuaries that form barriers to fish migration. | Scott *et al.,* 1999 | 70 | MAFF/ NAWAD, NERC, Statutory Conservation bodies. |
| 5.11 Detailed review of lake eutrophication models. | The review would focus on modelling of alternative stable states - a key component of lake modelling in relation to eutrophication and restoration not accommodated by traditional eutrophication models (e.g. from clear water dominated by submerged macrophytes to a state comprising phytoplankton dominated turbid water). | Mainstone *et al.,* 1999 | 50 | NERC, Statutory Conservation bodies, UKWIR |
| 5.12 Compartmentalisation of phosphorus. | To undertake research into the compartmentalisation of phosphorus between the dissolved and particulate phases in agricultural run-off and STW effluents, in order to provide simple methods for predicting likely in-river bioavailability | Mainstone *et al.,* 1996 | 80 | MAFF/ NAWAD |
| 5.13 Pathways of phosphorus inputs to rivers. | To investigate the precise pathways of phosphorus inputs to rivers from agricultural land and farmyard areas, particularly the importance of leaching into under-drainage systems and aquifers. | Mainstone *et al.,* 1996 | 100 | MAFF/ NAWAD |
| 5.14 Relationship between SRP and TRP. | To assess the significance of differences between soluble reactive phosphorus and total reactive phosphorus at representative river sites, to evaluate the degree of compatibility and comparability between the two. | Mainstone *et al.,* 1996 | 70 | Statutory Conservation bodies, SNIFFER |
| 5.15 Estuary sediment nitrogen mineralisation rates. | To review the potential for using estuarine sediment nitrogen mineralisation rates as a trophic index. | Parr and Wheeler, 1996 | 40 | DETR, NERC, Statutory Conservation bodies. |

| Ref Title of Project | Background and Overall Objectives | Source[2] | Estimated Cost (£k) | Potential collaborators |
|---|---|---|---|---|
| 5.16 Methods of assessing phosphorus bioavailability | To further the understanding of the geochemical pathways of phosphorus transport (such as whether and how much phosphorus exists in biologically reactive fractions, whether it moves primarily in solution or attached to particles, how vulnerable it is to redox changes, etc.). | This report (see Section 4) | 100 | MAFF/ NAWAD, NERC, Statutory Conservation bodies. |
| Focus Area 6: Development of tools for eutrophication control action plans as part of the catchment based approach to control<br>Sub-category 6.1: Methods for source apportionment | | | | |
| 6.1.1 Assessment of the impact of nutrient loss from septic tanks on groundwaters and surface waters. | To investigate the impact of nutrient loads from septic tanks on nutrient status of groundwaters and rivers. To investigate the relationship between septic tank condition, soil type and nutrient status of receiving waters. To determine the contribution of septic tanks to the national nutrient load. | Mainstone *pers. comm*. and Chilton *et al*, 1996 | 90 | SNIFFER MAFF/ NAWAD |
| 6.1.2 Assessment of contribution of sewer leakage to catchment nutrient budgets. | To undertake an assessment of the contribution of sewer leakage to catchment-based nutrient budgets in three contrasting trial catchments using a part modelling/part monitoring approach. | Parr *et al.,* 1999a | 120 | UKWIR |
| 6.1.3 Investigation into the significance of wet-weather events on nutrient enrichment of urban watercourses. | To include quantification of nutrient concentrations and loads in urban runoff; and effects of storm events on nutrient release by mobilisation of bed sediments. | Whitton and Kelly, 1998 | 160 | UKWIR, Highways Agency. |
| 6.1.4 Risk assessment of phosphorus loads to aquifers. | To undertake a qualitative risk assessment of phosphorus loads to aquifers from both point and diffuse sources. The project should investigate whether the current situation is likely to worsen and the need for Environment Agency groundwater phosphorus monitoring data. | Parr *et al.,* 1999a | 50 | DETR, NERC (BGS) |

| Ref Title of Project | Background and Overall Objectives | Source[2] | Estimated Cost (£k) | Potential collaborators |
|---|---|---|---|---|
| 6.1.5 Nutrient risk assessment tool (diffuse agricultural sources). | To develop a two-tier system of nutrient risk-assessment operating on different geographical scales. First targeting high risk catchments at a national or regional scale, and subsequently identifying high risk areas within those catchments at a local or farm scale. To include databases of spatial information relating to pollution risk (fertiliser usage, animal stocking densities, soil type, land use, slope). The GIS approach adopted in the MAGPIE model for nitrogen funded by MAFF should be evaluated against the needs of this system. | Mainstone *et al.,* 1994;<br>MAFF, 1999b | 100 | MAFF/ NAWAD, Statutory Conservation bodies, SNIFFER |
| 6.1.6 Nutrient loads to estuaries from the marine environment. | Phase I: desk study to identify which estuaries are most susceptible to large nutrient loads from the marine environment, and to determine which of the most susceptible estuaries have a high land-derived aerial nutrient loading rate (the latter information will be available from a recent DETR project).<br>Phase II: monitoring study on one of the most "at risk" estuaries to measure/model nutrient inputs from all sources to obtain a "worst case" reliable quantitative assessment of marine nutrient loads to UK estuaries. | Parr *et al.,* 1999b | 150 | DETR, SNIFFER, Statutory Conservation bodies, NERC, MAFF/ NAWAD |
| 6.1.7 Impact of non-sewered premises. | To quantify the impact, in terms of nutrient loads, of rural premises not connected to sewerage systems. | Coventry University Centre for Environmental Research and Consultancy (1998) | 60 | SNIFFER, Statutory Conservation bodies. |
| 6.1.8 Standard approach for nutrient budgets. | To develop a consistent, standard approach for creating nutrient budgets at a variety of scales from site to catchment and produce guidance notes. | Mainstone, *pers. comm.* | 40 | Statutory Conservation bodies, SNIFFER |

| Ref Title of Project | Background and Overall Objectives | Source[2] | Estimated Cost (£k) | Potential collaborators |
|---|---|---|---|---|
| Sub-category 6.2: methods for assessing cause-effect relationships | | | | |
| 6.2.1 Investigation of the role of riverine sediments and plant biomass in the uptake and release of phosphorus to and from the water column. | To provide a greater understanding of the role of sediments and plant biomass in the cycling of phosphorus in rivers in relation to reduction in loads entering rivers | Parr *et al.,* 1998; MAFF, 1999a | 150 | NERC, SNIFFER, Statutory Conservation bodies. |
| 6.2.2 Evaluation of the mechanisms of and implications of internal eutrophication in wetlands. | To carry out research to clarify the role of internal eutrophication in different wetland types (building on research undertaken in Europe) and to identify the anthropogenic stresses leading to this mechanism becoming important. | Mainstone *pers. comm.* | 50 | NERC, RSPB, Wildlife and Wetland Trust. |
| 6.2.3 Pilot testing of a scheme for assessing apparent eutrophication effects. | To pilot test the scheme developed for assessing apparent eutrophication effects in selected catchments and to render the scheme fit for operational use. | Hilton and Irons, 1998 | 40 | UKWIR |
| 6.2.4 Investigation of nutrient limitation to aquatic macrophytes. | To undertake further work to determine nutrient limitation to aquatic macrophytes through measurements of C:N:P ratios in plant tissue, together with bioavailable N:P ratios in sediment and overlying water. The work would involve sampling at a number of locations covering a range of nutrient concentrations and water body types. | Parr *et al.,* 1999a | 100 | NERC, Statutory Conservation bodies. |
| 6.2.5 Review of environment Agency nutrient data. | To undertake a review of recent EA nutrient data. This should include further investigations into likely N and P limitation in tidal waters and a re-assessment of the nutrient status of English and Welsh rivers. | Parr *et al.,* 1999b | 60 | DETR, NERC, Statutory Conservation bodies. |

| Ref Title of Project | Background and Overall Objectives | Source[2] | Estimated Cost (£k) | Potential collaborators |
|---|---|---|---|---|
| 6.2.6 Responses of bog and fen plant species to increased availability of N and P. | To investigate the responses of bog and fen species to increased availability of both N and P, with a view to predicting vegetation changes as a result of changes to the extent of both internal and external eutrophication. | Mainstone *pers. comm*. | 120 | Statutory Conservation bodies, RSPB, Wildlife and Wetlands Trust. |
| 6.2.7 Extent of phosphorus limitation in coastal waters. | To analyse marine baseline survey data in order to establish the extent of P limitation in Welsh and English coastal waters, and to assess the seasonality of both N and P limitation. | Parr *et al.,* 1999b | 70 | MAFF/ NAWAD, NERC, Statutory Conservation bodies. |
| 6.2.8 Responses of saltmarshes to increased nutrient levels. | To undertake a review of the responses of saltmarshes to increased nutrient levels. | Scott *et al.,* 1999 | 40 | NERC, Statutory Conservation bodies. |
| 6.2.9 Review of the status of low-nutrient estuaries. | To assess the ecological value of low-nutrient estuary sites in England and Wales, and to assess their potential responses to nutrient enrichment | Scott *et al.,* 1999 | 60 | NERC, Statutory Conservation bodies. |
| 6.2.10 Review of the relationships between physical and chemical parameters in UK estuaries. | To carry out a geomorphological review to describe the relationship between physical and chemical factors in estuaries which influence nutrient fluxes. This will allow better prediction of responses of estuaries to changing conditions. | Scott *et al.,* 1999 | 70 | NERC, Statutory Conservation bodies. |

| Ref Title of Project | Background and Overall Objectives | Source[2] | Estimated Cost (£k) | Potential collaborators |
|---|---|---|---|---|
| 6.2.11 Assessment of the relationship between plant tissue and ambient nutrient concentrations. | To assess the relationship between nutrient concentrations in plant tissues and in the ambient water column in order to assess whether plant tissues might provide a better measure of long term nutrient concentrations than water samples, in which nutrient concentrations may be highly variable. | Scott *et al.,* 1999 | 90 | NERC, Statutory Conservation bodies. |
| 6.2.13 Implications of climate change on eutrophication. | To consider the likely long term implications of climate change on eutrophication. | Coventry University Centre for Environmental Research and Consultancy (1998) | 50 | DETR, NERC, SNIFFER |
| 6.2.14 Further development of sediment equilibrium phosphorus concentration method. | To further develop the equilibrium phosphorus concentration method for sediments as a method for estimating phosphorus uptake and release to and from the water column | This report (see Section 4) | 90 | NERC, SNIFFER, Statutory Conservation bodies |
| 6.2.15 Assessment of sampling and analysis procedures. | To critically assess the EA's procedure for sample storage and analysis of water samples, particularly in relation to phosphorus and chlorophyll. | Whitton and Kelly, 1998 | 20 | Internal, SNIFFER |
| 6.2.16 Further understanding of denitrification. | To undertake a review to gain further understanding of the process of denitrification in rivers, wetland treatment systems and buffer zones with a view to enhancing nitrate removal. | Whitton and Kelly, 1998 | 40 | MAFF/ NAWAD, UKWIR |
| 6.2.17 Relationship between biological quality and nutrients in estuaries. | To undertake more detailed surveys to define the relationship between biological quality and nutrient status in estuaries, with a focus on sensitive marine areas. | Parr and Wheeler, 1996 | 120 | Statutory Conservation bodies. |

| Ref Title of Project | Background and Overall Objectives | Source[2] | Estimated Cost (£k) | Potential collaborators |
|---|---|---|---|---|
| 6.2.18 C:N and C:P ratios as indicators of estuarine trophic status. | To assess the relationship between C:N and C:P ratios in dominant salt marsh plant species and sediment from estuaries covering a wide range of trophic status, with a view to using C:N and C:P as trophic indicators. | Parr *et al.,* 1999b | 100 | DETR, NERC, Statutory Conservation bodies. |
| Sub-category 6.3: Methods for assessing cost-effectiveness of management options | | | | |
| 6.3.1 Development of an economic model of cost and benefits of phosphorus recovery from sewage and animal wastes. | The quantities of phosphorus present in sewage and animal waste are significant compared with the needs of the detergent and high-grade phosphate industry. EC regulations and local environmental objectives are making P-removal from wastewaters increasingly widespread. Thus in the future P-recovery for recycling could become economically viable. This project would develop an economic model of cost and benefits of phosphorus recovery from sewage and animal wastes in light of EC regulations and local environmental objectives. | CEEP, 1998 | 50 | MAFF/ NAWAD, Soap and Detergent Industry Association, UKWIR. |
| 6.3.2 Assessment of Agricultural Nonpoint Source Pollution (AGNPS)model. | To examine and adapt where necessary the source code of the AGNPS model to run on UK data, and test AGNPS against other similar models developed in the UK with a view to selecting the better performing model. Both models use the export coefficient approach to predict in-stream concentrations of nutrients given certain land-use and catchment characteristics. | Mainstone *et al.,* 1996 | 40 | MAFF/ NAWAD, SNIFFER |
| Sub-category 6.4: Mechanisms for collaboration | | | | |
| 6.4.1 Testing the feasibility of catchment-based nutrient trading within the UK legal framework. | To undertake pilot studies to test the feasibility of catchment-based nutrient trading to reduce nutrient inputs to water bodies. Investigate:<br>• Point-point trade<br>• Point-diffuse trade<br>• diffuse-diffuse trade | Parr *et al.,* 1999a | 120 | DETR |

| Ref Title of Project | Background and Overall Objectives | Source[2] | Estimated Cost (£k) | Potential collaborators |
|---|---|---|---|---|
| 6.4.2 Low risk agricultural practices: demonstration sites. | To demonstrate a range of best management practices (such as soil conservation practices, nutrient budgeting, targeted application methods and properly timed slurry spreading) on commercial landholdings within small catchments exhibiting high pollution risk.<br>To publicise results to the farming community. | Mainstone *et al.,* 1994 | 90 | MAFF/ NAWAD |
| 6.4.3 Regional slurry management centres. | To investigate the feasibility (technical, economic, socio-economic) of the operation of regional slurry management centres (including transportation costs) to assure a more even distribution of organic manures to agricultural land throughout the country (e.g. taxation of on-farm nutrient surpluses). | Parr *et al.,* 1999 | 60 | MAFF/ NAWAD |
| Sub-category 6.5: Control techniques | | | | |
| 6.5.1 Evaluation of the prospects of biomanipulation as a lake management tool | To undertake a detailed review to evaluate the prospects of biomanipulation as an effective management tool in lakes with special attention given to research on alternative steady states. | This report (see Section 4) | 50 | NERC, UKWIR, Statutory Conservation bodies. |
| 6.5.2 Review of effectiveness of public relations activities | To review the effectiveness of public relations material/campaigns (with particular emphasis overseas) to inform and educate a public that is mostly oblivious to the connection between their own activities and aspirations with the deterioration of waterways through eutrophication. | This report (see Section 4) | 40 | DETR, MAFF/ NAWAD, Soap and Detergent Industry Association. |
| Sub-category 6.6: Monitoring network | | | | |
| No projects identified | | | | |

**Table 3.3 Prioritised list of cost-weighted projects**

| Ref. No. | Title | Estimated Cost (£k) | Priority Score |
|---|---|---|---|
| 2.3 | P index scheme for P status of UK soils. | 30 | 63.5 |
| 4.5 | Livestock control in riparian areas. | 30 | 44.8 |
| 6.2.15 | Assessment of sampling and analysis procedures. | 20 | 42.5 |
| 4.1 | Agricultural nutrient balances. | 40 | 37.5 |
| 6.3.1 | Economic model of P recovery from wastes. | 50 | 35.6 |
| 4.3 | Acceptable soil P levels. | 40 | 32.5 |
| 6.2.8 | Saltmarsh response to increased nutrient levels. | 30 | 30.7 |
| 4.4 | Techniques to reduce farming non-point sources. | 60 | 30.5 |
| 6.2.3 | Pilot scheme for effects assessment. | 40 | 29.9 |
| 4.2 | Decision-support system for slurry spreading. | 80 | 29.7 |
| 6.4.3 | Regional slurry management centres. | 60 | 29.2 |
| 2.2 | Estuary classification and monitoring protocols. | 50 | 28.8 |
| 6.5.2 | Effectiveness of PR. | 40 | 28.6 |
| 1.2 | Ionic absorbents for removal of P. | 40 | 27.4 |
| 3.1 | Background concentrations in estuaries. | 50 | 26.8 |
| 6.1.4 | Risk assessment of P loads to aquifers. | 50 | 26.2 |
| 6.2.2 | Eutrophication in wetlands. | 50 | 25.4 |
| 6.4.1 | Catchment-based nutrient trading. | 100 | 22.8 |
| 6.3.2 | Assessment of AGNPS model. | 40 | 22.1 |
| 2.1 | N&P for high, good and moderate status. | 100 | 20.9 |
| 6.1.7 | Impact of non-sewered premises. | 60 | 20.7 |
| 5.7 | Strategy for wetlands eutrophication modelling. | 40 | 20.5 |
| 6.2.13 | Implications of climate change on eutrophication. | 50 | 20.0 |
| 6.1.8 | Standard approach for nutrient budgets. | 40 | 18.3 |
| 5.15 | Estuary sediment N mineralisation rates. | 40 | 18.0 |
| 5.3 | New ways to monitor estuarine trophic status. | 40 | 17.5 |
| 6.2.16 | Further understanding of denitrification. | 40 | 17.0 |
| 5.13 | Pathways of phosphorus inputs to rivers. | 100 | 16.7 |
| 6.4.2 | Low risk agricultural demos. | 90 | 16.3 |
| 6.2.7 | Extent of P limitation in coastal waters. | 70 | 15.6 |
| 6.2.12 | Trend analysis of EA data (linked with 5.3.5). | 60 | 15.5 |

| Ref. No. | Title | Estimated Cost (£k) | Priority Score |
|---|---|---|---|
| 5.14 | Relationship between SRP and TRP. | 70 | 15.1 |
| 6.5.1 | Biomanipulation for lake management. | 50 | 14.4 |
| 6.1.5 | Risk assessment tools (diffuse farm sources). | 100 | 14.3 |
| 6.2.14 | Development of sediment equilibrium P method. | 90 | 14.2 |
| 6.1.1 | Impact of septic tanks. | 90 | 13.8 |
| 5.9 | Models for estuaries and coastal waters. | 60 | 13.0 |
| 5.11 | Detailed review of lake eutrophication models. | 50 | 13.0 |
| 6.2.10 | Geomorphology and estuarine nutrients. | 70 | 12.9 |
| 6.2.4 | Nutrient limitation to aquatic macrophytes. | 100 | 12.5 |
| 6.1.2 | Sewer leakage contributions. | 120 | 12.0 |
| 6.2.5 | Review of EA nutrient data. | 60 | 11.6 |
| 6.2.9 | Review of the status of low-nutrient estuaries. | 60 | 11.5 |
| 5.8 | Estuarine diatom index feasibility study. | 80 | 10.1 |
| 5.12 | Compartmentalisation of phosphorus. | 150 | 9.6 |
| 5.4 | Development of a national nutrient export model. | 150 | 9.4 |
| 5.16 | Methods for P bioavailability. | 100 | 9.2 |
| 5.2 | Development of Trophic Diatom Index (TDI). | 150 | 9.2 |
| 6.1.3 | Significance of wet-weather events. | 160 | 8.9 |
| 5.1 | Catchment scale eutrophication risk tool. | 250 | 8.9 |
| 5.6 | Gravel pit enrichment for fishery management. | 80 | 8.3 |
| 5.10 | Nutrient role in DO barriers to fish migration. | 70 | 8.2 |
| 6.2.6 | Bog and fen plants and increased N and P availability. | 120 | 7.4 |
| 6.2.1 | Role of river sediments and plant biomass. | 150 | 7.0 |
| 6.2.17 | Biological quality and nutrients in estuaries. | 120 | 6.2 |
| 5.5 | Further development of algal bioassays. | 120 | 5.9 |
| 6.1.6 | Nutrient loads to estuaries from the sea. | 150 | 5.6 |
| 1.1 | P retention in buffer zones. | 300 | 4.8 |
| 6.2.18 | C:N and C:P ratios for estuarine trophic status. | 100 | 4.3 |
| 6.2.11 | Plant tissue and ambient nutrient concentrations. | 120 | 4.1 |

$$\text{Priority Score} = \frac{\text{Weighted Score}}{\text{Estimated Cost}}$$

**Table 3.4 Investigation of ionic absorbents for removal of free phosphate from lake water (project reference 1.2)**

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|---|
| **TITLE**:<br>Investigation of ionic absorbents for removal of free phosphate from lake water. |
| **PROPOSED PROJECT MANAGER**: |
| **OVERALL OBJECTIVE**:<br>To evaluate the potential efficacy of clays as scavengers of orthophosphate ions, with a view to their use in algal nuisance attenuation in natural waters. |
| **SPECIFIC OBJECTIVES**:<br>To review literature relating to the phosphate-binding capacity of hydrolysed clay minerals.<br>To carry out comparative laboratory experiments to determine relative uptake efficiencies of water-absorbing and lanthanum-rich clays.<br>To test performance at the pilot scale.<br>To make appropriate recommendations for the use of clay treatments in the attenuation of algal nuisance in eutrophic freshwaters. |
| **BUSINESS IMPACT STATEMENT**:<br>The project is directed towards novel and effective ways of removing phosphate from water otherwise available to support excess algal growth. Hydrolysed clay minerals have a well-known affinity for phosphate ions but, hitherto, clay treatments generate as many water quality problems as they solve. Water absorbing clays, with high lanthanum content appear to be advantageous in flocculating and sedimenting. There is a possibility that they can provide rapid and effective phosphorus inactivation in certain types of slow flushing water and provide a new, effective agent in attenuating eutrophication. |
| **THEME/FRAMEWORK**<br>The project will assist the Agency's perspectives on the attenuation of the symptoms of eutrophication and, possibly, lead to the development of effective preventative treatments. The project will fit within the Agency's Framework of "Delivering a Better Environment". |
| **OUTPUTS:**<br>Research report.<br>Development recommendations. |
| **COST**: £40k |
| **TIMESCALE**: One year |
| **EP PRIORITY SCALE:** 1 |

**Table 3.5 Nutrient levels in surface waters equating to high, good and moderate ecological status (project reference 2.1)**

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|---|
| **TITLE:**<br>Nutrient levels in surface waters equating to high, good and moderate ecological status. |
| **PROPOSED PROJECT MANAGER:** |
| **OVERALL OBJECTIVE:**<br>To define and quantify nutrient levels in rivers, lakes, estuaries and coastal waters equating to high, good and moderate ecological status as defined in the proposed Water Framework Directive. |
| **SPECIFIC OBJECTIVES:**<br>To review procedures and the operational applicability of methods for quantifying background levels of nutrients in all surface water types - this should build on work already undertaken during the EA's development of the lake classification scheme and the nutrient window of the river GQA scheme.<br>To propose levels of nutrients in all surface water types that will ensure the functioning of the ecosystem and the values of the biological quality elements equating to good ecological status will be achieved.<br>To propose levels of nutrients in all surface water types that will ensure that the values of the biological quality elements equating to moderate ecological status will be achieved.<br>To investigate habitat and physico-chemical factors controlling algal/macrophyte populations in the absence of nutrients and attempt to determine nutrient levels that present a significant risk of departure from this state.<br>To test the applicability of the proposed levels on a range of water body types as far as existing information allows, and propose how such levels may be further developed and validated. |
| **BUSINESS IMPACT STATEMENT:**<br>The proposed Water Framework Directive has an environmental objective of "preventing deterioration of ecological status and pollution of surface waters, with the aim of achieving good surface water status...." This objective will potentially have a significant effect on the need of the Agency to identify, quantify and control eutrophication in all surface waters. This research is seen as essential in preparing the Agency for the operational consequences of the Directive. |
| **THEME/FRAMEWORK:**<br>This Project will form part of the Agency's approach to measuring and controlling eutrophication, and relates to the viewpoint "health of environmental resources". Waters will require action to control eutrophication under the proposed EC Water Framework Directive. |
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| **OUTPUTS:**<br>Research Report.<br>Proposals for operational levels of nutrients that will equate to high, good and moderate status as required under the proposed Water Framework Directive. |
| **COST:** £100 K |
| **TIMESCALE:** One year |
| **PRIORITY SCALE:** 1 |

**Table 3.6 Evaluation of estuary classification procedures and monitoring protocols (project reference 2.2)**

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| **TITLE:**<br>Evaluation of estuary classification procedures and monitoring protocols. |
| **PROPOSED PROJECT MANAGER:** |
| **OVERALL OBJECTIVE:**<br>To evaluate estuary classification procedures and monitoring protocols for classification of nutrient impacts. |
| **SPECIFIC OBJECTIVES:**<br>This project builds on the work of Scott *et al*. (1999) which proposed classification and monitoring procedures for nutrients in estuaries. The objectives of the study would be:<br>To collate available information on the recommended physical characteristics of UK estuaries in order to select a sub-set of 20 to 30 estuaries on which to test the suggested classification procedure;<br>To review biological responses to nutrient enrichment in the selected sub-set of estuaries;<br>To test all aspects of the suggested monitoring protocol on the selected sub-set of estuaries;<br>To assess the performance of the estuary classification procedures and monitoring protocols and to make the case for wider application to all UK estuaries. |
| **BUSINESS IMPACT STATEMENT:**<br>This project will form the basis of a consistent approach to monitoring the effects of nutrient impacts in estuaries and begin to fill the gaps identified in the Environment Agency's Management Strategy for Aquatic eutrophication in England and Wales for the measurement of eutrophication in estuaries and coastal waters. A collaborative study with SNIFFER would extend the approach to all estuaries of the UK and facilitate reporting of environmental information to the EU. |
| **THEME/FRAMEWORK:**<br>This project will form part of the Agency's approach to measuring and controlling eutrophication, and relates to the viewpoint "health of environmental resources". Waters will require action to control eutrophication under the proposed EC Water Framework Directive. |
| **OUTPUTS:**<br>Research Report: Evaluation of estuary classification procedures and monitoring protocols for classification of nutrient impacts: a preliminary assessment. |
| **COST:** £50 K |
| **TIMESCALE:** One year |
| **EP PRIORITY SCALE:** 1 |

**Table 3.7 Evaluation of the current P index scheme to classify the phosphorus status of UK soils (project reference 2.3)**

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| **TITLE**:<br>Evaluation of the current P index scheme to classify the phosphorus status of UK soils |
| **PROPOSED PROJECT MANAGER**: |
| **OVERALL OBJECTIVE**:<br>To investigate the likely effects of further divisions of the soil P index scheme including the likely long-term water quality effects of changing fertiliser application rates based on knowledge of critical P levels and corresponding crop requirements. |
| **SPECIFIC OBJECTIVES**:<br>To review, using existing data sources, the relationship between soil available phosphorus levels and yield for different crops.<br>To review recent trends in classification of UK soils using the P-index.<br>To investigate the effect of further divisions of the P index (P index 3) on fertiliser application rates.<br>To extrapolate the potential changes in fertiliser application rates to long-term impacts on water quality.<br>To incorporate the findings into the MAFF Codes of Good Agricultural Practice. |
| **BUSINESS IMPACT STATEMENT**:<br>This project is ultimately directed towards reducing unnecessary over-fertilisation of soils through increasing the sensitivity of the P index scheme, which drives recommended fertiliser application rates. Close collaboration would be required with MAFF to ensure that the study findings would be incorporated within the Codes of Good Agricultural Practice. |
| **THEME/FRAMEWORK**<br>The project will assist the Agency's perspectives on reducing phosphorus loads within catchments through the application of source measures that are beneficial both to the farmer and to the environment. The project will fit within the Agency's Framework of "Delivering a Better Environment". |
| **OUTPUTS:**<br>Research report including recommendations on fertiliser application rates for inclusion in MAFF guidelines. |
| **COST**: £30k |
| **TIMESCALE**: Eight months |
| **EP PRIORITY SCALE:** 1 |

**Table 3.8 Decision support system for slurry spreading (project reference 4.2)**

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| **TITLE:** Decision support system for slurry spreading |
| **PROPOSED PROJECT MANAGER:** |
| **OVERALL OBJECTIVE:**<br>To undertake a study to produce decision-support systems for the effective spreading of slurries and manures |
| **SPECIFIC OBJECTIVES:**<br>MAFF funded R&D has produced scientific information to underpin advice on the best practice for the spreading of slurries and manures which is currently available to farmers in the Codes of Good Agricultural Practice and a number of MAFF publications (i.e. Managing Livestock Manures booklets). MAFF funded R&D has also produced a computer-based decision support system called MANNER (MANure Nitrogen Evaluation Routine) which calculates the nitrogen replacement value of manures to be spread on a field basis.<br>A computer-based decision-support system that combines the nutrient replacement advice for both nitrogen (as contained in MANNER) and phosphorus with specific recommendations on where, when and how best to spread available manures on a field basis (taking into consideration topography, soil type, proximity to a watercourse, rainfall, timing of application, rate and method of application) should reduce the risk of nutrient loss to controlled waters to the benefit of the farmer and the environment.<br>Field testing and training in the use of the system by farmers and/or their advisors should be an essential part of the project to ensure that the chance of farmers taking the advice on board is maximised. |
| **BUSINESS IMPACT STATEMENT:**<br>Slurries and manures are applied to 16% of tilled land and 48% of grassland in England and Wales each year. Inappropriate application can result in considerable losses of nitrogen and phosphorus to controlled waters. The development of a decision-support system to provide advice to farmers and/or their advisors on a field-by-field basis could help to significantly reduce large losses of nutrients to controlled waters from inappropriate application. |
| **THEME/FRAMEWORK:**<br>By controlling application of nutrients to land at source the decision support system will add to the suite of ECAP tools being assembled by the Agency and would fall within the Agency's framework for "delivering a better environment". |
| **OUTPUTS:**<br>Decision Support systems, user guide and training for users |
| **COST:** £80 K |
| **TIMESCALE:** Three years |
| **PRIORITY SCALE:** 1 |

**Table 3.9 Agricultural best management techniques to reduce non-point sources of nutrients (project reference 4.4)**

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| **TITLE:**<br>Agricultural best management techniques to reduce non-point sources of nutrients |
| **PROPOSED PROJECT MANAGER:** |
| **OVERALL OBJECTIVE:**<br>To investigate the applicability and cost-effectiveness of agricultural best management techniques for reducing non-point source nutrient loads |
| **SPECIFIC OBJECTIVES:**<br>There are a number of agricultural techniques and specialised machinery that can be used to reduce nutrient loss from agricultural land. These include contour ploughing, contour strip cropping, machinery to target inorganic fertiliser and manure at the crop roots and specialised machinery to avoid compaction of sensitive soils.<br>MAFF funded R&D has contributed significantly to the identification of control strategies to reduce nutrient loss from agricultural land which include both management techniques and specialised machinery. The extent to which these techniques have been tested for use in specific situations for both nitrogen and phosphorus and cost-effectiveness analysis for most techniques or items of machinery would be addressed in this project. |
| **BUSINESS IMPACT STATEMENT:**<br>Inappropriate agricultural techniques can enhance the transfer of nutrients from agricultural land to controlled waters. Changing agricultural practices can be very difficult especially when it involves additional short term costs to the farmer without clearly identified benefits in terms of farm income.<br>The identification of the most cost-effective techniques coupled with effective demonstration and communication to the farmer should encourage the use of these techniques and reduce the loss of nutrients from agricultural land to the benefit of the farmer and the environment. |
| **THEME/FRAMEWORK:**<br>As a diffuse source control measure the results of this project will contribute to the ECAP tools being assembled by the Agency and would fall within the Agency's framework for "delivering a better environment". |
| **OUTPUTS:**<br>Project Report |
| **COST:** £60 K |
| **TIMESCALE:** Three years |
| **PRIORITY SCALE:** 1 |

**Table 3.10 Development of a nutrient risk assessment tool for diffuse agricultural sources (project reference 6.1.5)**

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| **TITLE:**<br>Development of a nutrient risk assessment tool for diffuse agricultural sources. |
| **PROPOSED PROJECT MANAGER:** |
| **OVERALL OBJECTIVE:**<br>To develop a nutrient risk assessment tool for diffuse agricultural sources operating on two different geographical scales. |
| **SPECIFIC OBJECTIVES:**<br>To develop a tool that would allow a comprehensive picture of risk to be produced, first targeting high risk catchments at a national or regional scale and subsequently identifying high risk areas (critical source areas) within those catchments at a local or farm scale.<br>The national/regional scale tool would consist of a simple database of information relevant to pollution risk, linked and overlain by GIS. The system would most probably comprise modules on land vulnerability (which considers the characteristics of the land that determine the likelihood of contaminant transport to receiving waters), existing land use (which considers the use to which the land is currently put), existing contaminant inputs (which considers the loading potential of nutrients to the land) and receiving water quality (which considers the vulnerability of the receiving water in terms of its quality objectives).<br>The local/farm scale tool could be either: (1) steady state and GIS-based (providing a relative risk assessment of land cells) as in the national/regional scale tool (and would consist of the same modules) but would operate on higher resolution data, or (2) a dynamic tool consisting of a family of existing models of varying complexity that quantify contaminant loads to receiving waters, linked by a front-end user interface. |
| **BUSINESS IMPACT STATEMENT:**<br>The Agency has identified the need to evaluate the extent and risks of eutrophication and to undertake a wider assessment of risk to provide an early warning system for future problems which is essential where the principal aim is to protect waters rather than try to rehabilitate them.<br>Outputs from the national/regional tool would be of significant value to the Agency in strategic terms (i.e. where to target efforts for improvement) and political terms (i.e. in dealing with other organisations such as MAFF and DETR). The objective at this scale is to produce a system for use by Agency Head Office and Regional Headquarters staff providing outputs for strategy support.<br>At the local level the business objective is to produce a tool to be used by catchment planning staff, with map outputs available to pollution control staff in the field. Outputs could be used for both strategic liaison between the Agency and MAFF and local discussions with either local ADAS staff or farmers. |
| **THEME/FRAMEWORK:**<br>The software tool developed would be a key ECAP tool and would fall within the Agency's "Risks and Values" framework for identifying management options. |
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| **OUTPUTS:**<br>Risk assessment tool and associated research report. |
| **COST:** £200 K |
| **TIMESCALE:** two years |
| **PRIORITY SCALE:** 1 |

**Table 3.11 Pilot testing of a scheme for assessing apparent eutrophication effects (project reference 6.2.3)**

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| **TITLE:**<br>Pilot testing of a scheme for assessing apparent eutrophication effects. |
| **PROPOSED PROJECT MANAGER:** |
| **OVERALL OBJECTIVE:**<br>To pilot test a scheme developed for assessing apparent eutrophication effects in rivers in selected catchments and to render the scheme fit for operational use. |
| **SPECIFIC OBJECTIVES:**<br>To review and finalise for operational use, the questionnaire designed to distinguish whether the root causes of eutrophication are dominated by point sources, diffuse sources or by other causes (such as physical effects) in the case of "apparent eutrophication".<br>To pilot test the questionnaire on a range of river types with a range of underlying geology.<br>Pending the pilot testing, to amend the questionnaire as deemed appropriate for operational use and write user manual.<br>To implement the use of the questionnaire within the Agency. |
| **BUSINESS IMPACT STATEMENT:**<br>Once fully implemented into the Agency's operational programme, use of this questionnaire would provide a diagnostic screening tool for cost-effective targeting of source control measures. Use of the screening tool would reduce the likelihood of unnecessarily stringent limits being imposed on point source discharges. |
| **THEME/FRAMEWORK:**<br>This tool will provide a useful addition to the ECAP tools being assembled by the Agency and will contribute to the Agency's approach to identifying the causes and effects of eutrophication. It will, subsequently, influence the source control measures adopted. This project fits within the Agency's "stresses and strains" framework. |
| **OUTPUTS:**<br>Diagnostic screening tool with user manual. |
| **COST:** £40 K |
| **TIMESCALE:** One year |
| **EP PRIORITY SCALE:** 1 |

**Table 3.12 Economic model for P recovery from wastes (project reference 6.3.1)**

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| **TITLE:** Economic model for P recovery from wastes. |
| **PROPOSED PROJECT MANAGER:** |
| **OVERALL OBJECTIVE:**<br>To develop an economic model of costs and paybacks from phosphorus recovery from sewage and animal wastes. |
| **SPECIFIC OBJECTIVES:**<br>Recovery of phosphorus for recycling, rather than its transfer into sewage sludge, offers potential economic and environmental paybacks for the water industry. The economic model developed would provide a mechanism for comparing these benefits with the investment and running costs of P recovery installations.<br>The development of the economic model will build on the findings of a workshop held by CEEP in 1998 which endeavoured to identify the different factors that would influence the economic feasibility of P recovery from municipal waste water (such as sludge disposal and chemical costs compared with costs of P recovery and the value of recycled phosphorus to industry).<br>Whilst it is accepted that P recovery is inevitably more economically viable at the largest works it remains to be seen how small a works can be before the approach becomes impractical.<br>As far as animal wastes are concerned, it is preferable to optimise the use of manure as a fertiliser before looking at other options; however, the model should be able to take account of costs of transporting manure to neighbouring regions. |
| **BUSINESS IMPACT STATEMENT:**<br>In addressing the merits of P recovery from wastes, the model could lead to a reduction in the accumulation of phosphorus in sludge for disposal. For land disposal, reduced P levels would ultimately benefit surface waters and groundwater (especially in catchments with sandy soils).<br>Where sludge is incinerated, the phosphorus compounds that would otherwise accumulate in sludge as a result of biological/chemical removal (not recovery) would result in increased ash volumes needed to be disposed of to landfill sites. Thus recovery would be beneficial to the Agency's business needs regarding waste disposal. |
| **THEME/FRAMEWORK:**<br>This Project relates to the Agency's fourth framework "Delivering a Better Environment" and to the Theme of "Regulating Major Industries" through demonstration of BPEO. |
| **OUTPUTS:** An economic model and research report. |
| **COST:** £50 K |
| **TIMESCALE:** Three years |
| **PRIORITY SCALE:** 1 |

# 4. OVERSEAS EUTROPHICATION-RELATED R&D AND ITS RELEVANCE TO THE ENVIRONMENT AGENCY

## 4.1 Introduction

Eutrophication is a worldwide phenomenon and, almost everywhere, creates water quality problems of varying magnitude which often require management. In consequence, many countries have carried out specific management actions to deal with particular local problems, while in a number of countries, research has been carried out at a more strategic level in order to devise policies or advance technology to address eutrophication as a generic issue. In this section, we consider some of these broad R&D strategies and their underpinning drivers. It is not the intention to review any nation's projects in detail, neither is it especially helpful to review the programmes on a nation-by-nation basis. We seek to identify the direction of the work in the several countries where scientific studies into the understanding and the management science of eutrophication are relatively advanced, where we consider this to be of relevance to the business needs of the Environment Agency. Potential areas of research precipitating from this review worthy of further consideration by the Agency through contact and/or collaboration with overseas researchers and research organisations are discussed in Section 5. Projects identified through this process have been added to Table 3.1 and included within the ERDPS process.

By far the most commonly researched water body type is lakes and reservoirs (Section 4.2) and within this category the information is arranged thematically, following, as far as possible, the broad focus areas adopted elsewhere within this report. Owing to differences in the historical perception of the problems, or in the opportunities for corrective treatment, or simply in the economics of their application, the model is necessarily modified. Thus for lakes and reservoirs, the following topics are addressed:

**4.2.1** Historical attitudes and philosophies;

**4.2.2** Nuisance attenuation;

**4.2.3** Chemical objectives;

**4.2.4** Ecological targets;

**4.2.5** Ecological indicators;

**4.2.6** Management and information policy.

Rivers have received less attention than lakes and reservoirs but current research is summarised in Section 4.3. Relevant work on estuaries and coastal waters is referred to in Section 5 but has not been reviewed separately.

## 4.2 Lakes and reservoirs

### 4.2.1 Historical attitudes and philosophies

Although the recognition of the connection between aquatic productivity and the supply of resources from terrestrial catchments is almost as old as the science of limnology (see Reynolds, 1999), the problem of man-made eutrophication has intensified in a remarkably short and recent period of time. This is not entirely due to the novelty of understanding, for the nineteenth-century incidence of algal blooms in the Adriatic Sea were quite clearly linked to poor dissipation of anthropogenic discharges (Chiaudani *et al*., 1980). However, it is not doubted that the causes of eutrophication are predominantly also of very recent origin. As is also well appreciated, from the inception of the OECD reports (Vollenweider, 1968), to the concluding analyses (Vollenweider and Kerekes, 1982), the role of phosphorus enrichment was determined to be fundamental. Crucially, the apportionment and culpabilities of the additional phosphorus, to sewage, to agricultural practices and to the explosive increase in phosphate-based detergents, were not resolved. Moreover, hindsight allows us to recognise that the relative simplicity of the Vollenweider relationship was exaggerated by the overrepresentation of deep, temperate, oligo-mesotrophic systems. Considerable research effort has been expended in the pursuit of explanations for "departures" from the Vollenweider model, which include the role of the food web (extensively probed in North America), the role of water depth in influencing ecosystem function (notably in Netherlands and Denmark) and the fates and bioavailabilities of phosphorus (some interesting applications in Australia). Even where lakes have been affected as much as the base model provides, the attempts to control and reverse the eutrophication process have not always been rewarded by rapid improvement or, in many cases, by any improvement at all. These perplexing results were recognised first in Switzerland, where poor environmental returns for large investments of expenditure had to be explained to the sponsors of the public purse. Together with many similar subsequent experiences in Europe, they illustrate the shortcomings of management philosophies erected on the naïve assumptions that the primary productive base of a lake is precisely predictable from the external total phosphorus load it receives and that any reduction in the external load must necessarily reduce the biomass of algae that may be supported.

Before passing to specific national experiences, however, it is useful to draw attention to the two international collaborations which were set up to elucidate the linkages between distal source and primary response and the findings of which provide a modern contextual framework for understanding the issues in eutrophication. Both have resulted in source books that provide useful background to all interested in managing algal populations.

One of these is the report of the study entitled "Eutrophication Management in international Perspective", led by the Dutch Instituut voor Milieu- en Systeem- Analyse (Sas, 1989). The essential breakthrough in the Sas study came through the analysis of the resilience (the book referred to "reluctance") of eutrophic conditions to restorative reductions in the external phosphorus load. By separating nutrient availability within a lake (subsystem 1) from its biotic exploitation (subsystem 2), the study revealed that the delayed response owed to the margin of excess phosphorus in the water and to the labile "memory" in the lake sediment, which could provide a significant supplementary nutrient supply. The Vollenweider model does not, of course, accommodate such effects. With subsystem 2, the response is always direct and effectively immediate. In this way, the key step in understanding of eutrophication hinges on the variable role and behaviour of sediments in freshwater systems, particularly in shallow lakes. Since then, physical and chemical mechanisms have figured prominently in eutrophication studies, especially in Denmark and the Netherlands (see later).

The second study, sponsored by the Scientific Committee on Problems of the Environment (SCOPE), sought to improve the understanding of the transfer of phosphorus from terrestrial to aquatic ecosystems (Tiessen, 1995). The resultant book reflects the renewed interest in the pathways by which loads move from catchment to receiving water and the forms which may be readily bioavailable. It is very clear that the total phosphorus (TP) load may well contain large fractions of oxide- or hydroxide bound phosphorus which is effectively unavailable to algae or other autotrophs, whereas the molybdate-reactive soluble (MRP) fractions, so much enhanced by secondary sewage treatment methods, are most readily assimilated. In one of the most interesting contributions to the volume, Caraco (1995) presents an analysis of the area-specific transport of phosphorus in eighteen major river systems. The highest area-specific P-transport rates emanate from urbanised catchments in Western Europe (Po, Tiber, Thames), which yield some 0.7 kg per resident person per year. Populous agricultural catchments (Hwang, Yangtse, Ganges) but lacking much in the way of sewage treatment, generate less than 0.1 kg soluble P per individual per year. Intensively agricultural catchments, like the Mississippi, Volga and Danube also generate large fluxes of total phosphorus to water but the major fraction turns out not to be bioavailable. Thus, international evidence confirms that secondary treatment of urban sewage and disposal of effluents to freshwater as soluble MRP is the primary agent in eutrophication and its containment remains a major objective in cutting nutrient loads to waterbodies.

The relative apportionment of phosphorus deriving from agriculture and sewage sources continues to generate problems over culpability and liability for correction. In Europe, at least, the issues are seen increasingly as a collective, societal problem. Simply, an expanding human population, aspiring to ever higher lifestyles and making more exploitative demands on the planet's resources, leads directly to accelerated biospheric degradation and faster entropic dissipation of its assets. To increase agricultural yields demands greater mobility of plant nutrients. So far as phosphorus is concerned, its tendency to be immobilised by chemical oxide- and hydroxide-binding in soil is overcome primarily by augmenting the flux of bioavailable forms, through the application of appropriate fertiliser. Whether the mobile excess is lost as direct run-off from the land or through the waste products of the consumers of the biomass (that its application was designed to promote) is philosophically irrelevant. Eutrophication is the predictable consequence of the non-sustainable practice of importing (mainly Moroccan) phosphate in excess quantities.

Supposing this arrangement is not about to be easily reversed or at all, the management of eutrophication hinges upon a generic understanding of the key singularities along the geochemical paths that the overview summarises. Recognition of the ways in which these decisive nodes impinge upon the undesired biological activity of phosphorus is still a priority. The outstanding questions are still about whether and how much phosphorus is in biologically reactive fractions, whether it moves primarily in solution or attached to particles, how subject it is to redox changes, and so on. This important dimension is being developed in several overseas countries, most particularly in Finland (see Køllqvist and Berge, 1990; Ekholm 1994; Pietilüinen, 1997) and Australia (especially the work of Baldwin, e.g. 1996). Again, the strong indication is that the molybdate-reactive fractions in secondary sewage effluents always promote biological production, but the validity of past assumptions of the immobility of soil-bound phosphorus is seriously in doubt in both countries (Cullen, 1994; Sharpley and

Rekolainen, 1997). The work is of international importance and will command the Agency's attention. In particular, it points consistently to a conclusion that total phosphorus is a poor predictor of bioavailability, except at very low TP concentrations (when bioavailability has to be also very low) or at very high concentrations (only at >150 mg P/$m^3$ is most of the TP likely to be available, when it will have been delivered in solution anyway, as for example, in secondarily-treated sewage effluent). Methods of assessment of bioavailability, compounding the molybdate-reactive fractions and the portion of the particulate fraction that is in living cells but discounting the unavailable fraction, inactivated on stable oxides, are actively sought.

### 4.2.2 Nuisance attenuation

Schemes aimed at reducing the loads of phosphorus to particular aquatic systems continue to command popular support. It is widely understood that, if the symptoms of eutrophication are diagnosed soon enough and if the management response is correct, lake restoration has a reasonable success rate. However, it is less widely accepted that the corrective methods may not always be successful, or what the threshold conditions might be before the methods can expect to achieve some success. These lessons have been learned in Denmark and the Netherlands, but it is in Switzerland that the ability to attenuate the symptoms of effectively irreversible eutrophication is perhaps best developed. Switzerland was one of the first countries to diagnose the symptoms of eutrophication and one of the first to institute measures for lake restoration (Thomas, 1953). There was an early recognition that lakes were differentially susceptible to eutrophication, related in part to the settlement and human activities in their catchments and, in part, to their morphometries. Thus, the smaller lakes of the Swiss midlands (like Baldeggersee and Hallwilersee) showed symptoms of change before the larger, deeper water bodies like Bodensee, Zürichsee and Vierwaldstättersee. Precautions for protecting the lakes from further deterioration began to be adopted into national legislation, including regulations restricting the amounts of fertiliser added to soils and to the periods of application. Other schemes were aimed at the interception of wastewaters and, at least locally, precipitating phosphate as part of the disinfection treatment.

Deliberate attempts to restore quality in the larger lakes began in the 1970s. Over a period of years, the Zürichsee has shown a slow but steady decrease in total phosphorus concentration (from ~ 90 mg P/$m^3$ in 1974 to ~ 50 mg P/$m^3$ in 1990); using OECD guidelines, the lake should still be classified as being eutrophic, but its exposure and depth mitigate the worst symptoms. Interestingly, the perennial dominance of the phytoplankton by the Cyanobacterium, *Planktothrix rubescens*, truncated in the 1960s during intensifying eutrophication, has also been re-instated as a consequence of the restoration. This provides an important counter to the view that curing eutrophication is synonymous with eliminating Cyanobacteria. In this instance, the experience is diametrically opposite.

The delayed response of large lakes to therapy clearly involves a factor relating to hydraulic retention time. However, resilience of fertility has been more prolonged in some of the smaller lakes, owing most to accumulated richness. Sewage from settlements and food industries, together with agricultural sources of nutrients, contributed to the documented eutrophication of Baldegersee, which saw total phosphorus concentrations increase from 80 to 500 mg P/$m^3$ in the twenty years after 1955. The Cantonal Government of Luzern instituted action in 1980 to reduce the external input of phosphorus to the lake. This has been successful in reducing the loads but the enormous slack in subsystem-1 has yet to be overcome. The symptoms of advanced eutrophy have necessarily been countered by other techniques. The hypolimnion is now artificially aerated, overcoming the problems of sulphide-, ammonia- and methane- generation, whilst expanding the habitable range of commercial Whitefish (Stadelmann, Bürgi and Butscher, 1997). With total phosphorus concentrations stubbornly in excess of 80 mg P/m$^3$, the lake would still be classified as highly eutrophic but it is now in a manageable, productive state. This also represents a successful instance of nuisance abatement, which has been applied to several other of the smaller Swiss lakes. In another set of terms, already subject to jargon, the system has regained "health" (Constanza and Mageau, 1999). While the demand for artificial re-aeration persists, however, any claim of sustainability cannot be justified.

As was recognised explicitly in the Sas (1989) report, resilience is not exclusively attributable to the delayed response of subsystem 1 to adjust to a reduction in external phosphorus load for it is a generic feature of shallow lakes. In this context, "shallow" was defined as having greater than half the area less than 5 m deep. This number was arbitrarily nominated on the pragmatic judgement of Sas's panel of contributors. The decisive criteria are the extent to which the sediment surface is subjected to turbulent shear and the directness of the role played by sediments in the ecological functioning of the water column. Whereas the rigid compartmentalisation of sub-habitats and their dominant processes has been justifiable in deep systems, processes in shallow sediments impinge on the quality of the water with which they have direct contact.

Recent work, mostly in Denmark and the Netherlands, has served to emphasise that the metabolic character of shallow or exposed lakes is inseparable from the metabolism of their bottom deposits. In particular, the role of the shallow sediments in recycling phosphorus to and from the water column makes for a quite different appreciation of the mechanisms of its bioavailability. Indeed, the chemical reactions involving the blanket phenomenon of "release" have proved difficult to fathom and they are probably far from a complete explanation. The weight of evidence tends towards a view that, as elsewhere, it is the chemical binding behaviour of phosphate that is crucial. This appreciation has several facets and these can be highlighted sequentially.

First, consider that externally loaded phosphorus includes fractions which are particulate (eroded soil particles, refractory organic material) as well as in solution. Dissolved phosphorus is consumed, more or less rapidly, by biotic components and, to an extent, carried through the food web. It is lost from the open-water phase as biomass, via outwash, or through successive digesta and corpse material, to the bottom deposits. Detrital and microbial metabolism of the carbon generates some free phosphate again, which will fuel new anabolism or become immobilised through its great affinity for the binding sites on clay minerals, aluminium and iron oxides present in most superficial sediments. Thus, there is an overriding probability for the external phosphorus load to end up in non-bioavailable fractions. Moreover, the persistence of the shallow-water entrainment and non-selective redeposition cycles drives a process of "sediment focusing" (Likens and Davis, 1975) which results in the net transport of particulates to the profundal and eventual burial. So long as the organic carbon content is matched by the supply of oxidant, none of this material ever need be remobilised, at least, not within the lifetime of the lake. This mechanism is essential to the provisions of the Vollenweider model, which assumes all biological productivity to be load-driven and makes no allowance for any significant re-use of phosphorus.

The second step is, very clearly, that this net export cannot occur in a shallow lake: the particulates remain part of the current account. Moreover, particulate material remains liable to resuspension until it is finally buried by later accumulation. This is not an issue by itself, for the phosphate-binding capacity of sedimentary materials is conservative: total phosphorus is distributed among fractions precisely analogous to those found in soils and other aquatic sediments (molybdate-reactive, chloride-, alkali- and strong acid-extractable phosphorus and residual phosphorus); neither are the conditions of orthophosphate "release" from these fractions in any way different from those governing mobility elsewhere (de Groot and Golterman, 1993). However, what has also become clear is that the effect of continuous heavy external loading with phosphorus sooner or later brings a shallow-lake sediment to a point where its binding capacity is exhausted. Phosphorus remains in solution, especially in the interstitial water, whence it may persistently recharge the water column, by diffusion and, especially, by mechanical release through the intervention of turbulent resuspension or bioturbation. In either case, the accumulated reserve and the inflated quantity of unbound phosphate ceases to impose any limitation on new biomass production.

The best-studied and best-attested example of a lake reaching this condition is the shallow Danish lake, Söbygaard (Söndergaard *et al.*, 1993). The lake had a long history of intense algal growth. A significant reduction in external nutrient loading was implemented in 1982, from the region of 30 to < 5 g P $m^{-2}$ $y^{-1}$ but, to date, with very little effect on the algal production that is supported. This has demonstrably been sustained by an internal flux of phosphorus from the sediment of between 5 and 10 g P $m^{-2}$ $y^{-1}$. Moreover, because it is recycling, it is not obvious that the sediment should be shedding its accumulated phosphorus store but there is a slow water-born flux from the lake. It has been estimated that net release of phosphorus will sustain a further ten years of high algal crops before any capacity limitation on their production is imposed.

The third step is that it is very probable that many other small, shallow waters have reached a comparable state of the biological independence from constraints by phosphorus (Jeppesen *et al*., 1991; Scheffer, 1998). Thirty years of ingrained false reasoning about just what is meant by "phosphorus limitation" makes it difficult to accept the idea that, in such lakes, phosphorus availability has about the same ecological relevance as (say) sodium or sulphate - it is always present in saturating amounts.

This depressing conclusion is anticipated in Reynolds' (1992) decision tree for managing the symptoms of eutrophication and in the selection process instituted by Hosper and Meijer (1993) for lakes in the Netherlands. In a recent American analysis of the methods available for attenuating the impacts of eutrophication, Carpenter *et al*. (1999) have observed that eutrophied sites may be subdivided among those which are capable of reversible restoration (through correction to the phosphorus loading), those which are capable of hysteretic restoration (recovery demands extreme P reduction, including through internal control) and those which are beyond restoration by phosphorus reduction alone.

**Biomanipulation**

The question about what else can be done to overcome excessive biological production in sites that are practically beyond effective nutrient-load reduction is generally answered with the notion of altering architecture of the community so that energy and matter flow and accumulate in different parts of the food web. As a practical approach to the management of water quality, such biomanipulation is well established, though the underpinning theory and the measures required to improve the prospects of its successful application are still contested.

The principle of biomanipulation is very simple: it is to manage the aquatic system so that the sink for excess nutrient is one which is aesthetically more acceptable. Biology, generally, will not allow nutrient-depleted biomass to co-exist with available chemical resources; not even exclusion of light will prevent ecosystems from functioning, provided there is an alternative source of organic carbon. With adequate light, however, primary production will lead, either to abundant vegetal biomass, or to enhanced biomass at higher trophic levels. There is no obvious, *a priori* reason to suppose that the apportionment of the additional biomass capacities should not simply accommodate the same complex but incompletely-understood rules of community self-assembly and structural organisation of the biomass that apply in unenriched systems. Indeed, some eutrophic systems do fulfil these criteria and attain the characteristics of balanced, diverse and ecologically healthy systems, according to the criteria of Costanza and Mageau (1999). In most cases of anthropogenic eutrophication, the change is both very recent and often ongoing. Thus, the differing temporal scales at which the producer and consumer organisms react and regenerate are poorly matched. The result is one of considerable instability, in which the bottom-up production is frequently retained in the producer level while top-down consumption is inadequate to deal with it. This effect compounds the important "cascading effects" (Carpenter *et al*., 1986; but see Carpenter and Kitchell, 1993) which greatly influence the between-trophic level allocation of biomass. Compared to a phytoplankton-only system (resources move to primary biomass), a second level (herbivorous zooplankton) transfers biomass upwards. The introduction of plantivororous fish repeats the upward resource movement but weakens the removal of the primary producer mass.

Piscivorous fish represent a secondary carnivore level whose activities cascade back to zooplankton (now more prominent again) and to phytoplankton (now lower again). Several aquatic ecologists have picked up on an idea of great pedigree (we trace it back to N.G.Hairston) that food chains with an odd number of levels are green; those with an even number are barren.

The effect is easily shown experimentally. Many biomanipulation projects were initiated citing the famous results of Hrbcek *et al.* (1961), who demonstrated these relationships in highly managed carp ponds in central Europe. Yet experiences have been extremely varied and opposing opinions about the viability of the approach as a technique for abating eutrophication have been, at times, acrimonious. There have been many very successful biomanipulations, predominantly in small or shallow water bodies and ones in which the manipulation involved considerable reduction in previously-overstocked populations of carp (compare the reviews of De Melo *et al*., 1992, and of Carpenter and Kitchell, 1992).

Daphniid-dominated zooplankton in strictly pelagic systems can and does result in massive destruction of phytoplankton, but, even if protected from fish predation, the zooplankton collapses through starvation and the phytoplankton returns. No stable state is established, just a lurching, tracking of blooms by over-indulgent feeders (Reynolds, 1994). Biomanipulation can only ever be an adjunct to phosphorus reduction in large lakes.

To impart the desired element of stability to biomanipulation, it was gradually learned that the essential ingredient is a healthy and substantial macrophytic vegetation, especially of rooted, submerged higher plants. Such stands are usually a first victim of sustained and heavy eutrophication, yet elsewhere, they survive serenely in what is usually limpid water. Many factors have been supposed to account for this behaviour, although, in truth, they probably all have a contributory role. An early runner was that the macrophytes offer tangible, physical refugia for zooplankton against predation and many British experiments attest to this effect. Moreover, without phytoplankton, filter-feeding zooplankton must be kept alive on fine detritus and bacterial biomass, and it was supposed that macrophytes somehow generated this alternative resource of filterable organic carbon. Another possibility is that the macrophyte is in some way a better competitor (it is certainly a better repository) for free nutrients, but excess allows faster growing phytoplankton to become better competitors for light.

Currently, the collective appreciation in Europe is a strongly macroecological view of the systems in which macrophytes participate. Macrophytes are the largest and longest-lived primary producers. Where they are present in strength, macrophytes will fix most of the carbon and consume the most nutrient in the assembly of biomass, though these are as likely to be drawn through the rooting system as from the water itself. Much of the carbon that is fixed is retained in biomass, including storage organs (rhizomes, turions, etc.), which also comprise a significant store of phosphorus and nitrogen. Winter die-back provides a source of litter and debris, which is consumed mostly by invertebrate shredders and eventually, rendered to fine organic and bacterised detritus. Moreover, plant surfaces may be freely colonised by epiphytic algae, which constitute a food resource to snails and other insects, leading to the generation of yet more detrital carbon in due course. Importantly, the macrophyte cycle is very protracted relative to the generation times of plankton and even of fish: macrophyte activity occurs on a scale that damps the fluctuation of the resources supplied to open water. Provided a strong base of filter feeders can be maintained on this resource and so long as the plant growth is strong enough to provide significant refuge against fish predation, macrophyte stands impart their own relative stability to the system.

At the same time, macrophyte stands counteract wave and shear stresses: thus, the conditions for sedimentation are enhanced, resuspension is minimised and the opportunities for nutrient recycling through the water are greatly reduced.

By degrees, it becomes clear that the way that the macrophyte-rich pond processes carbon and allocates its nutrients is very different from the cycling in ponds perennially dominated by Oscillatoria- or Scenedesmus, free of macrophytes and few species of animal save chironomid larvae and carp. Both conditions achieve stability (Scheffer, 1989), both are perfectly viable and self-sustaining (Scheffer, 1990), at least until one changes from one state to the other (Blindow *et al*., 1993; Scheffer *et al*., 1993). From the aesthetic point of view, one is infinitely preferable to the other.

Currently, there is a great research interest in the existence of these alternative steady states, in their amenability to flip from one to the other and in what the triggers for this mutual substitution might be. Helpful publications in this context include those by Blindow *et al.* (1998), Faafeng and Mjeld (1998) and by Scheffer and Jeppesen (1998). The emerging consensus is that the ability of the macrophytes to absorb and store in biomass (rhizomes, turions, etc) large amounts of condensed phosphate effectively denies its availability to phytoplankton, whilst simultaneously providing succour and refuge to cladoceran plankton grazers (Söndergaard and Moss, 1998). The advantage is eventually lost to phytoplankton at very high levels of phosphate (~ 150 mg P/ $m^3$), which is beyond the exclusivity of the sequestering power of the macrophytes. Specialised feeding on macrophytes by water birds may also be a trigger to state change: migrating Bewick swans are reputed to affect year-to-year success in Potamogeton stands, owing to a particular partiality to the turions. Overstocking with planktivorous species of fish is a notorious cause as state-change for it greatly weakens the ability of zooplankton to bring about control of algae by grazing. The alternative output of fine, organically-rich detritus is beneficial to nothing other than microaerophilous benthic burrowers (among which, larval chironomines are particularly well-adapted); these serve as a resource to tactile foragers (especially cyprinids), whose activities cause considerable bioturbation and maintain an efficient return of recycling nutrients. To break this stable state requires physical intervention into the cycle, for instance, by flushing the algae, with or without a severe reduction in the number of fish (Hosper *et al*., 1992). Current work in Germany (as yet unpublished) points to a planktivore biomass equivalent to about 2 g fresh weight per $m^3$ as being critical to the ability of zooplankton to be able to graze down the phytoplankton.

Work is progressing in this area. SWALE, standing for Shallow Wetland Lake Experiment, is an international project, with partners drawn from Spain, Finland, Netherlands and UK, which aims to use enclosures to investigate the experimental criteria for transition between alternative steady states. *As an approach to understanding ecosystem function in small, shallow and irreversibly eutrophied lakes, this particular line of European research is generating management applications that will be of central interest to the Agency.*

### 4.2.3 Chemical objectives

Interest in protecting aquatic ecosystems, including rivers, estuaries and coastal waters, from eutrophication remains high. Mostly, this is manifest in directives, guidelines and mandatory limits on the amount of phosphorus (mainly) and other nutrients discharged to watercourses from point sources. The motivation for pursuing chemical targets is not questioned but they are not always devised on a sound scientific basis. The example with which Agency staff is already well familiar is the Urban Waste Water Treatment Directive. This was defined for the EU and adopted by member states. Guidelines must be quantitatively clear but the setting of critical limits ("…agglomerations of greater than 10,000 population equivalents…"; "…concentrations of greater than 1 mg P per litre…") is usually quite arbitrary. Many implicit assumptions are made which, if not verified in each particular application, can determine the effectiveness or otherwise of the restriction. An effluent of 1 mg P/l is achievable but it remains extraordinarily fertile; its potential biological effect depends entirely on the extent of its dilution in the receiving water it is hoped to protect. In warm countries with high evaporation rates and low flows, the limits are scarcely effective. In 1988, the Republic of South Africa imposed a phosphorus limit of 1 mg P/l on discharges from sewage treatment plants to reduce eutrophication but is now on the point of rescinding the limit because the improvements to water quality have been generally imperceptible.

At the other extreme, in areas of high rainfall, over-dilution of raw sewage can present its own problems. High throughput usually results in poor treatment but it is concealed by the dilution, to the point that consent standards continue to be met. However, the load is cumulative and, to a long-retention receiving water, one which remains available to biological exploitation. This problem is increasingly recognised in the urban areas in northwest Britain.

Chemical limits are not assisted by the intangibility of diffuse nutrient sources. This is a major political issue in the context of expenditure to meet imposed limits on urban waste-water discharges, which is not clarified by the consideration of total nutrient loads without account being taken of bioavailability. Notwithstanding, several countries have set guidelines for reducing the chemical load from agricultural land to drainage waters. Switzerland has developed a scale of economic instruments to help implement a target of fluvial nutrient transport, which are claimed to be successful (Curry and Stucki, 1997). The Netherlands and Belgium have focussed on manuring. Denmark and Germany, as has the UK, have taken steps to reduce nitrogen applications where concentrations exceed limits recommended by the World Health Organisation.

Chemical objectives apply most effectively within the receiving waters. Some of the earliest deductions from the Vollenweider model recognised the sensitivity of the receiving water to eutrophication by external phosphorus is a function of the morphometry and hydrology, while the Sas compartmentalisation demonstrated the dependence of the subsystem-2 response on the in-lake bioavailability of P. It is possible to nominate a maximum tolerable bioavailability for each water body and then to treat that water body to secure it. The notion that this should be done by direct chemical treatment is well established but has rarely been applied quantitatively. The best-attested case is that of the Wahnbach reservoir that supplies drinking water to Cologne and Bonn. Pre-treatment of the riverine intake, using serial iron-phosphate removal (analogous to tertiary treatment of waste water) renders the bioavailability of phosphorus in the reservoir below 2 mg P/$m^3$ at all times, with a minimal plankton biomass to match.

Direct treatment of ponds and ornamental waters to improve clarity is the promise of numerous commercial formulations, most of which invoke the precipitation of dissolved phosphorus in stable combination with calcium, provided ionically as chalk powder.

Clay minerals also have a powerful binding affinity for phosphate ions but the addition of clays to waters is not calculated necessarily to improve water quality. However, interest in formulations that increase the phosphorus sorption powers and raise the gravitation of the clay is running high in Australia (Douglas *et al*., 1998). Using a modified, Lanthanum-rich clay, Douglas *et al*. (1999) have succeeded in attaining an almost complete removal of soluble reactive phosphorus from a lake-water mesocosm. Moreover, the sedimented material formed a bottom layer that continued to prevent phosphorus diffusion from the sediment back to the water.

These are early days but a simple, safe, reliable and effective application of a modified natural mineral to water, in order to attain a pre-determined, lake-specific chemical objective would seem to be a highly promising management weapon in controlling eutrophication.

### 4.2.4 Ecological targets

Apart from the levels of phytoplankton, chlorophyll and the extent to which the phytoplankton biomass is dominated by particular organisms (chiefly toxin-producing cyanobacteria), there seems to have been little international effort to express quality criteria and management objectives in biological terms. The representation of certain plant associations, algal assemblages or of particular species of fish is still widely used as a qualitative basis for assessing habitats (see next section) but has hardly been used in the setting of targets for eutrophication control.

### 4.2.5 Ecological indicators

There has been a long-standing movement in Europe to match the distributions of particular species or definitive species-associations with particular environmental attributes, to the extent that their presence at a particular location will reveal properties characteristic of that location. It may be observed that the approach was promoted when there was a much better tradition in taxonomy, with an attendant capability of putting names to organisms, than is presently the case and when the measurement of relevant environmental variables was much more problematic than it is today. Indeed, the tendency is now to detect the pattern to the communities that are associated with robustly measurable environmental factors. It is also true that the exemplary success achieved with the "saprobien system" of classifying microbial communities (Kolkwitz and Marsson, 1909) has rarely been repeated. Notwithstanding, there are recognised separations among planktonic algae, benthic invertebrates and fish species for experts to have little intuitive difficulty in recognising the trophic state of the waters supporting a dominance of indicative species. The lack of success with other systems of indicators may be seen, with hindsight, to have been too reliant on individual species or phylogenetic divisions when, in reality, the truly indicative features are what the species and communities are doing; that is, what *functional groups* are represented? This is, in point of fact, what the saprobien system analysed. So, apart from the computer-based analytical tools, like RIVPACS (Wright *et al*., 1989) and AMOEBA (Colijn *et al*., 1991), which recognise functional associations of named species to determine environmental attributes, indicator species have never really fulfilled their original promise.

Thus, it is curious to note that there is presently a considerable international interest in the definition of system-level bioindicators that will attest to "ecosystem health". As the perceptions about eutrophication and biodiversity are separated, there is growing interest in how the systems actually work as opposed to what it is that drives them. In one recent international workshop, it was accepted that there are major distinctions about the "how" element but which consistently determine the functional attributes most likely to be in demand (Reynolds, 1999). In turn, these requirements predispose the system to select for particular functional groups of organisms, which will be expressed at the species-representational level. A simple example is the metabolic distinction to be made intuitively between the lake dominated by *Oscillatoria, Chironomus* and *Cyprinus* and the one dominated by *Dinobryon*, *Siphlonurus* and *Salmo*. Many of the questions will require a great deal more sensitivity than this but the approach is promising. The priority is to quantify the thresholds which pressage the replacement of one way of doing things and one structure by another way and another structure. This has relevance to other topics related to ecosystem health, like whether it is sustainable, and what does it do for the enhancement of biodiversity. Or even to "how healthy is healthy enough?" (Walker, 1996).

*Many of these are important issues faced on a regular basis by the Agency.*

### 4.2.6 Policy on Management and Information

While governments ponder how best to manage increasingly threatened quantity and quality of water resources, without incurring excessive cost to present economies, legislative development seems to have adopted a minimalist approach to regulation. In the context of eutrophication, the criteria for control are based more on what is achievable rather than what is desirable or even sufficient to have impact.

This is not to say that nothing is being done. It is probably true that the intellectual understanding of eutrophication has undergone considerable revision and, though the problems remain the same, the new philosophies for remediation are still evolving, particularly with respect to diffuse pollution issues.

In several countries, the opportunity is being taken to inform and educate a public that is mostly oblivious to the connection between their own activities and aspirations with the deterioration of waterways through eutrophication. In fact, the message can be transparent and inspirational, as several examples of educational campaigns have demonstrated. In Switzerland, several Cantonal Governments collaborated to the publication of a factual but accessible, well-illustrated booklet intended to explain policy and share ownership of problem and solution with the wider public. It contains lots of encouragement to individuals to involve themselves and take more care over their individual impacts.

Australia has been at the forefront of these campaigns of public involvement. The severe Cyanobacterial blooms that beset the rivers of the Murray-Darling basin in 1992 made a memorable impact on the social psyche and it was projected very much as an issue of eutrophication. Major regional campaigns of advertising and social pressure projected an image of lifestyle impact, with exhortations to curb the flow of phosphorus. Regular full-time farmers were to guard against soil erosion, "hobby farmers" were warned to be sparing and intelligent in fertiliser usage. Detergents based on polyphosphates were to be so identified and shunned. Even the washing of cars was advised to take place on the lawn rather than on hardstanding draining to sewerage. As an exercise in public communication, the campaign is judged to be highly successful. There have been no more serious blooms and, perhaps, there are some that believe that the public campaign has achieved its goal. The flow of nutrients to the river may have reduced but it is still high and it is still capable of sustaining blooms on the 1992 scale. When it does happen again, as probabilities determine, the public may be demanding another explanation. People do need to be informed, the public information campaigns in both countries are soundly motivated and the information is clear and readily assimilable. Those who would imitate this role are urged to make sure of the connections between symptoms and cause and that uncertainties and response times are also clearly indicated.

## 4.3 Rivers

The situation concerning eutrophication in rivers was summed up by Marsden *et al.* (1997), who stated that "Compared with standing waters, the trophic status of running water has been neglected with few studies describing the extent of eutrophication in rivers". As a result out of 410 "hits" on a bibliographic search with keywords "eutrophication + river" 42 were directly relevant to eutrophication in rivers. The rest reported information on rivers flowing into eutrophic lakes or eutrophic estuaries and/or mathematical model development.

The reasons for this dearth of studies on eutrophic rivers results from the fact that, until recently "eutrophication" was assumed to be a process occurring only in lakes, or more recently estuaries. There is in fact, no clear definition of eutrophic conditions in rivers. Unlike the case for lakes where excessive phytoplankton biomass is an almost universal description, rivers are described as being eutrophic if one or more of the following are present:

a. too much planktonic algae (deep rivers).

b. too much benthic algae (shallow rivers).

c. excessive amounts of filamentous algae.

d. too many macrophytes (highlighted in flood control).

e. reduced diversity of plants present.

f. move from macrophyte dominance to algal dominance.

g. regular DO sags due to excessive plant growth.

The consequence of this complex of effects, which are taken as indicative of eutrophication, is that there are no models for rivers as reliable as, say, the PROTECH model for lakes. There are one or two models that make an attempt at predicting the biomass of one of the above components given information on nutrient levels and other physical factors, e.g. (phytoplankton) Cloot and Pieterse, 1999, Thebault and Qotbi, 1999; (benthic algae) Portielje *et al.*, 1996. However, none appear to be particularly successful, even for the areas they were originally tested on. There are no models that make any attempt to identify which of the above effects is likely to be the observed effect of eutrophication at any site. Hence, although Dodds *et al*., (1997) gave some simplistic methods of estimating target levels of nutrients, there is no fundamental basis upon which to set target concentrations of nutrients (particularly P) in the river, i.e. there is no way to link P concentrations/ fluxes in rivers with the biological effect on plants, etc. At present a limit has been set on the basis of expert knowledge at 0.1 mg/l P. However, recent work by Dawson *et al.*, (1999) suggest that there is no discernible relationship between in-river P concentrations and macrophyte community structure above this target concentration and that, in fact, this is an upper limit and that observable changes will only start to occur below this level. In order to set realistic targets, significant research is required into mechanistic models linking in-river P concentrations and macrophyte/ planktonic algae/ benthic algae/ filamentous algae biomass and/ or macrophyte and benthic algal community structure. Because of the lack of a mechanistic link a significant proportion of the literature on eutrophic rivers is devoted to methodologies to identify the level of effect, e.g. diatom index (Kelly and Whitton, 1995, 1998), macrophyte index (Robach *et al.*, 1995, 1996; Demars and Harper, 1998; Thiebaut and Muller, 1998; Haury *et al.*, 1998 and Dawson *et al.*, 1999) and chemical indices (Marsden *et al.*, 1997). Macrophyte indices are particularly popular in France. However, in the UK there are two practical systems in operation; one based on diatoms and one based on macrophytes. Hence, unless new methodologies can develop more robust relationships with in-river nutrient concentrations (e.g. the proposed PLANTPACS approach) there is little need for further research except to improve the present methodologies.

Despite the fact that target setting is extremely difficult there is a requirement, particularly under the Urban Waste Water Treatment Directive (UWWTD) and US equivalents, to reduce the levels of eutrophication along stretches of rivers. In order to manage this situation, a significant amount of UK and international work has gone into the development of methods to identify the main sources of nutrients in catchments. In a recent Environment Agency R&D report, Hilton *et al.* (1998) developed a scheme incorporating all the possible sources/ processes which might bring about eutrophication in a river and, using simple tests, reduces the field to the most likely sources and/or processes. However, most work has assumed two main sources of nutrients into any system, point source and diffuse source inputs. A significant number of studies have attempted to quantify the relative proportions of these two sources at a range of scales from national to small catchment (e.g.; MacDonald *et al.*, 1995; Foy *et al.*, 1995; Muscutt and Withers, 1996; Kinniburgh *et al.*, 1997 and Bendoricchio *et al.*, 1999).

Diffuse sources are generally considered to result from one of two sources: agricultural run-off and/ or urban storm water discharges. Much less work has been done on urban run-off than for agricultural sources. In fact almost all the effort has gone into the latter. In general there has been an attempt to relate diffuse P and N loads from agriculture with land use type or animal numbers. One approach to identifying sources makes statistical links between changes in river nutrient concentrations and changes in land use, e.g. Cahoon *et al.* (1999); McFarland and Hauck, (1999). An alternative approach has been to allocate run-off coefficients (e.g. Young *et al.*, 1996; Xue *et al.*, 1998) to different types of land use and, through a GIS determine the area of the total catchment under each type of land use. Hence, by simple multiplication, the diffuse load of nutrient above a certain point can be estimated. Following a US lead in this field, application of the GIS approach in Britain has been pioneered by Johnes (1996). All of her work, however, has been carried out on small catchments with low population densities. Under these conditions it is possible to use long term data on in-river water quality and land use change to calibrate the run-off coefficients to each particular catchment. However, Hilton *et al.* (2000) recognised that this level of information was not available for most catchments. They showed that for a highly populated catchment (the Warwickshire Avon), it is possible to use uncalibrated run-off coefficients to estimate diffuse source run-off since the major errors are in the estimation of annual in-river loads.

On the basis of these types of study, there is increasing evidence that, in many places in the UK, simple application of the UWWTD will not achieve the minimum targets for eutrophication control (e.g. Foy *et al.*, 1995; Hilton *et al.*, 2000). However, many of these studies are based on total P flux estimates and a number of studies, mainly from Europe and the US, suggest that it is more realistic to consider only bioavailable P (i.e. the P likely to be available to plants and not permanently fixed in solid matrices). For example, work in Germany showed that a large proportion (about 70%) of the P discharged from point sources (sewage treatment works) is in bioavailable form whereas only about 30% of the P originating from diffuse agricultural sources is bioavailable (Gerdes and Kunst, 1998). As a result, when only the proportion of the bioavailable P was considered in the P flux from point and diffuse source estimates, the relative importance of diffuse sources decreased significantly and point sources remained the main target for P reduction programmes. Similar results were obtained in France (Dorioz *et al.*, 1998 a and b). Very few bioavailability studies have been carried out in the UK. The relevance of these results to run-off coefficient estimates of diffuse P should be considered with respect to catchment management strategies in the UK.

Since UK experience has not generally considered bioavailability, mass flux estimates have consistently pointed towards the importance of controlling diffuse sources. As a result, a large number of Best Management Practices (BMPs) have been identified, which can reduce P run-off from agricultural sources (Hilton *et al.*, 2000, present a compilation based on several reviews). However, good data on the effectiveness of each method is not generally available and those that are available are often obscured by incorrect transfer to P reduction of BMP efficiencies appropriate to other pollutants which can also be reduced by BMPs (e.g. nitrates, suspended solids, pesticides, etc.). If the Agency is to use BMP's in catchment management strategies, work is required to assess how they can be used to best effect. In particular information is required on the variation in efficiency of individual BMPs with factors such as slope and soil type. A methodology is required to identify a "practicable" sub-set of BMPs for Agency use, i.e. BMPs which farmers will be prepared to use. This is one of the factors that influence BMP uptake by farmers. Further socio-economic research is required to identify other drivers so that realistic catchment management plans can be drawn up. Hilton *et al.* (2000) also presented an outline model approach for including cost-effectiveness of remedial measures into the development of catchment management strategies. Further development of this type of approach is required to allow field trials to be carried out.

Once a eutrophication control action plan has been initiated, the question arises as to the length of time a system will take to recover. As with lakes this is dependent on the rate of recycling and loss of the pool of stored sediment P. Work has been done in a number of countries (e.g. Qotbi *et al.*, 1996) on the storage and release of P in river sediments. Some of the most sophisticated work has been carried out by House *et al*. (1995 a, b) who transferred the concept of the Equilibrium phosphorus concentration ($ECP_0$ ) from soil science to sediment studies. The $ECP_0$ is the concentration of P in the water in contact with the solid at which no transfer into or out of the sediments occurs. If water column concentrations are below this concentration then release from the sediments will occur. Conversely, if water column concentrations are above this level then P sorption will occur. The rate of uptake or release by sediments is described by the Elovich equation (House *et al.*, 1995a). There is evidence to suggest that the rate of transfer across the sediment water boundary is a function of the $ECP_0$ , the water column P concentration and the velocity of the water, which in turn defines the boundary layer thickness (House *et al.*, 1995b). The outstanding research problem in this area is the prediction of $ECP_0$ values for a given sediment. At present, although there are clear relationships with redox status and some mineralogy, the only reliable method of obtaining an $ECP_0$ is by measurement. Further work is required on this aspect.

# 5. COLLABORATIVE RESEARCH AREAS

## 5.1 Introduction

One of the objectives of this report was to identify potential areas for collaborative eutrophication-related research nationally and internationally. Potential areas for national collaboration have already been covered in Section 3 with possible collaborating parties for each recommended R&D project given in Table 3.1. In addition, as detailed in Section 3, each project has been evaluated by the project team in relation to its potential as a "Collaboration Mechanism" and in relation to its role in developing "Partnership Opportunities".

Several of the more recent studies summarised in Appendix A have been funded by MAFF, English Nature and DETR with recommendations for further work being targeted primarily at these organisations. Indeed, many of these recommendations show considerable overlap with the business needs of the Agency and represent considerable opportunity for Agency collaboration and/or input. For example:

- DETR's marine and land based inputs to the sea (MLIS) Research Programme for 2000/2001 identifies the requirement for "Generic Research" into developing knowledge of the natural variability of the marine environment against targets set under the OSPAR strategies on nutrients and eutrophication. In addition, the research programme identifies a need for the development of methods to facilitate the assessment of the eutrophication status of UK marine waters.

- MAFF have commissioned a large number of R&D projects under the Nitrates and Phosphate loss from agriculture programmes (Currently funded at £4 million and £1 million annually). All of these projects deal with the nutrient loss from agricultural land aspect of the eutrophication problem. MAFF and the Environment Agency have a common business need to reduce the loss of nutrients from agricultural land. Collaboration with MAFF as a potential funding partner should be explored for all Environment Agency funded R&D in this area. The outputs of all of MAFF funded R&D projects should be taken into consideration either in the development of Environment Agency R&D projects or at an early stage in any Environment Agency funded R&D related to nutrient losses from catchments.

- Research to define and quantify nutrient levels in rivers, lakes, estuaries and coastal waters equating to high, good and moderate ecological status as defined in the proposed Water Framework Directive would be of interest to a number of research establishments both the UK and overseas including DETR, SEPA and the European regulatory authorities.

- Research to develop an economic model of costs and paybacks from phosphorus recovery from sewage and animal wastes (Table 3.11) could involve potential collaboration from CEEP, SDIA, and water companies (UKWIR).

Having identified areas for collaboration on a national basis in Section 3, the following sections provide information on eutrophication-related research being undertaken overseas that will be of interest to the Agency's business needs. Contact names and addresses have been provided.

## 5.2 Europe

In Europe, research activities are carried out both by individual Member States and by the European Union.

The European Environment Agency develops approaches to describe the quality of the environment on a European scale including assessment of the impacts of particular pollutants such as nutrients.

### 5.2.1 Member States

Eutrophication-related R&D is undertaken by most EU Member States but access to these research programmes is not always straightforward. The following descriptions provide some information on eutrophication-related R&D in selected Member States with contacts, where appropriate, for possible collaboration.

**Finland**

**Phosphorus geochemistry and losses from soils**

Section 4.2 identified the need for the Agency to further develop its understanding of the geochemical pathways of phosphorus transport (such as whether and how much phosphorus exists in biologically reactive fractions, whether it moves primarily in solution or attached to particles, how subject it is to redox changes, etc.). It is important for the Agency to take note of developments in this area in several overseas countries, most notably, Finland (and Australia - see Section 5.4.1) particularly at the Finnish Environmental Institute where opportunities exist for potential collaboration. Useful contacts within the area of *phosphorus geochemistry and losses from soils* within the Institute are:

| | |
|---|---|
| *P. Ekholm, and* | *Finnish Environmental institute* |
| *R. Rekolainen* | *P.O. Box 140,* |
| | *SF-00251* |
| | *Helsinki,* |
| | *Finland* |
| | |
| | *http://www.vyh.fi/eng/fei/fei.html* |

**Netherlands and Denmark**

**Biomanipulation and alternative steady states**

Section 4.3 states that, as a practical approach to the management of water quality in lakes and reservoirs, biomanipulation (the management of the aquatic system so that the sink for excess nutrient is one that is more aesthetically acceptable) is well established though the underpinning theory and the measures to improve the prospects of its successful application are still an area of contention. Further work is recommended to elucidate the prospects of biomanipulation as an effective management tool.

Related to this is the concept of alternative stable states whereby macrophyte dominated systems can “flip over” to systems dominated by phytoplankton which are far less desirable. Currently there is a great deal of research interest in the existence of these alternative steady states with experiments being conducted in several European countries. Indeed, as stated in Section 4.3, as an approach to understanding ecosystem function in small, shallow and irreversibly eutrophic lakes, such research is generating management applications that will be of central interest to the Agency.

Useful contacts within the area of *biomanipulation and alternative steady states* are:

| | |
|---|---|
| *E. Jeppersen* | *National Environment Research Institute*<br>*P.O. Box 314,*<br>*Vejsøvej,*<br>*DK-8600,*<br>*Silkborg,*<br>*Denmark*<br><br>*www.dmu.dk/index_en.htm* |
| *S.H. Hosper, and*<br>*M. Scheffer* | *RIZA*<br>*P.O. Box 17,*<br>*NL-8200AA,*<br>*Lelystad,*<br>*Netherlands* |

One further institution involved in eutrophication-related R&D in the Netherlands is the Department of Aquatic Ecology and Water Quality Management of the Wageningen Agricultural University (www.wau.nl). Researchers from this university co-ordinated a recent International Association of Water Quality (IWAQ) Symposium entitled: Eutrophication Research. State of the Art: Inputs, Processes, Effects, Modelling, Management (Roijackers *et al*, 1997). The Department continues to carry out eutrophication-related R&D producing the following publications of various types since 1995 as well as the aforementioned symposium proceedings:

- The role of eutrophication models in water management;
- Dynamics and stability of *Chara* sp. and *Potamogeton pectinatus* in a shallow lake changing in eutrophication level;
- Agricultural non-point load of nitrogen to surface waters : A regional estimation in GIS;
- Biomanipulation in shallow lakes in The Netherlands: an evaluation of 18 case studies;
- Nitrogen fluxes and processes in sandy and muddy sediments from a shallow eutrophic lake;
- Estimation of sediment-water exchange of solutes in Lake Veluwe, the Netherlands;

- Top-down control of cyanobacteria: A theoretical analysis;
- Switches between clear and turbid water states in a biomanipulated lake (1986-1996): the role of herbivory on macrophytes;
- Clear water associated with a dense *Chara* vegetation in the shallow and turbid Lake Veluwemeer, the Netherlands;
- Leaching of nutrients to the surface waters in unfertilised areas: monitoring design and first results;
- Anoxic N-2 fluxes from freshwater sediments in the absence of oxidized nitrogen compounds;
- Control of *Volvox* blooms by *Hertwigia*: a rotifer;
- Changes in sediment phosphorus as a result of eutrophication and oligotrophication in Lake Veluwe, The Netherlands;
- The role of characean algae in the management of eutrophic shallow lakes;
- Ecologically based standards for nutrients in streams and ditches in The Netherlands;
- Nitrogen removal in buffer strips along a lowland stream in the Netherlands: a pilot study;
- Nitrogen removal by denitrification in the sediments of a shallow lake;
- Increased diversity of trophic relationships in lakes after restoration by biomanipulation;
- Early diagenesis of phosphorous in continental margin sediments;
- Clearing lakes. An ecosystem approach to the restoration and management of shallow lakes in the Netherlands;
- Nitrogen Dynamics in buffer strips along a lowland stream;
- Effects of the nutrient loading gradient in shallow lakes;
- Phosphorus fixation in lake sediments; the case of Lake Veluwe, The Netherlands;
- Comparison of denitrification rates in lake sediments obtained by the N2 flux method, the 15N isotope pairing technique and the mass balance approach;
- The trophic state of shallow lakes in The Netherlands;
- Bivalve grazing, nutrient cycling and phytoplankton dynamics in an estuarine ecosystem;
- Transition of a lake to turbid state six years after biomanipulation: mechanisms and pathways;

- Influence of benthic diatoms on the nutrient release from sediments of shallow lakes recovering from eutrophication;

- Coprecipitation of phosphate with calcium carbonate in Lake Veluwe;

- Modelling nutrient cycles in relation to food web structure in a biomanipulated shallow lake;

- Development and eutrophication: experiences and perspectives;

- Predicting the impact of eutrophication on the survival of the submerged vegetation in shallow temporary lakes;

- Primary succession of aquatic macrophytes in experimental ditches in relation to nutrient input.

A useful contact is the Head of the Department:


| | |
|---|---|
| *Prof. Marten Scheffer* | *Wageningen Agricultural University Department of Aquatic Ecology and Water Management*<br><br>*E-mail: marten.scheffer@aqec.wkao.wau.nl* |


**Switzerland**

**Public relations**

Section 4.7 identified that, in several countries, most notably Switzerland (and Australia) the opportunity is being taken to inform and educate a public that is mostly oblivious to the connection between their own activities and aspirations with the deterioration of waterways through eutrophication. In fact, the message can be transparent and inspirational, as several examples of educational campaigns have demonstrated. It is recommended that the Agency review its own publicity material and public information programmes in light of the results of successful campaigns overseas.

A useful contact within the area of *public relations* is:


| | |
|---|---|
| *P. Stadelman* | *Kant. Amt für Umweltschultz Luzern,*<br>*Klosterstrasse 31,*<br>*CH-6002,*<br>*Luzern,*<br>*Switzerland* |

**Ireland**

The Irish Environmental Protection Agency (EPA) (www.epa.ie) was contacted with respect to the funding of eutrophication R&D and a number of completed and ongoing initiatives were identified.

Completed projects include:

- Remote sensing of lakes – improved chlorophyll calibration and data processing;
- Investigation of eutrophication processes in the littoral zones of western lakes;
- Quantification of phosphorus losses to water due to soil P desorption;
- Investigation of toxins produced by Cyanobacteria;
- Investigation of nutrient inputs, fluxes and productivity in selected brackish waterbodies.

Ongoing projects include:

- A commissioned report on phosphorus loss to water from agriculture;
- An in-house report on river eutrophication dealing with a wide range of issues;
- Research report in final draft on the large Western Lakes which, in part at least, deals with early stage eutrophication and ecological assessment techniques;
- Major in-house report on P loading to two of the large western lakes Lough Conn and Lough Mask.;
- National Regulations for phosphorus under the Dangerous Substances Directive based on established empirical links between river phosphate levels and biological quality as determined by our Quality Rating Index.

Future topics for funding related to eutrophication may include:

- P loss pathways from agriculture, including control strategies, risk assessment;
- Mechanisms by which eutrophication impacts on benthic invertebrates - not just oxygen regime but feeding ecology, habitat siltation, etc. This is important from the point of view of the Quality Rating Index (Q-Values) which is used in Ireland to describe the biological quality of rivers and relies to a large extent on macroinvertebrates;
- Links between biotic Q-Values and fish stocks with a view to understanding the relationship between fish, macroinvertebrates and eutrophication impacts. This is important for the forthcoming EU Water Framework Directive, which requires much more extensive fish stock assessments than heretofore.

- Pilot project on ecological assessment of lakes which follows on from an initial project which carried out more basic research aimed at selecting candidate monitoring techniques suitable for the EU Water Framework Directive's needs. This is not strictly an eutrophication project but obviously an important element of lake monitoring.

- Analytical problems associated with chlorophyll determination.

A useful contact within the Irish EPA is:

*Martin McGarrigle* *EPA, Castlebar*

*+353 94 21588*
*E-mail: m.mcgarrigle@epa.ie*

### 5.2.2 European Union (www.cordis.lu)

European Union research activities are implemented for the most part under multi-annual research, technological development and demonstration (RTD) framework programmes. The most relevant of these with respect to this project are the Fifth RTD Framework Programme (1998-2002) and the previous Fourth RTD Framework Programme (1994-1998). Other relevant research related programmes include Co-operation in the field of Scientific and Technical Research (COST) and EUREKA[3].

The fifth framework programme (FP5) (www.cordis.lu/fp5) is currently open and proposals for eutrophication-related R&D would be appropriate for the 'Quality of Life and Management of Living Resources' and 'Energy, Environment and Sustainable Development (ESSD)' thematic programmes. Some projects have been approved under the FP5 but details have yet to be published on the CORDIS website. Among the eutrophication-related proposals submitted to FP5, WRc is involved in PREMIER (Biological and physico-chemical Phosphorus REMoval from wastewater in an Integrated, Effective and Reliable way). The FP5 offers one of the obvious routes for collaboration on eutrophication-related R&D through research institutes and organisations.

The FP4 comprised three programmes relevant to eutrophication: Environment and Climate (www.cordis.lu/env/), Agriculture and Fisheries (FAIR) (www.cordis.lu/fair/) and Marine Science and Technology (MAST III) (www.cordis.lu/mast/). Searches for ongoing projects under these sub-programmes revealed a number of eutrophication-related projects. Similar searches of the COST (www.cordis.lu/cost/) and EUREKA (www3.eureka.be) programmes revealed a further three projects related to eutrophication. Results of completed and ongoing eutrophication R&D are, or will be, available from the EU and should inform future research in the UK.

3 EUREKA is a pan-European framework for research and development cooperation through which industry and research institutes from 27 European countries and the European Union develop and exploit the technologies crucial to global competitiveness and a better quality of life.

**Environment and Climate**

- Water quality monitoring by luminescent cyanobacterial biosensors: a novel early warning system against algal blooms (Estimated end-date: November 2000, Ref: ENV4970493);

- Shallow wetland lake functioning and restoration in a changing European environment (Estimated end-date: September 2000, Ref: ENV4970420);

- Applied remote sensing and GIS integration for model parameterisation (Estimated end-date: December 2000, Ref: ENV4970396);

- Atmospheric nitrogen inputs into the coastal ecosystem (Estimated end-date: January 2001 ENV4970594);

- European Diatom Database: an information system for palaeo-environmental reconstruction (Estimated end-date: March 2001, Ref: ENV4970562);

**Agriculture and Fisheries (FAIR)**

- Nutrient management legislation in EU countries (Estimated end-date: Jan 2002, Ref: FAIR 984215).

**MAST III**

- Comparative analysis of food webs based on flow networks: effects of nutrient supply on structure and function of coastal plankton communities (Completed, Ref: MAS3960052). Project website at www.maricult.org/public/comweb/;

- Effects of eutrophicated seawater on rocky shore ecosystems studied in large littoral mesocosms (Estimated end-date: March 2001, Ref: MAS3 970153). Project website at www.maricult.org/public/eulit/;

- Changes in bacterial diversity and activity in Mediterranean coastal waters as affected by eutrophication (Completed, Ref: MAS3960047). Project website at www.dsmz.de:81/Chabada/;

- Effects of nutrient ratios on harmful phytoplankton and their toxin production (Estimated end-date: September 2000, Ref: MAS3 970103);

- Preparation and integration of analysis tools towards operational forecast of nutrients in estuaries of European rivers (Estimated end-date: August 2001, Ref: MAS3 980170);

- Nitrogen cycling in estuaries (Completed, Ref: MAS3960048). Project website at www.dmu.dk/LakeandEstuarineEcology/NICE/.

**COST**

- Quantifying the Agricultural contribution to eutrophication (Ref: COST 832).

This significant European project is co-ordinated by ADAS in the UK and further details can be found at the project website (www.ab.dlo.nl/eu/cost832/welcome.html).

**EUREKA**

- Reducing N losses: Improving nitrogen utilisation in cows which are fed on silage diets (Estimated end-date: Jan 2000, Ref: E!1477);

- Electrochemical destruction of nitrate in effluents (Estimated end-date: April 2001, Ref: E!1857).

### 5.2.3 The European Environment Agency (www.eea.eu.int)

The European Environment Agency (EEA) actively uses and promotes the wider application of Integrated Environmental Assessments (IEA). This is the interdisciplinary process of identification, analysis and appraisal of all relevant and natural human activities and their interactions, which determine the current and future state of the environment on appropriate spatial and temporal scales, thus facilitating the framing and implementation of policies and strategies. This approach was recently used to describe the current status of nutrients in European ecosystems (including aquatic ecosystems (EEA, 1999)).

In effect, IEA links Driving forces, Pressures, State, and Impacts in terms of the policies (or Responses) currently in place or being considered for the future. This process, termed DPSIR is similar to the "Frameworks and Themes" methodology employed by the Environment Agency. This similarity in approach therefore lends added weight to collaboration between the EA and the EEA.

The EEA has set up an IEA Core Group to give general support particularly in the context of the development of the Second Multi-Annual Work Programme and the future development of the European Topic Centres. Representatives of several institutions around Europe with experience in the development and use of IEA have now been identified and it is recognised that more intensive co-operation with these individuals and their institutes could improve the effectiveness of the work of the EEA. Included in the terms of reference of this Core Group is a responsibility for openness and the opportunity is available to the EA to make use of this group (or selected individuals) for collaborative discussions.

The moderator of the IEA Core Group is:

*Hans Luiten*
*Project Manager*
*European Environment Agency*
*Kongens Nytorv 6*
*DK-1050 Copenhagen K*
*Denmark*

*Tel: +45 33 36 7133*
*Fax: +45 33 36 7128*
*Email: hans.luiten@eea.eu.int*

The following institutions are involved in the Core Group:

- National Institute of Public Health and the Environment (RIVM - The Netherlands);
- Institute for Integrated Applied Systems Analysis (IIASA - Austria);
- Joint Research Centre of the European Commission (JRC - Ispra, Italy);
- National Technical University of Athens (NTUA - Greece);
- European Commission DG XI (EC DG XI - Brussels);
- Representatives of the Scientific Committee of the EEA (in particular Professor Poul Harremoës of the Danish Technical University, Lyngby).

For specific expert advice on the application of IEA to the issue of Eutrophication the EEA has set up a network of European experts called IEA-EUNET. This network is managed on behalf of the European Topic Centre on Inland Waters (ETC/IW) by the National Environmental Research Institute (NERI) of Denmark. Current topics under consideration are:

1. **Development in point source discharges in the EU and Central and Eastern European Countries**

   This draws upon work by the ETC/IW for the EEA and is an assessment of current inputs of nutrients to inland and coastal waters from industrial and sewage treatment plant point sources. In addition there is a scenario assessment as to how this situation will change under full implementation of the Urban Waste Water Treatment Directive up to the year 2015.

2. **Agriculture and nutrient losses**

   This draws upon work carried out by LEI-DLO in the Netherlands and is an attempt to assess the environmental effects (largely with reference to nitrogen) of agricultural policy reform and which tools are needed for assessing the impact of changes in agriculture at a European level.

The current composition of IEA-EUTRO is as follows:


| | | |
|---|---|---|
| *Hans Luiten* | *European Environment Agency<br>Kongens Nytorv 6<br>DK-1050 Copenhagen<br>Denmark* | *+45 33 36 71 33<br>hans.luiten@eea.eu.int* |
| *J.Duchemin* | *The European Commission<br>Directorate-General XI<br>European Commission<br>Rue de la Loi 200<br>B-1049 Brussels* | *Jean.Duchemin@dgxI.cec.be* |

| | | |
|---|---|---|
| *Dr. Kalliopi Pagou* | *National Centre for Marine Research<br>Institute of Oceanography<br>Aghios Kosmas, Hellinikon, 16604, Athens, GREECE* | *popi@erato.fl.nmcr.gr* |
| *Dr. Horst Behrendt* | *Institute of Freshwater Ecology and Inland Fisheries<br>Department for Limnology of Shallow lakes and Lowland Rivers<br>SeestraBe 82<br>P.O. Boks 850 335<br>D-12563 Berlin<br>Germany* | *+0049 30 648 407 17<br>+0049 30 648 407 10<br>behrendt@ igb-berlin.de* |
| *Vesa Gran* | *Eutrophication unit,<br>Impact Research Division<br>Finnish Environment Institute<br>P.O. Boks 00251<br>Helsinki 140<br>Finland* | *+358 9 4030 0317<br>+358 9 4030 0390<br>vesa.gran@vyh.fi* |
| *Tor Bokn<br>Kari Nygaard* | *NIVA and ETC/IW partner<br>NIVA Norwegian Institute for Water Research<br>Brekkeveien 19<br>P.O. Boks 173<br>Kjelsås0411 Oslo<br>Norway* | *+47 2218 5100<br>+47 2218 5200<br>tor.bokn@nivaa.no<br>kari.nygaard@niva.no* |
| *Bronno de Haan* | *RIVM<br>Antonie van Leeuwenhoeklaan 9<br>NL-3720 BA Bilthoven<br>The Netherlands* | *+31 30 274 30 80<br>+31302284435<br>Bronno.de.haan@rivm.nl* |
| *Paul Boers* | *RIZA,WSE<br>Postbus 17<br>8200 AA Lelystad<br>the Netherlands* | *+31 320 29 84 29<br>+31 320 24 92 18<br>P.Boers@ RIZA.RWS.minvenw.nl* |
| *Ramon Penä* | *CEDEX, Spain* | *rpena@cedex.es* |
| *Sotiris Orfanidis* | *Greece* | *fri@otenet.gr* |

| | | |
|---|---|---|
| *Brane Maticic* | *IZVOR, Preradoviceva 44, 1000 Ljubljana,*<br>*or*<br>*Biotechnical Faculty, Jamnikarjeva 44, 1000 Ljubljaana Slovenia* | *+386-61-317-913,*<br>*+386-61-123-31-90*<br>*Fax. +386-61-133-51-04*<br>*brane.maticic@guest.arnes.si* |
| *Torben Moth Iversen*<br>*Jens Bøgestrand* | *National Environmental Research Institute (NERI)*<br>*P.O. Boks*<br>*Vejlsøvej 25*<br>*DK-8600 Silkeborg*<br>*Denmark* | *vma@dmu.dk*<br>*jbo@dmu.dk* |
| *Peter Kristensen*<br>*Jan Juul Jensen*<br>*Berit Hasler* | *National Environmental Research Institute (NERI)*<br>*P.O. Boks 358*<br>*Frederiksborgvej 399*<br>*DK- 4000 Roskilde*<br>*Denmark* | *+45 4630 1365*<br>*+45 4630 1212*<br>*pkr@dmu.dk* |


## 5.3 Outside Europe

### 5.3.1 Australia

Two key funders of eutrophication-related R&D in Australia have been identified: CSIRO (the organisation for scientific and industrial research in Australia) and the National Eutrophication Management Program (NEMP).

**CSIRO (www.csiro.au)**

CSIRO undertakes scientific and industrial research for Australia in a wide range of areas including environment and natural environment and the built environment.

CSIRO participates in a number of Co-operative Research Centres (CRC) including the CRC for Freshwater Ecology (http://enterprise.canberra.edu.au/WWW/www-crcfe.nsf) which undertakes research in the following programmes: flowing waters, water quality and ecological assessment, floodplain and wetland ecology, standing waters and eutrophication, urban water management and fish ecology.

Ongoing projects in these programmes related to eutrophication include:

**Flowing Waters**

- Relationships between nutrients, algal growth and macroinvertebrates in rocky and soft bottom streams.

**Standing Waters and Eutrophication**

- Nutrient Limitation of Algal Growth: Physiological Assays and Chemical Analyses
- Rapid measurement of algal biomass, species composition and physiological condition
- Darling River: algal growth, cycling and sources of nutrients
- River Murray Phytoplankton - The Role and Population Dynamics of *Melosira granulata* (now renamed *Aulacoseira granulata*)
- Ackinetes of *Anabaena circinalis*
- Physical and nutrient factors controlling algal succession and biomass in Burrinjuck Reservoir
- Development of a predictive model for algal growth in Cairn Curran reservoir
- Control Strategies for Cyanobacterial Blooms in Weir Pools
- Destratification and water quality
- Role of suspended particles/colloids and bottom sediments in modifying the bioavailability of phosphorus
- Algal availability of phosphorus discharged from different catchment sources
- Development of phytoplankton bioassessment protocol for Australian rivers
- Sediment - Nutrient Processes: Phase I. (IP2)

**Floodplain and Wetland Ecology**

- Management of Non-point Source Pollution in Rural and Semi-rural Catchments
- The storage, production and transfer of nutrients and carbon in lowland floodplain river systems: the Condamine Balonne River.

**Water Quality and Ecological Assessment**

- Measurement of bioavailable nutrients in natural waters
- Bioavailable phosphorus
- Nature and behaviour of condensed phosphates in wastewaters
- Humic substances and phosphorus speciation
- Optimisation of Procedures for the Determination of Total Phosphorus in Turbid Waters

- Nutrient guidelines for Victorian inland streams
- Biological assessment using diatoms as water quality indicators in the Kiewa River system
- Impact of nutrients on invertebrate communities of the Lower Goulburn River
- Sedimentary Phosphorus - Speciation and Dynamics
- Abiotic hydrolysis of phosphate esters in mineral phases
- Nutrient release from sediments
- The effects of drying on the nitrogen cycle in reservoir sediments
- Study on biotic and abiotic uptake / release of phosphorus by sediment

**Urban Water Management**

- Importance of phosphorus in detergents

The contact point for the CRCFE is:

*Professor Peter Cullen*
*CRC For Freshwater Ecology, University of Canberra*
*Tel: 02 6201 5167*
*Fax:02 6201 5038*
*E-mail: cullen@lake.canberra.edu.au*

CSIRO research into the built environment includes work towards ecologically sustainable development. The following eutrophication-related project is taking place in this area:

- Nutrient removal from sewage - CSIRO Molecular Science is developing technologies for the reduction of the amounts of nitrogen and phosphorus in the effluent discharge from sewage treatment plants. Successful outcomes for this research will benefit the aquatic environment and may result in the production of a high-value fertiliser by-product.

The contact point for this project is:

*Dr Calum Drummond*
*CSIRO Molecular Science*
*Bag 10*
*Clayton South VIC 3169*
*Phone: +61 3 9545 2617*
*Fax: +61 3 9545 2515*
*Email: C.Drummond@molsci.csiro.au*

**The National Eutrophication Management Program (www.nemp.aus.net)**

This program was established in 1995 by the Land and Water Resources Research and Development Corporation and the Murray-Darling Basin Commission. It funds and coordinates a range of research projects across western Australia concerned with a better understanding of the causes and effects of algal contamination of waterways.

Topics currently under consideration are:

1. **Reductions of algal blooms by flow management**

   This work is being carried out on the Fitzroy River in Northern Queensland and is an attempt to increase the flow and hence turbidity of the river feeding into the Fitzroy Barrage and thereby control the growth of algae in the barrage.

2. **Available phosphorus from catchments**

   This work measures the algal availability of phosphorus discharged from different catchment sources and the rate at which the phosphorus becomes available. This has implications for time lags in the traditional nutrient load:algal response relationships.

3. **Critical processes for Eutrophication**

   This work on the Burrinjuck Reservoir indicates that management needs to be undertaken in the reservoir and the catchment. Specifically:

   - establishing a means to intercept organic material before it enters the reservoir;
   - limiting annual draw-down rates and setting minimum storage volumes;
   - installing mixers where feasible;
   - capping sediments to reduce internal loading.

4. **Whole lake bio-remediation.**

   This is an attempt to manage fish populations in two reservoirs in South-East Queensland to reduce nuisance micro-algae and to improve the quality of water more generally. This involves the manipulation of different species of planktivorous fish.

Other research projects funded by NEMP are categorised as follows:

**Nutrients (Sources and transport of nutrients in catchments)**

- A study of nutrient changes over time in some riverine systems (CWS7)
- Measurement and treatment of the movement of phosphorus through subsoils (UAD7 and UAD10)
- Effects of landscape, land use and climate on erosion, phosphorus and suspended sediment (Namoi Basin) (R5061)
- Sources and delivery of suspended sediment and phosphorus to Australian rivers:

  Part A - radionuclides and geomorphology (CWA21)

Part B - using natural environmental tracers

**Sediment (Management of internal nutrient sources)**

- Are sediments a major source of nutrients in Wilson Inlet? (AGS2)
- Modelling nutrient release from sediments in lowland rivers and storages (CEM4)

**Blooms (Factors leading to the initiation and development of blooms)**

- Nutrient cycling by *Ruppia megacarpa* and epiphytes in Wilson Inlet (UWA17)
- A study of phytoplankton ecology of Wilson Inlet (UTA8)
- The interaction of physics, biology and nutrient regimes on the initiation and development of algal blooms (CSF1)
- Validation of the NIFT (Nutrient Induced Fluorescence Transient) assay for identifying N and P limitation of phytoplankton growth (MDR18)

**Other**

- Phytoplankton monitoring in Australian freshwaters (ULN2)

The contact point for NEMP is:

*Dr Richard Davis*
*NEMP Coordinator*
*CSIRO Land and Water,*
*GPO Box 1666,*
*CANBERRA ACT 2601*
*Tel:00 61 6 6246 5706*
*Email: Richard.Davis@cbr.clw.csiro.au*

**Further Contacts in Australia**

Phosphorus geochemistry and losses from soils:

*D.S. Baldwin*
*CRC Freshwater Ecology*
*P.O. Box 921,*
*Albury,*
*NSW,*
*Australia*

Novel P-removal techniques:

*J. A. Adeney*
*(See Table 3.4)*

*CSIRO Land and Water*
*Private Bag, P.O.,*
*Wembley,*
*WA,*
*Australia*

### 5.3.2 South Africa

**WRC: Water Research Commission**

The Water Research Commission (WRC) based in Pretoria, South Africa, supports a multidisciplinary approach to water research within South Africa. It enters into contractual agreements with organisations and individuals and provides the necessary funding to conduct the research. A large number of bodies are involved in WRC research comprising universities, statutory research agencies, government departments, local authorities, NGOs, water boards, consultants, and industry. Research activities supported by the WRC are closely linked to the national water-related concerns. Strategic plans for research in various research fields have been developed to guide and assist in the prioritisation of research. *(WRC homepage: http://www.wrc.org.za)*.

Current eutrophication-related studies that may be of interest to the Agency include:

- Control of problem algae and aquatic weeds in irrigation systems;
- Impact of agricultural practices on groundwater resources in South Africa;
- Problem blooms of microalgae: investigation of causal factors, seasonality of recruitment and growth, and efficiency of control methods;
- Biology of Vaal River phytoplankton in relation to water quality and utilisation problems;
- Identification of diatoms and their use in the assessment of water quality;
- Surveillance network for toxic blue-green algae in South Africa;
- Use of pathogenic organisms for the biological control of the troublesome alga *Cladophora glomerata;*
- Detergent phosphorus in South Africa: impact on eutrophication with special reference to the Umgeni catchment;
- Eutrophication management model for the middle Vaal River: phase II;
- Extension of the management orientated models for eutrophication control;
- Feasibility of using low cost modelling techniques to relate river water quality and diffuse loads to a range of land uses;

- Guide to assess non-point source pollution of surface water resources in South Africa;
- Use of artificial aeration to control eutrophication and its effects in the Inanda dam.

Useful contacts within WRC (Research Managers):

| | |
|---|---|
| *Mr. H Meiring du Plessis* | *E-mail: meiring@wrc.org.za*<br>*Research areas: water quality management (including eutrophication), non-point source water pollution, hydrodynamic models and water quality models* |
| *Mr. Hugo Maaren* | *E-mail: hugo@wrc.org.za*<br>*Research areas: surface water (hydrology) and integrated catchment management* |

### 5.3.3 United States

Eutrophication-related R&D is undertaken by the US Environment Protection Agency (US EPA), the US Department of Agriculture (USDA) and the Water Environment Research Foundation (WERF).

**US Environment protection Agency (US EPA)**

The US EPA sponsors eutrophication-related research through the Office of Research and Development's National Centre for Environmental Research (http://es.epa.gov/ncerqa/). Broadly speaking, recent research has addressed aspects of harmful algal blooms, nutrient (particularly nitrogen) supply pathways from the catchment to receiving waters and impacts of eutrophication in estuaries and coastal waters (see Table 5.1). The US EPA Office of Water is co-ordinating a National Strategy for the Development of Regional Nutrient Criteria (US EPA 1998) aimed at the adoption of nutrient criteria into water quality standards by the end of 2003.

**Table 5.1 US EPA National Center for Environmental Research eutrophication-related R&D projects**

| Project title | Proposed Dates |
|---|---|
| Detection and Identification of the Toxins from *Pfiesteria* and Related Harmful Algal Blooms | September 1, 1998 - August 31, 2001 |
| CISNet: Molecular to Landscape-Scale Monitoring of Estuarine Eutrophication | October 1, 1998 - September 30, 2001 |

| Project title | Proposed Dates |
|---|---|
| Anthropogenic Pollutant Effects on Aquatic Ecosystems: Impacts of Atmospheric Nitrogen Deposition on Phytoplankton Dynamics and Eutrophication | October 1, 1996 - September 30, 1999 |
| ECOHAB: Control of Harmful Algal Blooms using Clay | November 23, 1998 - November 22, 2001 |
| CISNet for the Neuse River Estuary, NC: A Program for Evaluating Nitrogen Driven Eutrophication Associated with Changing Land Use in a Coastal Watershed | October 1, 1998 - September 30, 2001 |
| Biogeochemical Indicators of Watershed Integrity and Wetland Eutrophication | 10/1/1999 - 9/30/2002 |
| Effects of Nutrient Enrichment and Large Predator Removal on Seagrass Nursery Habitats: An Experimental Assessment | January 1, 1998 - December 31, 1999 |
| ECOHAB: Trophic effects of two dinoflagellates. | January 15, 1998 - January 14, 1999 |
| Spatial and Temporal Environmental Variation in a Eutrophic Coastal River: Impacts on Fish and Marine Mammals | October 20, 1997 - October 19, 2000 |
| Fate and Effects of *Gymnodinium breve* Toxins in the Marine Environment, Phase 1 | January 15, 1998 - January 14, 1999 |
| Microbial indicators of biological integrity and nutrient stress for aquatic ecosystems | September 1, 1997 - August 31, 2000 |
| Developing an Indicator for Nutrient Supply in Tropical and Temperate Estuaries, Bays, and Coastal Waters Using the Tissue Nitrogen and Phosphorus Content of Macroalgae | August 1, 1999 - July 31, 2002 |
| The Development of a DNA Based Specific Assay for *Pfiesteria piscicida* in Water and Sediments | October 8, 1998 - October 7, 2001 |
| ECOHAB: DNA-Based Molecular Diagnostics for *Pfiesteria*-Complex Organisms in Chesapeake Bay | October 1, 1998 - September 30, 2001 |
| Physiological and Behavioral Effects of Nutrient Limitation on the Toxic Dinoflagellate *Alexandrium Tamarense* | none |
| Research Project To Construct and Calibrate a GIS Based Model to Predict the Trophic State of More Than 500 Lakes in the Seven-County Twin Cities Metropolitan Area. | September 24, 1998 |
| CISNet: In Situ and Remote Monitoring of Productivity and Nutrient Cycles in Puget Sound | October 1, 1998 - September 30, 2001 |
| Agricultural production results in the loss of unutilized nutrients such as nitrogen (N) and phosphorus (P) to ground and surface waters. | January 11, 1999 |

| Project title | Proposed Dates |
|---|---|
| The Fate of Wastewater Phosphate in Saline Carbonate Groundwater: Key Colony Beach, Florida | none |
| Use of Mathematical Modeling Techniques to Predict Dairy Cow Management Strategies That Will Reduce Nutrient Losses to the Environment | none |
| Quantification of the Dry Deposition Flux and Air Water Exchange of Reactive and Reduced Nitrogen: The Water Surface Sampler | October 1, 1998 - September 30, 2001 |

**US Department of Agriculture (USDA)**

The US Department of Agriculture (USDA) sponsors research into all aspects of agriculture including its environmental impact. The Agricultural Research Service (ARS) (www.ars.usda.gov) is the main in-house research arm of the USDA and sponsors research in three research areas including Natural Resources and Sustainable Agricultural Systems (NRSAS). This research area comprises seven National Programs including Water Quality and Management that in turn has the following components: Agricultural Watershed Management and Landscape Features, Irrigation and Drainage Management Systems, Water Quality Protection and Management Systems. The latter component is described as follows:

'New and improved strategies are needed to reduce water contamination from agricultural lands. Improved technologies are required for the management of agricultural chemicals (fertilisers and pesticides) and wastewaters (agricultural, municipal, and industrial effluent waters) and for transferring specific farming management systems from one geographic area to another. Field practices will be developed to reduce impacts of pesticides, nutrients, sediments, salts, toxic trace elements, and bacterial contaminants in surface waters and groundwaters. New strategies will be developed that use Management Systems Evaluation Areas (MSEA) and Agricultural Systems for Environmental Quality (ASEQ) sites to determine the water quality and other environmental benefits of alternative farming systems at field, farm, watershed, and river basin scales on irrigated and rainfed croplands and grazing lands. Water resource management to improve water quality will be evaluated on regional ecosystems in the context of its diversity and risk management for precision agriculture, integrated farming systems, and sustainable agricultural systems. Models and decision support systems will be developed that optimize strategies: to manage water resources; to resolve conflict among competing water demands when the supplies are limited; and to determine the socioeconomic and environmental impact of proposed water, nutrient, and pesticide management programs and policies. Water databases will be developed to demonstrate on-farm and off-site opportunities to improve water quality. Science-based results and technologies will be transferred to various user groups and policy makers and integrated into other ARS National Programs.'

The following eutrophication-related projects in the Water Quality and Management National Program are ongoing (in 1999) at ARS:

- Develop alfalfa to enhance nitrogen cycling and protect water quality;

- Improve nitrogen-use efficiency and water and environmental quality;
- Improve nitrogen-use efficiency to protect groundwater quality;
- Water and nitrogen management to protect groundwater quality;
- Integrated crop and soil management to improve nitrogen-use efficiency;
- Integrated nitrogen water and pesticide management systems to protect ground water quality;
- Controlling nitrogen loss from animal manure during composting;
- Integrate chemical and hydrologic processes for phosphorus management in agricultural watersheds;
- Effects of alum applications to hen manure on egg production and phosphorus runoff;
- Development of a thermostable feed additive to reduce phosphate contamination in groundwater;
- Integrated soil-nutrient-crop-microbial-pest-waste management strategies for sustainable agriculture;
- Fate and environmental impact of agricultural nutrients in sustainable production systems;
- Management effects on water, soil, nutrient, and pesticide losses from cropped and grazed watersheds;
- Improvement of nutrient use efficiency in agricultural systems;
- Improving nutrient cycling with perennial crops;
- Management of nutrients impacting the environment from beef feedlots;
- Efficient and environmentally sound conservation use of nutrients and carbon from animal manure;
- Conservation tillage-diverse crop systems to use water and nutrients efficiently to protect the environment.

In addition to these projects, ARS have recently produced a publication called ‘Agricultural Phosphorus and Eutrophication’ (USDA, 1999) which summarises issues and research in this area.

**Water Environment Research Foundation (WERF) (www.werf.org)**

WERF is the research arm of WEF, the Water Environment Federation, an international non-profit educational and technical organisation of over 40,000 water experts. WEF is a federation made up of 67 Member Associations throughout the world whose mission is "To Preserve and Enhance the Global Water Environment" through:

- providing technical information to a world-wide audience;
- expanding quality services to its members;
- building alliances with other organisations.

WERF is currently funding research in three broad areas of interest to its subscribing members:

1. collection and treatment systems;
2. human health effects and products;
3. watershed and ecosystem management.

Examples of recent and on-going eutrophication-related research projects in the area of watershed and ecosystem management have included:

- Development of technically-based site-specific measures for identifying the ecological impacts associated with nutrients;
- Use of riparian buffer zones in water quality management programs;
- Nitrogen credit trading for Long Island Sound watershed;
- Establishing a state-wide framework for nutrient trading in Maryland;
- Initiating watershed-based phosphorus trading in the Fox Wolf Basin of Northeast Wisconsin.

The use of tradable rights to ensure specific pollution quota are not exceeded within a particular catchment (the so-called Total Maximum Daily Load or TMDL) is an economic instrument that is currently being tested in several catchments within the United States. Tradable permits work on the principle that the total load of a pollutant entering a particular watershed (or catchment) must not exceed a certain level in order to meet the water quality objectives set within the catchment. Within the catchment, individual "polluters" can trade "pollution reduction credits" to other polluters. For example, in a "point-point" trade one point source discharge may easily be able to meet its discharge permit (or consent) and could further improve the quality of its effluent at relatively low cost whereas another point source within the catchment may not easily be able to do so. The former point source, could improve its effluent quality and then "sell" the excess pollution reduction credit to the latter point source at a price that is beneficial to both parties whilst still meeting the overall catchment TMDL.

Tradable permits have been the subject of great interest in the US in recent years, indeed, WERF are currently funding several such watershed-based trading demonstration projects in the US with the principle focus on nutrient trading. It is recommended that pilot studies should be considered to test the feasibility of catchment-based nutrient trading within the UK legal framework using the in the US as the basis for these studies.

Useful contacts within WERF:


| | |
|---|---|
| *Charles I. Noss*<br>*Research Deputy Director* | *E-mail: cnoss@wef.org*<br>*601 Wythe Street Alexandria.,*<br>*VA,*<br>*22314-1994,*<br>*Tel: 001 703 684 2470*<br>*Fax: 001 703 299 0742* |
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# 6. CONCLUSIONS AND RECOMMENDATIONS

1. R&D reports have been reviewed with particular emphasis on recommendations made for further studies. These recommendations have been carefully evaluated by the project team in light of the team's knowledge, expertise and opinion on future needs and with consideration of the Agency's business needs.

2. To assist in the prioritisation of R&D activities, a clear, simple and transparent process has been developed by combining a simple scoring and weighting exercise with a cost-effectiveness analysis. The majority of this prioritisation process has been implemented in a spreadsheet system - the Eutrophication R&D Prioritisation System (ERDPS). It is recommended that the Agency use this system in the prioritisation of any subsequent eutrophication-related research projects identified. The Agency may wish to modify the spreadsheet (e.g. change some of the weighting factors used) in light of their evolving business needs.

3. A priority list of cost-weighted recommended projects has been derived and selected projects entered onto a template that has been constructed by the Agency for proposals submitted to its national R&D programme. It is recommended that these projects be given careful consideration for commissioning within the Agency's R&D programme.

4. As part of the review process, the relevance of overseas eutrophication-related R&D has been identified, in particular, where scientific studies into the understanding and the management science of eutrophication are relatively advanced and is of relevance to the business needs of the Agency. Potential areas of research precipitating from this review worthy of further consideration by the Agency through contact and/or collaboration with overseas researchers and research organisations have been included within the ERDPS prioritisation process. Areas of interest identified include:

   ***Phosphorus geochemistry and losses from soils:*** *It is recommended that the Agency should further develop its understanding of the geochemical and hydrological pathways of phosphorus transport (such as whether and how much phosphorus exists in biologically reactive fractions, whether it moves primarily in solution or attached to particles, how subject it is to redox changes, etc.). In addition to working with MAFF, it is important for the Agency to take note of developments in this area in several overseas countries, most notably, Finland, US and Australia.*

   ***Biomanipulation and alternative steady states:*** *As a practical approach to the management of water quality in lakes and reservoirs, biomanipulation (the management of the aquatic system so that the sink for excess nutrient is one that is more aesthetically acceptable) is well established though the underpinning theory and the measures to improve the prospects of its successful application are still an area of contention. Further work is recommended to elucidate the prospects of biomanipulation as an effective management tool.*

   *Related to this is the concept of alternative stable states whereby macrophyte dominated systems can "flip over" to systems dominated by phytoplankton which are far less desirable. Currently there is a great deal of research interest in the existence of these alternative steady states with experiments being conducted in several European countries.*

*Indeed, as an approach to understanding ecosystem function in small, shallow and irreversibly eutrophic lakes, such research is generating management applications that will be of central interest to the Agency.*

***Public relations:*** *In several countries, most notably Switzerland and Australia the opportunity is being taken to inform and educate a public that is mostly oblivious to the connection between their own activities and aspirations with the deterioration of waterways through eutrophication. In fact, the message can be transparent and inspirational, as several examples of educational campaigns have demonstrated. It is recommended that the Agency review its own publicity material and public information programmes in light of the results of successful campaigns overseas.*

***Catchment-based nutrient trading:*** *Tradable permits have been the subject of great interest in the US in recent years, indeed, WERF are currently funding several such watershed-based trading demonstration projects in the US with the principle focus on nutrient trading. It is recommended that pilot studies should be considered to test the feasibility of catchment-based nutrient trading within the UK legal framework with the work in the US being used as the basis for these studies.*

5. The DPSIR approach (Driving forces, Pressures, State, and Impacts and Responses) to integrated environmental assessment adopted by the European Environment Agency is similar to the "Frameworks and Themes" methodology employed by the Environment Agency. This similarity in approach therefore lends added weight to collaboration between the EA and the EEA.

6. The EEA has set up an IEA Core Group to give general support particularly in the context of the development of the Second Muti-Annual Work Programme and the future development of the European Topic Centres. Included in the terms of reference of this Core Group is a responsibility for openness and the opportunity is available to the Agency to make use of this group for collaborative discussions. For specific expert advice on the application of IEA to the issue of Eutrophication the EEA has set up a network of European experts called IEA-EUNET.

7. Potential areas for national collaboration have been identified and contact names and addresses of potential overseas collaborators identified from the network of contacts available to the project team.

## REFERENCES

Baldwin, D.S. (1996) The phosphorus composition of a diverse series of Australian sediments. *Hydrobiologia*, **335**, 63-73.

Bendoricchio, Calligaro, G.L. and Carrer, G.M. (1999) Consequences of diffuse pollution on the water quality of rivers in the watershed of the Lagoon of Venice (Italy*). Water Science and Technology*, **39**, No. 3, 113-120.

Blindow, I., Andersson, G., Hargeby, A. and Johansson, S. (1993) Long-term pattern of alternative stable states in two shallow eutrophic lakes. *Freshwater Biology*, **30**, 159-167.

Blindow, I., Hargeby, A. and Johansson, S. (1998) Alternative steady states in lakes. What causes shift? In: *The structuring role of submerged macrophytes in lakes.* Ed. E.Jeppessen, M.Söndergaard, M.Söndergaard and K.Christoffersen, pp. 353-360. Springer Verlag, New York.

Cahoon, L.B., Mikucki, J.A. and Mallin, M.A. (1999) Nitrogen and phosphorus imports to the Cape Fear and Neuse river basins to support intensive livestock production. *Environmental Science and Technology*, **33**, No.3, 410- 415.

Caraco, N. F. (1995) Influence of human populations on P transfers to aquatic systems: a regional scale study using large rivers. In: *Phosphorus in the global environment*. Ed. H.Tiessen. John Wiley and Sons, Chichester, pp. 235-244.

Carpenter, S.R. and Kitchell, J.F. (1992) Trophic cascade and biomanipulation: interface of research and management. A reply to the comment of De Melo *et al*. *Limnology and Oceanography*, **37**, 208-213.

Carpenter, S.R. and Kitchell, J.F. (1993) The trophic cascade in lakes. Cambridge University Press, Cambridge.

Carpenter, S.R., Kitchell, J.F. and Hodgson, J.R. (1985) Cascading trophic interactions and lake productivity. *BioScience*, **35**, 634-639.

Carpenter, S.R., Ludwig, D. and Brock, W.A. (1999) Management of eutrophication for lakes subject to potentially irreversible change. *Ecological Applications*, **9**, 751-771.

Chiaudani, G.R., Marchetti, R. and Vighi, M. (1980) Eutrophication in Emilia-Romagna coastal waters (North Adriatic Sea, Italy): a case history. *Progress in Water Technology*, **12,** No. 1, 185-192.

Cloot, A.H.J. and Pieterse, A.J.H. (1999) Modelling phytoplankton in the Vaal River (South Africa). *Water Science and Technology*, **40**, No.10, 119-124.

Colijn, F., ten Brink, B.J.E. and Cofino, W. (1991) Biological trend monitoring as part of an integrated monitoring approach in the Netherlands. Discussion Paper R32, Seminar on the Ecosystems Approach to Water Management. UN/ECE, Geneve.

Costanza, R. and Mageau, M. (1999) What is a healthy ecosystem? *Aquatic ecology*, **33**, 105-115.

Cullen, P. (1994) Catchments: where water quality starts. In: *Sustainable management of Australia's inland waters.* Eds B.D.Mitchell and D.G.Day, pp. 29-43. ARUMRG, Warnambool.

Curry, N. and Stucki, E. (1997) Swiss agricultural policy and the environment. An example for the rest of Europe to follow? *Journal of Environmental Management and Planning*, **40**, 465-482.

Dawson F.H., Newman J.R. and Gravelle M.J. (1999) Mean Trophic Rank Macrophyte Survey: An Assessment of the Trophic Status of Rivers using Macrophytes. R & D Technical Report E39, Environment Agency, 200pp.

de Groot, C.J. and Golterman, H.L. (1993) Sequential fractionation of sediment phosphorus. *Hydrobiologia*, **252**, 117-126.

De Melo, R., France, R. and McQueen, D.J. (1992) Biomanipulation: hit or myth? *Limnology and Oceanography*, **37**, 192-207.

Demars, B.O.L. and Harper, D. M. (1998) The aquatic macrophytes of an English lowland river system: assessing response to nutrient enrichment. *Hydrobiologia*, **384**, 75-88

Dodds, W.K., Smith, V.H. and Zander, B. (1997) Developing nutrient targets to control benthic chlorophyll levels in streams: A case study of the Clark Fork River. *Water Research*, **31**, No.7, 1738-1750

Dorioz, J.M., Cassell, E.A., Orand, A. and Eisenman, K.G. (1998 a) Phosphorus storage, transport and export dynamics in the Foron river watershed. *Hydrological Processes*, **12**, No.2, 285-309.

Dorioz, J.M., Pelletier, J.P., and Benoit, P. (1998 b) Physico-chemical properties and bioavailability of particulate phosphorus of various origin in a watershed of Lake Geneva (France). *Water Research*, **32**, No.2, 275-286.

Douglas, G.B., Adeney, J.A. and Robb, M. (1999) A novel technique for reducing bioavailable phosphorus in water and sediments. Proceedings of the International Conference on diffuse pollution, Perth (in press).

Douglas, G.B., Coad, D.N. and Adeney, J.A. (1998) Reducing phosphorus in aquatic systems using modified clays. *Water*, **25,** No. 3, 42-43.

Environment Agency (1997) An Environmental Strategy for the Millenium and Beyond. Environment Agency, Bristol, UK.

Environment Agency (1998) Aquatic eutrophication in England and Wales: a proposed management strategy. Consultative Report. Environment Agency, Bristol, UK.

Environment Agency (1999) Corporate Plan 1999-2000. Our look forward to 2002. Environment Agency, Bristol.

European Environment Agency (EEA) (1999) Nutrients in European ecosystems. Environmental Assessment Report No. 4, EEA Copenhagen.

Ekholm, P. (1994) Bioavailability of phosphorus in agriculturally loaded rivers in southern Finland. *Hydrobiologia*, **287**, 179-194.

Faafeng, B. and Mjeld, M. (1998) Clear and turbid water in shallow Norwegian lakes related to submerged vegetation. In: *The structuring role of submerged macrophytes in lakes*. Ed. E.Jeppessen, M.Söndergaard, M.Söndergaard and K.Christoffersen, pp. 361-368. Springer Verlag, New York.

Foy, R.H., Smith, R.V., Jordan, C. and Lennox, S.D. (1995) Upward trend in soluble phosphorus loadings to Lough Neagh despite phosphorus reduction at sewage-treatment works. *Water Research*, **29**, No.4, 1051-1063.

Gerdes, P. and Kunst, S. (1998) Bioavailability of phosphorus as a tool for efficient P reduction schemes. *Water Science and Technology*, **37**, No.3, 241-247.

Haury, J., Jaffre, M., Dutartre, A., Peltre, M.C., Barbe, J., Tremolieres, M., Guerlesquin, M. and Muller, S. (1998) Application of the standardized protocol "Milieu Et Vegetaux aquatiques fixes" to 12 French rivers: preliminary floristic typology. *Annales de Limnologie-International Journal of Limnology*, **34**, No.2, 129-139.

Hilton, J. and Irons, G.P. (1998) Determining the causes of "apparent eutrophication" effects. Environment Agency R&D Technical Report P203, Bristol.

Hilton, J., Irons, G.P. and McNally, S. (2000) Pilot Catchment Study of Nutrient Sources – Control Options and Costs. Environment Agency R&D Technical Report P345, Bristol.

Hosper, S.H. and Meijer, M.L. (1993) Biomanipulation, will it work in your lake? A simple test for the assessment of chances for clear water, following drastic fish-stock reduction in shallow, eutrophic lakes. *Ecological Engineering*, **2**, 63-72.

Hosper, S.H., Meijer, M.L. and Walker, P.A. (1992) Handleiding Actief Biologisch Beheer - Beoordeeling van de mogelijkhedenvan visstandbeheer bij het herstel van meren en plassen. RIZA-OVB, Lelystad.

House, W.A., Denison, F.H. and Armitage, P.D. (1995a). Comparison of the uptake of inorganic phosphorus to a suspended and stream bed sediment. *Water Research*, **29**, No.3, 767-779

House, W.A., Denison, F.H., Smith J.T. and Armitage, P.D. (1995b) An investigation of the effects of water velocity on inorganic phosphorus influx to a sediment. *Environmental Pollution,* **89**, No.3, 263-273.

Hrbcek, J. Dvorckovc, M., Korpnek, V. and Prochczkovc, L. (1961) Demonstration of the effect of the fish stock on the species composition of the zooplankton and the intensity of the metabolism of the whole plankton association. *Verhandlungen der internationale Vereinigung für theoretische und angewandte Limnologie*, **14**, 192-195.

Jeppesen, E., Kristensen, P., Jensen, J.P., Söndergaard, M., Mortensen, E. and Lauridsen, T.L. (1991) Recovery resilience following a reduction in external phosphorus loading of shallow eutrophic Danish lakes: duration, regulating factors and methods of overcoming resilience. *Memorie dell'Istituto italiano di Idrobiologia*, **48**, 127-148.

Johnes, P. J. (1996) Evaluation and management of the impact of land use change on the nitrogen and phosphorus load delivered to surface waters: the export coefficient modelling approach. *Journal of Hydrology*, **183**, 323-349.

Kelly, M.G. and Whitton, B.A. (1995) Trophic diatom index - a new index for monitoring eutrophication in rivers. *Journal of Applied Phycology*, **7**, No.4, 433-444.

Kelly, M.G. and Whitton, B.A. (1998) Biological monitoring of eutrophication in rivers. *Hydrobiologia*, **384**, 55-67.

Kinniburgh, J.H., Tinsley, M.R. and Bennett, J. (1997) Orthophosphate concentrations in the River Thames. *Journal of the Chartered Institution of Water and Environmental Management*, **11**, No.3, 178-185.

Kolkwitz, R. and Marsson, M. (1909) Okologie der tischen Saprobien. Beitrage zur Lehre von der Gewasserbeurteilung. *Internationale Revue der gesamten Hydrobiologie und Hydrographie*, **2**, 126-152.

Køllqvist, T. and Berge, D. (1990) Biological availability of phosphorus in agricultural run-off compared to other phosphorus sources. *Verhandlungen der internationale Vereiniging für Hydrobiologie*, **24**, 214-217.

Likens, G.E. and Davis, M.B. (1975) Post-glacial history of Mirror Lake and its watershed in New Hampshire, USA: an initial report. *Verhandlungen der internationale Vereinigung für theoretische und angewandte Limnologie*, **19**, 982-993.

Macdonald, A.M., Edwards, A.C., Pugh, K.B. and Balls, P.W. (1995) Soluble nitrogen and phosphorus in the river Ythan system, UK - annual and seasonal trends. *Water Research*, **29**, No.3, 837-846

Marsden, M.W., Smith, M.R. and Sargent, R.J. (1997) Trophic status of rivers in the Forth catchment, Scotland. *Aquatic Conservation – Marine and Freshwater Ecosystems*, **7**, 211-221.

Mainstone, C.P., Clarke, S. and Parr, W. (1998) A review of ecological models of potential use in environmental forecasting. Report to the Environment Agency. WRc, Medmenham.

McFarland, A.M.S. and Hauck, L.M. (1999) Relating agricultural land uses to in-stream storm-water quality. *Journal of Environmental Quality*, .**28**, No.3, 836- 844

Muscutt, A.D. and Withers, P.J.A. (1996) The phosphorus content of rivers in England and Wales. *Water Research*, **30**, No.5, 1258-1268.

OSPAR (1998). OSPAR Strategy to Combat Eutrophication (Ref. No. 1998-18). Available from www.ospar.org.uk.

Pietilüinen, O.P. (1997) Agricultural phosphorus load and phosphorus as a limiting factor for algal growth in Finnish lakes and rivers. In: *Phosphorus loss from soil to water*. Eds H.Tunney, O.T.Carton, P.C.Brookes and A.E.Johnston, pp. 354-356. CAB International, Wallingford.

Portielje, R., Kersting, K. and Lijklema, L. (1996) Primary production estimation from continuous oxygen measurements in relation to external nutrient input. *Water Research*, **30**, No.3, 625-643.

Qotbi, A., Dauta, A., Sarpedon, V., and Promeyrat, S. (1996) Estimation of the available phosphate for phytoplankton stored in the soft sediments of the river Lot. *Hydrobiologia*, **335**, No.1, 49-53.

Reynolds, C.S. (1992) Eutrophication and the management of planktonic algae: what Vollenweider couldn't tell us. In *Eutrophication: research and application to water supply*. Eds D.W.Sutcliffe and J.G.Jones, pp. 4-29. Freshwater Biological Association, Ambleside.

Reynolds, C.S. (1994) The ecological basis of biomanipulation of aquatic communities. *Archiv für Hydrobiologie*, **130**, 1-33.

Reynolds, C.S. (1999) Metabolic sensitivities of lacustrine ecosystems to anthropogenic forcing. *Aquatic Sciences*, **61**, 183-205.

Robach, F., Hajnsek, I., Eglin, I. and Tremolieres, M. (1995) Phosphorus sources for aquatic macrophytes in running waters: Water or sediment? *Acta Botanica Gallica*, **142**, No.6, 719-731

Robach, F., Thiebaut, G., Tremolieres, M. and Muller, S. (1996) A reference system for continental running waters: Plant communities as bioindicators of increasing eutrophication in alkaline and acidic waters in north-east France. *Hydrobiologia*, **340**, No.1-3, 67-76.

Roijackers, R., Aalderink, R.H. and Blom, G. (Eds.) (1998) Eutrophication Research. State-of-the-Art: Inputs, Processes, Effects, Modelling, Management. *Water Science and Technology*, **37** (3).

Sas, H. (ed.). (1989) Lake restoration by reduction of nutrient loading. Academia Verlag Richarz, Skt. Augustin.

Scheffer, M. (1989) Alternative steady states in eutrophic, shallow freshwater systems: a minimal model. *Hydrobiological Bulletin*, **23**, 73-83.

Scheffer, M. (1990) Multiplicity of stable states in freshwater system. *Hydrobiologia*, **200/201**, 475 - 486.

Scheffer, M. (1998) Ecology of shallow lakes. Chapman and Hall, London.

Scheffer, M. and Jeppesen, E. (1998) Alternative stable states. In: *The structuring role of submerged macrophytes in lakes.* Ed. E.Jeppessen, M.Söndergaard, M.Söndergaard and K.Christoffersen, pp. 397-406. Springer Verlag, New York.

Scheffer, M., Hosper, S.H., Meijer, M.L., Moss, B. and Jeppessen, E. (1993) Alternative equilibria in shallow lakes. *Trends in Ecology and Evolution*, **8**, 275 -279.

Sharpley, A.N. and Rekolainen, S. (1997) Phosphorus in agriculture and its environmental implications. In: *Phosphorus loss from soil to water*. Eds H.Tunney, O.T.Carton, P.C.Brookes and A.E.Johnston, pp. 1-53. CAB International, Wallingford.

Söndergaard, M. and Moss, B. (1998) Impact of submerged macrophytes on phytoplankton in shallow lakes. In: *The structuring role of submerged macrophytes in lakes*. Ed. E.Jeppessen, M.Söndergaard, M.Söndergaard and K.Christoffersen, pp. 115-132. Springer Verlag, New York.

Söndergaard, M., Kristensen, P. and Jeppesen, E. (1993). Eight years of internal phosphorus loading and changes in the sediment phosphorus profile of Lake Söbygaard, Denmark. *Hydrobiologia*, **253**, 345-356.

Stadelmann, P., Bürgi, H.-R. and Butscher, E. (1997) Massnahmen zur Seensanierung: Beispiel des Baldergersees. *Monatsbulletin der Scweizerische Vereinigung für Gas und Wasserfaches*, **77**, 25-32.

Thebault, J.M. and Qotbi, A. (1999) A model of phytoplankton development in the lot river (France). Simulations of scenarios. *Water Research*, **33**, No.4, 1065-1079.

Thiebaut, G. and Muller, S. (1998) Aquatic macrophyte communities as water quality indicators: example of the river Moder (Northeast France). *Annales de Limnologie-International Journal of Limnology*, **34**, No.2, 141-153.

Thomas, E.A. (1953) Zur Bekümpfung der See-Eutrophierung: empirische und experimentelle Untersuchungen zur Kentniss der Minimumstoffe in 46 Seen der Schweiz und angrenzender Gebiete. *Monatsbulletin der Scweizerische Vereinigung für Gas und Wasserfaches*, **33**, 25-32.

Tiessen, H. (ed.). (1995) Phosphorus in the global environment. John Wiley & Sons, Chichester.

USDA (1999) Agricultural phosphorus and eutrophication. USDA Agricultural Research Service ARS-149.

Vollenweider, R.A. (1968) Scientific fundamentals of the eutrophication of lakes and flowing waters, with particular reference to nitrogen and phosphorus as factors in eutrophication. OECD, Paris.

Vollenweider, R.A. and Kerekes, J. (1982) Eutrophication of waters, monitoring, assessment and control. OECD, Paris.

Walker, H.F. (1996) Some philosophical issues in conservation and management of Australia's rivers. In: *Sustainable management of Australia's inland waters*. Eds B.D.Mitchell and D.G.Day, pp.47-63. ARUMRG, Warnambool.

Whitehead, P.G., Wilson, E.J. and Butterfield, D. (1998a) A semi-distributed Integrated Nitrogen model for multiple source assessment in Catchments (INCA): Part I - model structure and process equations. *Science of the Total Environment*, **210/211**, 547-558.

Whitehead, P.G., Wilson, E.J., Butterfield, D. and Seed, K. (1998b) A semi-distributed Integrated Nitrogen model for multiple source assessment in Catchments (INCA): Part II - application to large river basins in south Wales and eastern England. *Science of the Total Environment*, **210/211**, 559-583.

Wright, J.F., Armitage, P.D., Furse, M.T. and Moss, D. (1989) Prediction of invertebrate communities using stream measurements. *Regulated Rivers, Research and Management*, **4**, 139-146.

Xue, Y., David, M.B., Gentry, L.E. and Kovacic, D.A. (1998). Kinetics and modelling of dissolved phosphorus export from a tile-drained agricultural watershed. *Journal of Environmental Quality*, **27**, No.4, 917-922.

Young, W.J., Marston, F.M. and Davis, J.R. (1996). Nutrient exports and land use in Australian catchments. *Journal of Environmental Management*, **47**, No.2, 165-183.

# APPENDIX A REVIEW OF EUTROPHICATION-RELATED R&D PROJECTS

## A1 INTRODUCTION

Eutrophication-related R&D projects were identified from the major UK funders (see Section 2) and added to a spreadsheet. Using information from a project summary or the title, each project was cross-referenced with the Eutrophication Focus Areas (see Section 3 and Table A1) in an effort to identify which of the Focus Areas was addressed, at least to some extent, by the project. In excess of 150 projects were identified and the tables in each of the following sections indicate which of the Eutrophication Focus Areas the project addressed.

The following sections detail the UK eutrophication-related R&D projects in relation to the Eutrophication Focus Areas. The requirements for further research arising from key projects, especially recent review documents, are described more fully.

**Table A1 Eutrophication Focus Areas**

| Focus Areas | Sub-divided into Waterbody type? |
|---|---|
| PAC 1 Attenuating nuisance impact | Y |
| PAC 2 Chemical targets | Y |
| PAC 3 Ecological targets | Y |
| PAC 4 Source measures | N |
| PAC 5 Impact assessment | Y |
| PAC 6.1 ECAP tool: Source apportionment | N |
| PAC 6.2 ECAP tool: Cause-effect relationships | Y |
| PAC 6.3 ECAP tool: Cost-benefit and effectiveness | N |
| PAC 6.4 ECAP tool: Collaboration mechanisms | N |
| PAC 6.5 ECAP tool: Control techniques | N |
| PAC 6.6 ECAP tool: Monitoring framework | N |

## A2 ATTENUATING NUISANCE IMPACT

Table A2 lists the projects, where identified, addressing nuisance attentuation in lakes and reservoirs, rivers, estuaries and coastal waters and wetlands. Further information on each project is available from the funding bodies (see Section 2 for contact details).

**Table A2 UK funded eutrophication-related R&D projects addressing nuisance attentuation in lakes and reservoirs, rivers, estuaries and coastal waters and wetlands**

| Ref | Title | End Date | Funding body | Lakes and reservoirs | Rivers | Estuaries and coasts | Wetlands |
|---|---|---|---|---|---|---|---|
| TR W105 | Biological control of weeds - a scoping study of the feasibility of biological control of aquatic and riparian weeds in the UK | 1996 | EA | x | x | | |
| Note 395 | Aquatic Weed Control Operation Best Practice Guidelines | 1995 | EA | x | x | | |
| FR 0461 | The use of straw to control blue-green algal growth: final report on work undertaken by the Aquatic Weeds Research Unit 1991-94 | 1994 | FWR | x | x | | |
| Note 276 | Is biomanipulation a useful technique in lake management? | 1994 | EA | x | | | |
| PR 294/7/W | Control of invasive riparian and aquatic weeds | 1994 | EA | x | | | |
| FR 0458 | Further studies to investigate microcystin-LR and anatoxin-a removal from water | 1994 | FWR | x | | | |
| FR 0434/Doe 372 | Toxins from blue green algae: toxicological assessment of anatoxin-a and a method for its determination in water | 1994 | FWR | x | | | |
| FR 0491 | Executive summary for project F-1002: Guidelines for removing algal toxins from water | 1994 | FWR | x | | | |
| Note 189 | Aquatic Weed Control Operations - Phase 1. Existing Practice | 1993 | EA | x | x | | |
| FR 0363 | An analytical method for anatoxin-a, a blue green algal neurotoxin, in reservoir water | 1993 | FWR | x | | | |

| Ref | Title | End Date | Funding body | Lakes and reservoirs | Rivers | Estuaries and coasts | Wetlands |
|---|---|---|---|---|---|---|---|
| FR 0365 | Biological control of blue green algal levels in reservoirs: the utility of silver carp | 1993 | FWR | x | | | |
| FR 0367 | Microsystin-LR removal from water | 1993 | FWR | x | | | |
| FR 0248 | A review of potential methods for controlling phytoplankton, with particular reference to cyanobacteria, and sampling guidelines for the Water Industry | 1992 | FWR | x | x | x | |
| Note 53 | Grass carp for aquatic weed control | 1992 | EA | x | x | | |
| FR 0285 | Investigations into the use of straw to control blue green algal growth | 1992 | FWR | x | x | | |
| FR 0327 | Further development and optimisation of a pilot-scale straw based bankside fermenter for control of algal growth | 1992 | FWR | x | x | | |
| FR 0269 | Toxicology of microcystin-LR | 1992 | FWR | x | | | |
| FR 0292 | An investigation into the degradation of microcystin-LR | 1992 | FWR | x | | | |
| FR 0300 | Manipulation of fish communities to control algal levels in reservoirs | 1992 | FWR | x | | | |
| FR 0303 | Algal toxin removal from water | 1992 | FWR | x | | | |
| FR 0272 | Analytical methods for the analysis of blue green algal toxins - a review | 1992 | FWR | x | | | |
| FR 0223 | Detection and removal of cyanobacterial toxins from freshwaters | 1991 | FWR | x | x | | |
| FR 0224 | Development of an analytical method for blue-green algal toxins | 1991 | FWR | x | | | |

## A2.1 Lakes and Reservoirs

The nuisance attenuation issues addressed in these projects include:

- Control of phytoplankton blooms (especially cyanobacteria) including the use of straw and fish;
- Biomanipulation;
- Aquatic weed control;
- Algal toxins: identification, analysis and removal.

There appears to be little recent research (since 1995) in this area. Biomanipulation is of current interest (see Section 4) and further research is proposed on this topic.

## A2.2 Rivers

The nuisance attenuation issues addressed in these projects include:

- Control of phytoplankton blooms (especially cyanobacteria) including the use of straw and fish;
- Aquatic weed control.

There appears to be little recent research in this area.

## A2.3 Estuaries and coastal waters

There appears to have been little research into nuisance attenuation in estuaries and coastal waters. The issue of Harmful Algal Blooms (HABs) is an active research area in the US sponsored by the US EPA (see Section 5.3.3) and has received some attention in EU sponsored research (see Section 5.2.2).

## A2.4 Wetlands

Nuisance attention issues on wetlands appear to have received little research activity.

# A3 CHEMICAL TARGETS

Table A3 lists the projects, where identified, addressing chemical targets in lakes and reservoirs, rivers, estuaries and coastal waters and wetlands. Further information on each project is available from the funding bodies (see Section 2 for contact details).

**Table A3 UK funded eutrophication-related R&D projects addressing chemical targets in lakes and reservoirs, rivers, estuaries and coastal waters and wetlands**

| Ref | Title | End Date | Funding body | Lakes and reservoirs | Rivers | Estuaries and coasts | Wetlands |
|---|---|---|---|---|---|---|---|
| E54 | Trial classification of lake water quality in England and Wales: a proposed approach | 1999 | EA | x | | | |
| Note 253 | Lakes: Classification and monitoring - a strategy for the classification of lakes | 1994 | EA | x | | | |
| NR 2397 | An assessment of the environmental quality standards for inorganic nutrients necessary to prevent eutrophication (nuisance growth of algae) | 1991 | EA | x | x | x | x |
| PR 469/11/HO | Development and testing of GQA schemes: Nutrients in rivers and canals | 1995 | EA | | x | | |
| NR 3698 | River Eutrophication Risk Modelling: A GIS Approach | 1994 | SNIFFER | | x | | |
| P269 | The impacts of nutrients in estuaries Phase II | 1999 | EA/EN | | | x | |
| 639/1/A | The impacts of nutrients in estuaries - Proceedings of the scoping workshop | 1995 | EA/EN | | | x | |

Chemical targets in the form of environmental quality standards (EQSs) or classification scheme class thresholds form an important part of water quality protection in the UK. An early attempt was made to consider the development of EQSs for nutrients that would apply to all controlled waters but such standards were not proposed. The development of classification schemes for all controlled waters has involved the derivation of chemical targets for nutrients to be used as class thresholds.

## A3.1 Lakes and reservoirs

The Environment Agency has commissioned significant R&D into approaches to the classification of lakes. The two main processes affecting lake quality are eutrophication and acidification and two approaches have been suggested to classify lakes in relation to these processes: the Spatial State Scheme and the State Changed Scheme. The Spatial State Scheme is a classification system whereby the conditions in an ecosystem are used to assign that system to a particular class or category for the purposes of establishing the current state of the resources. The State Changed scheme is a system in which the present conditions in an ecosystem are compared with those at a previous time or with a reference or baseline state. The chemical targets used in relation to eutrophication include: mean annual lake total P concentration (Spatial State) and mean annual inflow of total N, P and nitrate-N, mean annual lake total N and P, minimum secchi depth (State Changed). In addition to these chemical targets, measurements of chlorophyll *a* are used as well (see Section A4.1).

## A3.2 Rivers

The Environment Agency commissioned significant R&D into the development and testing of General Quality Assessment schemes. A classification scheme for nutrients in rivers was one of the modules developed but has only been implemented as a pilot scheme. Chemical targets for nutrients in relation to risk of eutrophication were also used in the development of a GIS based modelling approach for assessing eutrophication risk in Scotland.

## A3.3 Estuaries and coastal waters

The issue of classification of estuaries using chemical targets for nutrients alongside other measures was considered as part of a recent review of the impact of nutrients in estuaries (Scott *et al.,* 1999).

### A3.3.1 Impact of Nutrients in estuaries - Phase 2 (Scott *et al*., 1999)

This important and wide ranging review was commissioned by the Environment Agency and English Nature to contribute towards a sound scientific understanding of the impacts of nutrients in estuaries on which to base effective management strategies. The review considered:

- The effect of physico-chemical factors;
- Biological impact of nutrients;
- Available tools for monitoring and management;
- Recommendations for monitoring and management.

With particular reference to chemical targets, the use of nutrient standards and targets was reviewed in the context of proposed classification schemes.

#### A3.3.1.1 Proposed Estuary Classification Schemes

Scott *et al*. (1999) identified eight physico-chemical characteristics that could be used together to classify estuaries in terms of the impact of nutrients. These were:

- Nutrient input;
- Turbidity;
- Flushing time;
- Tidal range (relative to depth);

- Risk of stratification;
- Freshwater input (relative to volume);
- Width:depth ratio;
- Intertidal:subtidal area ratio.

The most important of these were considered to be nutrient input, turbidity and flushing time.

Three approaches were described to combine measures associated with these variables into a classification scheme (for more information see Scott *et al.,* 1999):

- Multivariate statistical approach;
- Tabulated representations;
- 'Decision tree.'

The multivariate statistical approach was considered to be the ideal approach for estuary classification because it was the most objective procedure. The ultimate goal for the Environment Agency (and English Nature) should be to collate sufficient data to apply this approach. However, this technique will require an extensive collation of data, the development of highly accurate normalised scales for the eight classification criteria and very detailed understanding of the relationship between criteria. For these reasons this approach was considered impractical in the short term.

The most realistic approach, and the one that is recommended here, is the 'tabulated representation' procedure. It is believed that sufficient data are presently available to apply this technique although an extensive data collation exercise is still required. The 'decision tree' approach is simply a variant on this approach and could be tested when sufficient data are obtained.

Scott *et al.* (1999) recognised that information on all eight key physico-chemical characteristics would not be readily available for sufficient estuaries to readily proceed with the development of the proposed classification schemes. They suggested some alternative approaches using fewer of the physico-chemical characteristics (see Scott et al. (1999) for more information):

- Three factor approach – using just nutrient inputs, turbidity and flushing time;
- Nutrient input/output – evaluating the nutrient capacity of an estuary, or regions in an estuary, based on the input and output of nutrients;
- Best expert judgement – this largely qualitative approach involves the compilation and completion of a questionnaire for an estuary followed by the 'best expert judgement' about an estuary's susceptibility to nutrient impacts.

The qualitative 'best expert judgement' technique has the advantage that many details can be obtained through this approach that may be missed by applying a purely quantitative approach. Therefore, some form of qualitative analysis should be used in conjunction with the objective techniques described above. It is likely that other management schemes adopted by the Environment Agency (and English Nature), for example for the management of SACs, will require elements of this approach.

Scott *et al.* (1999) also proposed a monitoring and management protocol to identify estuaries most at risk from the impacts of nutrients based on ecological targets (see Section A4.3) and a number of other research projects addressing the impacts of nutrients in estuaries (see Section A5.3).

### A3.4 Wetlands

There appears to have been little research addressing the use of chemical targets in wetlands in relation to eutrophication.

## A4 ECOLOGICAL TARGETS

Table A4 lists the projects, where identified, addressing ecological targets in lakes and reservoirs, rivers, estuaries and coastal waters, and wetlands. Further information on each project is available from the funding bodies (see Section 2 for contact details).

**Table A4 UK funded eutrophication-related R&D projects addressing ecological targets in lakes and reservoirs, rivers, estuaries and coastal waters and wetlands**

| Ref | Title | End Date | Funding body | Lakes and reservoirs | Rivers | Estuaries and coasts | Wetlands |
|---|---|---|---|---|---|---|---|
| E54 | Trial classification of lake water quality in England and Wales: a proposed approach | 1999 | EA | x | | | |
| Note 253 | Lakes: Classification and monitoring - a strategy for the classification of lakes | 1994 | EA | x | | | |
| TR E2 | The trophic diatom index: a users manual | 1996 | EA | | x | | |
| NR 3698 | River Eutrophication Risk Modelling: A GIS Approach | 1994 | SNIFFER | | x | | |
| | Scientific support for the management of nutrients II | 2000 | DETR | | | x | |
| P269 | The impacts of nutrients in estuaries Phase II | 1999 | EA/EN | | | x | |
| 639/1/A | The impacts of nutrients in estuaries - Proceedings of the scoping workshop | 1995 | EA/EN | | | x | |

Ecological targets in the form of Ecological Quality Objectives (EcoQOs) or standards based on biological rather than chemical characteristics (e.g. chlorophyll *a*) have been used in classification schemes and have been proposed for monitoring the effects of eutrophication.

## A4.1 Lakes and reservoirs

The proposed approaches to lake classification (see Section A3.1 for more detail) include the following measurements of chlorophyll *a*: mean annual chlorophyll *a* concentration (Spatial State Scheme) and maximum chlorophyll *a* concentration (Changed State Scheme).

## A4.2 Rivers

In addition to the measurements of chlorophyll *a*, some other ecological targets have been developed to measure the effects of eutrophication in rivers.

### A4.2.1 Use of diatoms to monitor nutrients in rivers (Kelly, 1996)

The Trophic Diatom Index (TDI) is a new biological index, developed by the EA to meet the challenges of the UWWTD for and against nutrient stripping at large sewage treatment works. Based on the identification of less than 100 taxa, the principal innovation of the TDI is its ability to differentiate between sites where organic pollution has a significant impact on the benthic flora and those where eutrophication has an impact independent of organic pollution. Related indices include the Diatom Quality Index (DQI), based on diatoms, and the Mean Trophic Rank (MTR), based on macrophytes (see Kelly (1996) for more information).

#### A4.2.1.1 Use of diatoms: future research

- Evaluate relationship between the Diatom Quality Index (DQI) (scale identical to MTR) and TDI.
- Evaluate the potential of the TDI beyond monitoring of UWWTD Sensitive Areas e.g. SSSIs and SACs.
- Role of TDI/DQI in nutrients GQA window.
- Examine reasons why some genera presented taxonomic problems.
- Development of computer-based ID aids and more user-friendly keys i.e. including more taxa.
- Evaluate the potential for using artificial substrates and other novel techniques in rivers.

## A4.3 Estuaries and coastal waters

Scott *et al.* (1999) proposed a monitoring and management protocol to identify estuaries most at risk from the impacts of nutrients based on Ecological Quality Objectives (EcoQOs).

The proposed protocol comprises four stages:

- Screen estuaries for symptoms of eutrophication;

- Assess the severity of biological symptoms and the status of available biological data;
- Identify reasons for severe symptoms, determine whether nutrient enrichment is the causal factor and assess the status of available physical and chemical data;
- Define the response by the Environment Agency and English Nature.

To assist in the screening stage of the process a set of EcoQOs was proposed to describe the symptoms of eutrophication in estuaries (see Scott *et al.* (1999) for further details). Scott *et al.* (1999) suggested that further research be carried out to further develop this monitoring and management protocol and the proposed classification schemes using chemical targets (see Section A3.3).

The recommended direction for further research was towards:

(a) an evaluation of the estuary classification schemes/procedures;

(b) monitoring and management protocol.

These two goals are not mutually exclusive because a valid classification system is required within the monitoring protocol therefore these two studies should be carried out together.

It is of note at this stage, that the classification procedure will have a value beyond just the investigation of nutrient impacts. As it describes the capacity of estuaries to retain nutrients it may also indicate the potential capacity for the retention of their ‘pollutants’ such as heavy metals or phthalates.

It will first be necessary to ensure that these two projects are workable before resources are committed to their implementation on national scale (which should be the ultimate aim of this project). It is recommended that a preliminary testing approach is taken whereby the classification procedure, assessment of biological symptoms and the subsequent designation of protocols for monitoring and management should all be tested on a small subset of estuaries.

The procedure for this preliminary investigation involves the following three stages:

1. A preliminary test of the classification scheme using data both to test the efficacy of the scheme and ultimately to identify the absolutes or extremes of each factor within the scheme (e.g. the highest and lowest tidal ranges). As physical data are readily available for almost all UK estuaries, it should be relatively straightforward to collate the minimum data required to make a preliminary selection of 20-30 estuaries. The classification scheme could be applied on a subset of estuaries that should cover a range of areas around England and Wales and particularly all Environment Agency regions. Consideration should also be given to the next stage of the programme, the review of biological responses (see below), and estuaries with a range of symptoms should also be included (where these are known). There are sufficient data available on the physical environment of estuaries that can be used and much work has already been done by the JNCC in bringing together this information. This database would be a valuable starting point for the development and testing of the classification procedures and the refinement and further development of EcoQOs.

2. A review of biological responses in these selected estuaries should be undertaken. Data should be collected from each Environment Agency region and other agencies according to a standard protocol. This stage should test all aspects of the monitoring protocol including the 'Estuary Screening' Process, the conclusions about Symptom Severity and the assessment of reasons for, or risks of problem conditions occurring.

3. Finally, a decision should be reached about whether clear monitoring and management decisions can be made in the light of the information collected during the first two stages.

The use of ecological targets in the proposed monitoring and management procedure is consistent with the proposed Water Framework Directive where descriptors of 'ecological quality' would be required for transitional waters (estuaries). The concept of EcoQOs is also being addressed in ongoing DETR sponsored research in support of the OSPAR Strategy to Combat Eutrophication.

### A4.4 Wetlands

There appears to have been little research into ecological targets to describe the response of wetlands to eutrophication.

## A5 SOURCE MEASURES

Table A5 lists the projects, where identified, addressing source measures. Further information on each project is available from the funding bodies (see Section 2 for contact details).

**Table A5 UK funded eutrophication-related R&D projects addressing source measures**

| Ref | Title | End Date | Funding body |
|---|---|---|---|
| | Landscape analysis of transport, transformation and fate of reactive nitrogen and abatement strategies | | NERC GANE |
| | Application of catchment scale data to the quantification of soluble organic and inorganic N fluxes within and from UK upland soils | | NERC GANE |
| | MAFF Nitrate R&D Programme | | MAFF |
| | MAFF R&D on phosphate loss from agriculture | | MAFF |
| MAF12260 | Optimising soil management to prevent contamination of surface waters by sediment, phosphorus and micro-organisms | 2003 | BBSRC |
| MAF12247 | Scale and uncertainty in modelling phosphorus transfer from agricultural grasslands to watercourses: development of a catchment scale management tool | 2003 | BBSRC |
| P2-123 | Soil erosion and control in maize | 2001 | EA, MAFF |

| Ref | Title | End Date | Funding body |
|---|---|---|---|
| D08080 | Colloidal organic matter and phosphorus transfer in grassland hydrological pathways | 2000 | BBSRC |
| | Nitrates Directive: catchment based study to identify options for reductions in nutrient outflows to sea | 2000* | DETR |
| | Catchment based study to identify options for reductions of nutrient flows to sea II | 2000* | DETR |
| | Diffuse pollution: sources of nitrogen and phosphorus | 2000 | DETR |
| P2A(97)01 | Pilot Catchment study of nutrient sources – control options and costs | 2000 | EA |
| 24303010 | Leaching and ion transport in grassland soils | 1999 | BBSRC |
| 031479 | Measure run-off and soil losses, and associated losses of phosphate, other nutrients and pollutants on land liable to erosion | 1999 | BBSRC |
| P203 | Determining the causes of 'apparent eutrophication' effects | 1998 | EA |
| | Eutrophication in controlled waters in the Warwickshire Avon catchment | 1998 | EA |
| HO-06/98-5K-B-BCJL | Diffuse pollution from agriculture – a field guide | 1998 | EA |
| | Assessment of potential for phosphorus reduction in river waters | 1998 | DETR |
| | Eutrophication control via nutrient reduction in rivers: Literature Review | 1998 | EA Anglian |
| TR E13 | Controlling pollution from diffuse sources: Approaches taken in selected Member States | 1997 | EA |
| TR P17 | Alternative farming methods. A study of the effects of an integrated arable management system on levels of herbicide and nutrients reaching 'controlled waters.' | 1997 | EA |
| TR P40 | Best management practices to reduce diffuse pollution from agriculture | 1996 | EA |
| Note 470 | A review of methods for assessing and controlling non-point sources of phosphorus | 1996 | EA/SNIFFER |
| Note 320 | Land management techniques | 1994 | EA |
| Note 32 | Review of R&D priorities – Agricultural impacts on water quality | 1992 | EA |
| FR0316 | The fate of nitrogen resulting from the application of sewage sludge | 1992 | FWR |

* Proposed new starts in the DETR MLIS programme 2000/2001 (see Section 2 for contact details)

Source measures are ways of minimising nutrient inputs from point and diffuse sources. There are a number of ongoing research projects funded by BBSRC, EA/MAFF and DETR. While there are a number of projects that mention source measures, there are relatively few that deal with the subject comprehensively. Part of the MAFF Nitrates R&D programme addresses source measures. A major review of land management techniques (Mainstone *et al*., 1994) dealt with control measures for all diffuse pollutants (including nutrients). Source measures for phosphorus were addressed in a major review of the Environment Agency and SNIFFER (Mainstone *et al*., 1996).

## A5.1 MAFF Nitrates R&D Programme

The MAFF Nitrates R&D Programme (MAFF, 1996 and 1999a) addresses both source apportionment (see Section A7.1) and control measures (see Section A7.5) in addition to source measures.

### A5.1.1 Development of improved advice for farmers and advisers

An important component of the Nitrates Programme is the 'technology transfer' process to get the results of the research translated into effective strategies that can be implemented by the farming industry.

MAFF commissioned a number of studies within the Nitrates Programme to establish the main factors that influence farming decisions. Of the available methods of information dissemination, the studies showed that farmers preferred:

- one-to-one interaction;
- written text;
- farm demonstrations.

Peer group example and pressure were also shown to be very effective.

One major difficulty that has been identified is convincing farmers that they are responsible in the most part for nitrate pollution problems and that the required changes in practices can be justified on economic or other grounds.

Based on the findings of these studies a range of face-to-face discussions, literature, computer-based Decision Support systems and demonstrations farms have been produced or set-up to get the key messages across to farmers.

Identified continuing needs from this area of research were:

- continued effort to inform and encourage all existing and prospective farmers to adopt good nitrogen management practices over many years;

- requirements to train users to understand and have confidence in the nitrogen advice provided by computer-based Decision Support Systems;

- continuing need for R&D results and conclusions to be collated in publications and for targeted dissemination campaigns with emphasis on economic benefits and practical farm demonstrations.

## A5.2 Land management techniques (Mainstone *et al.*, 1994)

Although this report was written some five years ago, for the NRA, many of the recommendations are considered relevant to present circumstances. A summary of the findings of this report is presented below.

Diffuse pollution from agricultural sources is of great concern in the UK and elsewhere. The complexities of diffuse contaminant behaviour have historically resulted in a concentration of effort at point source problems, but there is now an urgent need to address non-point source pollution issues if significant improvements in water quality are to be observed in rural areas. Failure on the part of environmental regulators to take action against this form of pollution would result in a continuance of current problems at best, and significant deterioration in existing water quality at worst. Owing to a lack of practical tools to combat such pollution, the National Rivers Authority commissioned WRc to conduct a scoping study to identify and outline suitable research. This report summarises the findings of the work and outlines recommended research.

Practical methods of controlling pollution risk, including both in-field (soil conservation measures and application practices) and edge-of-field (buffer zone) techniques are reviewed. It was concluded that much could be done now to reduce risk through the implementation of these low-risk practices, but that there appeared to be a communication gap between completed and on-going R&D and the farming community. There also seems to be a reluctance on the part of the farmer to forego established modern practices in favour of unknown techniques that may result in lost revenue. Buffer zones are likely to be effective in improving run-off quality with respect to certain contaminants if physico-chemical conditions are favourable, but should be regarded as a curative measure that is distinct from the preventative ethos of input minimisation and soil conservation. Furthermore, research is required to identify: a) areas where most benefit would accrue from buffer zone establishment; and b) optimal design criteria for different contaminants (including hydrological solutions on under-drained soils).

Non-point source models developed in the UK and abroad were reviewed in order to evaluate their usefulness to the NRA for the assessment of diffuse agricultural pollution risk. Models range from very simple expressions of contaminant export to complex conceptual models that predict loads to receiving waters according to local environmental conditions and agricultural practice. Specifications for possible risk assessment tools, operating on low (national/regional) and high (catchment/farm) resolutions, were developed on the basis of this review.

Recommendations for future work were made that covered diffuse pollution risk assessment, the catchment demonstration of in-field low-risk agricultural practices, and optimal buffer zone design for ameliorating run-off quality.

### A5.2.1 Land Management techniques: Conclusions

The report made the general statement that: ‘Diffuse agricultural pollution is a significant problem in the UK that has to be addressed in a comprehensive and integrated manner. Although MAFF are very active in this area, the NRA needs to take positive steps to ensure that improvements in water quality are achieved. Failure to take action is likely to result in a continuance of diffuse pollution problems at best, and deterioration in existing water quality at worst'.

The following specific conclusions were made in relation to nutrients:

**Low-risk agricultural practices**

There are many agricultural practices in existence that could reduce pollution risk across England and Wales, some through the minimisation of inorganic and organic fertilisers and others through better retention of potential contaminants within the soil. These include practices in the areas of soil conservation and fertiliser application (form, rates, timing, location). There are many more practices that have potential for reducing pollution risk but require further work before they can be implemented.

Implementation of existing low-risk practices seems to be constrained by:

1. a lack of farmer knowledge of the options available and where they should be applied;
2. concern about possible reduced yields and/or farm income;
3. reluctance on the part of impartial advisors to endorse reduced inputs for fear of liability for yield loss.

Development of promising techniques is possibly further constrained by reluctance on the part of fertiliser manufacturers to support R&D that may result in the reduced usage of their products, without any assurance that product prices could be increased to offset this reduction.

NRA research should aim to dovetail with the large MAFF R&D programme already in existence concerning land management practices for the protection of water. Information on phosphorus and agriculture in the UK is generally lacking at present, although this is now being addressed by a major MAFF programme of research (see Section A7.1). Erosion management is also receiving increased attention from MAFF through its soil protection R&D programme.

In general, the majority of MAFF-funded work is highly process-orientated and aimed at producing general guidance for the farmer. Monitoring of both the uptake of guidance and the extent of actual benefits (in terms of improvements in environmental quality) seems to be lacking.

Two main areas of work may therefore be identified:

1. detailed, process-orientated research into developing best practices;
2. implementation of best practice and assessment of overall benefits (economic and environmental).

Catchment-scale implementation of existing best practices, with monitoring of farm income and environmental benefits, is urgently required and, with the limited R&D funds available to the NRA, would be an effective way of contributing to the agricultural pollution research area. Results could be disseminated to the farming community to demonstrate that low-risk practices can be adopted cost-effectively.

**Buffer zones**

The information currently available indicates that buffer zones could be effective in permanently removing nitrate, suspended solids, BOD and some pesticides from surface and shallow sub-surface run-off if conditions are optimal, but that there may be incompatibility between nitrate and pesticide retention due to interference with denitrification processes. Phosphorus is likely to be retained in the short-term, but periodic releases are probable if physico-chemical conditions change, and longer-term continual release will occur as soil adsorption capacity is saturated. In addition, buffer zone conditions optimal for nitrate removal are likely to enhance phosphorus release.

Physico-chemical conditions crucially dictate buffer zone retention efficiency for all contaminants, and under-drainage is an unsolved obstacle to their effective establishment in many areas of high pollution risk in England and Wales. Although some design criteria have been suggested, a good deal of research is required to produce scientifically defensible guidelines for their establishment in different UK situations. Some form of buffer zone management is likely to be necessary in order to maximise benefits to run-off quality.

Buffer zones, whilst a valid diffuse pollution control option, are not a solution to the root cause of poor agricultural run-off quality. Establishment of a 'no-application' strip alongside a watercourse will always, however, reduce the likelihood of direct overspray of contaminating materials, and also minimise near-field run-off from the riparian zone.

In general, the implementation of low-risk, in-field agricultural practices, focusing on minimising inputs through maximising the efficiency of resource use and implementing alternative techniques, is favoured for water quality improvement above the establishment of buffer zones. However, buffer zones are likely to have some water quality benefits in most situations, and also have positive effects that extend beyond the control of diffuse pollution of receiving waters (e.g. conservation).

The establishment of buffer zones in areas of intensive arable or pastoral farming is likely to greatly increase the ecological quality of the river corridor. However, benefits will be restricted to riparian land unless the buffer zone improves run-off and, consequently, receiving water quality. Low-intensity management of buffer zones, which will vary in nature between sites, is likely to be necessary to maximise ecological benefits.

The most effective way forward in land management terms is likely to be the complementary use of both in-field practices and buffer zones to suit local requirements for improved water quality and ecological enhancement.

In order to provide an objective basis for buffer zone establishment and design, modelling of hydrological pathways and contaminant retention efficiency is required. A simple model, based upon process-monitoring under a range of conditions, should allow the production of site-specific design criteria. The long-term efficacy of buffer zones can only be ascertained in the short-term by: a) studying buffer zones that have been in existence for some time (probably a number of decades); or b) modelling short-term data and extrapolating to the longer term.

**Integrated land management**

Agricultural pollution research often concentrates on the development of practices that minimise contamination by one contaminant of particular interest, with little consideration of the implications for other contaminants or, indeed, the wider environment. Future research needs to focus on ensuring compatibility between low-risk practices, so that reducing contamination by one contaminant is not achieved at the expense of increasing contamination by another (i.e. whole-farm management concept).

There is a need for decision-support systems, for use either by the farmer or by impartial advisors, that will enable farmers to develop cost-effective and environmentally sound management strategies based upon objective information. Such systems would make vital information on existing low-risk practices more widely available and should increase their use. Most importantly, systems are required for rationalising slurry spreading, nutrient analysis and budgeting.

**Diffuse pollution risk assessment**

Controlling diffuse pollution from agricultural land will not be possible without a sound knowledge of the spatial and temporal distribution of pollution risk. Risk assessments are needed at different resolutions in order to satisfy both the political and operational requirements of the NRA.

A vast array of non-point source pollution models are potentially available for assessing pollution risk. These range from simple loading functions to complex deterministic models. GIS can be used in combination with these, or can operate on its own, possibly as a simple, distributed database of risk information with empirically-derived distributions of relative pollution risk. With the more complex models, determination of loads to receiving waters, simulations of land use change and cost-benefit optimisation of land management are all possible. However, model usage will be more complicated, data requirements will be higher, run-times will be longer, and results will be vulnerable to uncertainties concerning contaminant behaviour.

### A5.2.2 Land Management Techniques: Recommendations

The report made the general statement that: The NRA should seek to promote the reduction of artificial inputs (inorganic fertilisers and pesticides) to agricultural systems, through increased knowledge and farmer awareness of soil conservation measures, efficient nutrient cycling on the farm, the proper distribution of organic inputs (slurry, dirty water, silage liquor) across available land to maximise their nutritive value, and Integrated Pest Management techniques.

The following specific recommendations were made in relation to nutrients:

**Research into low-risk agricultural practices**

The NRA should concentrate on enhancing the implementation of existing low-risk practices or those ready for validation, since the development of new practices is largely being addressed by a substantial on-going programme of MAFF research. Demonstration of low-risk practices in commercial situations and publicisation of results to the farming community would be the best way of achieving this goal. Owing to the overlap in interests between the

NRA and MAFF, and the strong links between MAFF and the farming community, it would be sensible to conduct such work in collaboration.

It is recommended that demonstration of a range of best practices is undertaken on commercial landholdings within small catchments exhibiting high pollution risk. High risk catchments would be identified using the risk tools described below. Best practices would include soil conservation practices, nutrient budgeting, targeted application methods and properly scheduled slurry spreading.

Both the nature of land use and catchment characteristics are important influencing variables in the success of low-risk practices. Effort should initially be focused on those land uses and catchment types that are typical in the UK or where success is likely. In terms of land use, study catchments would ideally be located in: livestock-dominated areas (upland and lowland); an arable/vegetable dominated area; a mixed farming area; and a soft fruit/hop area.

The recommended work would have to draw on the experience of a number of organisations in the field of agricultural research, in addition to an organisation experienced in monitoring all aspects of the aquatic environment. Cooperation of landholders would be crucial to the implementation of best practices. Dialogue with farmers would ideally take place through local ADAS staff, although consultations would have to be non-chargeable to ensure cooperation. Compensation payments or insurance against loss of farm income may need to be arranged in order to overcome the risk-aversiveness of farmers in adopting new practices.

Opportunities for linking with LEAF (Linking Environment and Farming), an organisation committed to publicising good agricultural practice (Integrated Crop Management, ICM) through a chain of demonstration farms, should be investigated. So far, LEAF has established 14 demonstration farms and is clearly experienced in this area, having developed guidelines for ICM and a farm audit procedure. The NRA, however, need to ensure that demonstration catchments are based in areas of high pollution, or high impact, risk so that environmental benefits are maximised.

Monitoring of water quality benefits (both chemical and biological), operational and economic implications for farm management and perhaps benefits to terrestrial ecology should be undertaken. Comparison with either a temporal control (i.e. initial background monitoring of study catchments) or a spatial control (i.e. contemporary monitoring of a similar catchment under modern agricultural management) would allow success to be gauged. There would need to be a mixture of process monitoring and receiving water monitoring in order to assess the effectiveness of individual best practices and the overall effect of the integration of practices. An important aspect of the work would be assessing the effects on overall water quality of low-risk practices designed to minimise pollution by one contaminant (e.g. nitrate).

Collaboration with other interested funding bodies in this area is strongly recommended. There are existing on-going projects, with the agricultural infrastructure already in place, that are relevant to the NRA's needs. These include LIFE (Low Input Farming and Environment) and TALISMAN (Towards A Lower Input System Minimising Agrochemicals And Nitrogen) (see MAFF Nitrates and Phosphorus Loss from Agriculture Research Programmes (MAFF 1996, MAFF 1999 a and b). Both studies are aimed at reducing the cost and increasing the environmental safety of arable farming in the UK through the development of integrated farming systems. The rationale for both projects is to produce a shift of emphasis away from the ethic of maximum production, with the associated chemically-orientated technology and high inputs, towards improved production efficiency using more environmentally acceptable alternative practices. LIFE is a long-term study, using one 19 ha site, whilst TALISMAN occupies 17 ha spread over four sites. In both projects, different systems are compared at an overview level, supported by detailed study of system components. It is recommended that these are investigated in detail with the purpose of assessing the possibilities for collaboration.

**Research into buffer zones**

On the basis of current knowledge, a national geographical analysis of where buffer zones are likely to be effective in ameliorating run-off quality should be undertaken. This should involve an analysis of the distribution of: a) diffuse pollution risk for different contaminants (see below) and b) physico-chemical factors likely to affect retention efficiency. At a national scale, however, it would not be practical to determine the distribution of under-drainage, which is a major (though modifiable) determinant of buffer zone efficacy.

It is recommended that a major study is undertaken to test the efficacy of buffer zones in the field in order to develop proper design criteria for their use and verify those situations in which they would be most beneficial. This would involve detailed process studies of contaminant (phosphorus, nitrate, sediment, pesticides, BOD) fluxes under different conditions of soil type, hydrology, temperature, buffer zone dimensions and management. Monitoring of conservation benefits within established buffer zones should also be undertaken. The selection of initial study catchments should be given careful consideration to maximise the likelihood of success, so that the full potential of buffer zones can be demonstrated.

MAFF has commissioned a three year study into the efficacy of buffer zones, which will involve the establishment of riparian and in-field buffer areas, on the basis of expert judgement, in a number of small arable catchments. The recommended work does not link well with this research, since the latter will not test a range of buffer zone designs under similar physico-chemical conditions in order to produce specifications for optimal design. In addition, the level of pollution risk in the planned MAFF study catchments is not clear, and may be relatively low (all catchments will lie within National Trust landholdings). The study should, however, determine whether buffer zones are capable, at least in the short-term, of producing measurable improvements in receiving water quality in the UK. It would therefore be sensible for the NRA to ensure that all major agricultural contaminants are being monitored in the MAFF study, so that the value of the work is maximised. Planned monitoring covers nutrients and sediment. Further discussions should be undertaken with MAFF, in order to agree any collaborative work.

Land acquisition for buffer zone establishment is likely to be a major financial consideration. MAFF has recently established a Habitat Scheme under the Set-Aside umbrella, which carries a Water Fringe option. There are currently six pilot areas across England where intensively cultivated riparian land can be managed extensively with grant support. There should be scope for using this scheme to acquire land for establishing a range of experimental buffer zone regimes, although there seem to be problems in moving away from the management prescription laid down by MAFF.

On undrained land, it is intended that buffer zones would be established simply through a reduction in the intensity of management, with appropriate fencing, seeding and/or planting where necessary. The timescales for establishment will vary between vegetation types, from grass sward to wooded zones. Willow or alder coppice could be established within a relatively short time period, and use could also be made of existing wooded riparian zones if deemed to be suitable.

On drained land, research should be undertaken to develop effective engineering solutions to the short-circuiting of riparian buffer zones by under-drainage systems. This could be conducted as a separate hydrological project to the main study being recommended (although close links would need to be maintained), or could be an integral part of the main study.

The data produced from process monitoring of different buffer designs in study catchments should be used to develop a simple model of buffer zone retention efficiency, which could be used to produce site-specific criteria for buffer zone establishment on the basis of local conditions (this may involve modification of existing non-point source models, such as CREAMS).

Since the long-term retention efficiency of buffer zones for different contaminants cannot be rapidly ascertained for buffer zones to be established as part of the recommended study, information will need to be acquired from another source. It is recommended that the following approaches are explored in the proposed study: a) investigation of buffer zones that have been in existence for some time (probably a number of decades); or b) modelling short-term data and extrapolating to the longer term.

**Research into diffuse pollution risk assessment**

It is recommended that a two-tier system of risk assessment, operating on two different geographical scales, is developed. This would allow a comprehensive picture of risk to be produced, first targeting high risk catchments at a national or regional scale, and subsequently identifying high risk areas within those catchments at a local or farm scale. The national/regional scale tool would be a simple database of information relevant to pollution risk, linked and overlain by GIS using simple empirical weighting factors. Two options are given for the catchment/farm scale, depending upon whether estimation of loadings to receiving waters is required to link land management to SWQO compliance. It should be recognised, however, that such estimates would have a relatively low associated confidence, owing to the complex behaviour of diffuse contaminants.

**Development of decision-support systems**

In conjunction with recommended work outlined above and relevant work being carried out by agricultural research organisations, it is recommended that studies are undertaken to produce decision-support systems for optimal slurry spreading (to include consideration of topography, soil type, proximity to watercourse, rainfall, timing of application, rate of application and method of application) and nutrient budgeting. Such systems would be operated either by the farmer or impartial advisors and used to plan farm management according to local conditions. They would sensibly utilise spatial data available from the recommended catchment/farm scale risk assessment tools.

## A5.3 A review of methods for assessing and controlling non-point sources of phosphorus (Mainstone *et al.*, 1996)

Phosphorus is a critical factor in the eutrophication of freshwaters. Whilst sewage treatment work effluents produce much of the total phosphorus load to rivers, the significance of the relative contribution of other sources is unclear, particularly non-point sources such as run-off from agricultural land. The relative contribution of non-point sources will be highly variable between catchments, depending upon factors such as land use (and intensity of land use), population density and the efficiency of sewage treatment. Importantly, it will also increase in significance as point source loads are brought under control.

A need has been identified by the NRA and SNIFFER for practical guidance on the quantification of non-point source contributions, in order to assess their relevance in relation to phosphorus control. This project was commissioned to provide this guidance and to identify techniques that could be applied to control non-point source loads.

A range of issues were investigated during the course of the project:

- the driving forces behind phosphorus control;
- the behaviour of phosphorus in soils and rivers;
- methods of quantification of non-point source contributions;
- methods of control;
- models for predicting the effects of control measures on river quality.

The reviewed literature indicated that phosphorus has a strong association with the particulate phase in run-off, but that sub-surface leaching may be significant in soils overloaded with phosphorus (sandy soils are particularly vulnerable to leaching). The labile fraction of particulate-bound phosphorus in run-off may be rapidly desorbed rapidly once in the river, depending upon ambient phosphorus concentrations. Phosphorus concentrations are increasing in many soils of the UK and elsewhere due to the regular application of maintenance fertiliser dressings (irrespective of the likelihood of a crop response) and the application of animal excreta in excess of crop requirements.

Regarding the quantification of non-point source loads, two basic approaches were identified:

1. instream methods involving data on riverine phosphorus concentrations and flow;
2. export coefficient methods using estimates of phosphorus loss per unit area of production.

The seasonality of the load is critical, since much of the total load can be transported down rivers in the winter without significant consequences for riverine communities. Such winter loads are only ecologically important to rivers if they are retained in the river system and released during the period of active plant growth. The capacity for retention depends upon the characteristics of the catchment and the river in question.

Methods of nutrient control comprise soil/nutrient conservation techniques, the low-risk application of fertilisers, and buffer zones. Erosion control techniques are highly important due to the association of phosphorus with particulate run-off, but should be implemented hand-in-hand with input minimisation/rationalisation. In particular, the use of maintenance dressings should be linked to the likelihood of crop response. Other possible approaches to phosphorus control include the reduction of phosphorus levels in livestock feed and the development of crops that respond to low levels of soil phosphorus.

Research has been recommended on the further development of automated sampling systems and models for the quantification of non-point source loads of phosphorus and the assessment of control options. Investigations of phosphorus behaviour in soils and rivers, and the effectiveness of a number of possible control methods, are also required.

### A5.3.1 Controlling non-point sources of phosphorus: Conclusions

**Fate and behaviour of phosphorus in soils and flowing waters**

1. Phosphorus interactions between the dissolved and particulate phases in both soil and river systems involve two stages: rapid reactions with the external surfaces of particulates and slower diffusion into the particulate matrix. The initial reactions are rapidly reversible, whilst the reversibility of the slower reactions is largely uncertain.

2. Phosphorus has a strong affinity for the particulate phase and is accumulating in most cultivated soils due to the inaccessibility of tightly bound soil phosphorus reserves to crops and surplus applications due to a lack of nutrient budgeting. Fresh phosphorus is applied annually as a maintenance dressing to ensure that the nutrient is readily available to the crop, but the majority of this becomes locked up in soil reserves. This produces enriched particulate run-off and the potential for enhanced leaching to sub-surface drains.

3. Mineralisation reactions are important in taking inorganic phosphorus out of solution, in both soil and river systems. Important minerals include coprecipitates with calcite, calcium phosphates and iron oxides/hydroxides. The likelihood of such reactions depends on a number of site-specific considerations, including calcium and iron availability, pH, redox potential and temperature.

4. Owing to the strong association with particulates, the majority of phosphorus loss from cultivated land is in the form of particulate run-off. However, leaching of soluble phosphorus into shallow sub-surface drains is likely to become more important as soil phosphorus reserves increase. Leaching from agricultural soils to groundwater is unlikely to be significant in most instances, owing to the high adsorption capacity of most sub-soils. The exceptions to this are sandy soils, which have little capacity to retain phosphorus and are thus highly vulnerable to leaching.

5. Much of the phosphorus in the particulate phase of run-off may become rapidly available once in the river, depending upon how much is only loosely adsorbed to the particle surface. The Equilibrium Phosphorus Concentration (EPC) of the suspended sediment, which is measurable analytically, and the soluble phosphorus concentration in the river provide an indication of the propensity for desorption.

6. The majority of the total phosphorus load from agricultural land occurs during the winter months, with much of this being produced during a few major storm events. The extent to which this part of the load is retained within the river system and is available for plant

growth in subsequent growing seasons will depend upon the extent of depositing zones within the river in question.

7. Internal cycling between the river-bed sediments and overlying water largely depends again upon the EPC of the sediment and the soluble phosphorus concentration in the water column. In addition, the velocity of the water flowing over the bed is critical, since the interaction is diffusion-dependent. Modifying factors in this process include the bioturbation effect of sediment infauna, which can bring deeply buried phosphorus to the surface and also alter sediment redox potential (affecting mineralisation reactions), and the growth and subsequent microbial decomposition of aquatic macrophytes, which produces seasonal changes in fluxes.

8. Little work has so far been undertaken to quantify fluxes into and out of riverine sediments, but it is known that these will vary widely depending upon the historical phosphorus loading, the extent of deposition zones, soluble phosphorus levels in the water column and a variety of other factors. Available evidence suggests that peak outflux is likely to occur during the autumn and winter periods, largely related to increased flows producing a sharper diffusion gradient. During the spring, increased microbial activity may produce further releases from the sediment, either directly through release of phosphorus that is excess to requirements or by reducing sediment redox potential and altering phosphorus/iron mineralisation. Uptake by macrophytes, algae and bacteria will be much more important during the growing season and may produce a net uptake of soluble phosphorus out of the water column.

9. Sluggish rivers with high phosphorus loads and a high level of recreational activity (e.g. boating and fishing) may be subjected to strong internal loading during the growing season, owing to disturbance of fine, phosphorus-laden sediment. However, this will be offset by high uptake from algae and higher plants. Fast-flowing rivers will have little fine sediment and therefore little capacity to retain phosphorus, resulting in low internal loading even if external loading is high.

**Methods of identifying and quantifying non-point source contributions**

1. Two basic, pragmatic approaches to quantifying non-point source loads of phosphorus have been identified:

   a: instream approaches, using data on riverine phosphorus concentrations and flow;

   b: export coefficient approaches, using estimates of phosphorus loss per unit area of production.

2. Many of the methods examined in this review, particularly export coefficient techniques, involve the quantification of annual loads of phosphorus, with no discrimination of seasonal loads. Whilst annual loads are important for static water bodies with long residence times, and have consequently been used extensively in the assessment of lake eutrophication, a large proportion of the annual load can run through a river system over the winter period without significant consequences for riverine communities. Discrimination of seasonal contributions is therefore important if the true significance of non-point source loads is to be assessed.

3. Where data are available, instream approaches offer a means of using real, catchment-specific data and examining the seasonality of point source and non-point source contributions. However, the user needs to be aware of the limitations of such techniques, including tendencies to both under- and over-estimate the contribution of non-point sources. A number of confounding factors need to be addressed, at least in broad terms, if a realistic interpretation of results is to be made. Perhaps the methods of most relevance are the spatial analyses of riverine phosphorus concentrations, comparison of total loads and point-source loads, and the hydrograph separation approach, although the latter requires work to produce simple automated procedures.

4. Manual calculation of non-point source loads using export coefficients is possible, although no manual of coefficients and guidance for their use exists in the UK. Indeed, there is a wide range of values reported for export coefficients that can contribute to large variations in non-point source load estimates. The closest approximation is the work of Johnes *et al*. (1994 quoted in Mainstone *et al*., 1996), although this is based on annual coefficients and there is much scope for modifying these subjectively, based on site-specific conditions. These could be formalised and an indication of seasonal loads produced from hydrograph separation techniques.

5. The most relevant automated systems using export coefficients are POPPIE, a national system currently being developed to assess pesticide loads to rivers, and MINDER for Rivers, a catchment-scale model producing seasonal estimates of instream soluble phosphorus concentrations. POPPIE currently has most of the required datasets and, if modified for phosphorus, would simulate mean total and soluble phosphorus concentration at the foot of each catchment across the UK. MINDER for Rivers currently has a number of limitations that need to be addressed, including the somewhat simplistic calculation routines used for phosphorus export, a lack of flexibility in model output, and the lack of a user-friendly interface. Both systems would require further work before they could be used by pollution control staff.

6. One problem specific to all export coefficient approaches is the conversion of coefficients expressed in terms of Total Phosphorus to estimates of the contribution to instream Soluble Reactive Phosphorus concentrations. Exploratory analysis of instream data indicates that no simple surrogate measure of the TRP:TP ratio, such as catchment altitude, is likely to provide any degree of accuracy in determining the instream bioavailable fraction. Instream TRP:TP ratios in UK rivers have been found to range from near zero to one, with values varying enormously within the same river and even the same site. This is largely due the sharp declines in values observed through rainfall events, due to the low concentrations (in general) of bioavailable phosphorus in surface run-off. In catchments where sufficient SRP/TRP, TP and flow data are available, it may be possible to derive useful case-specific relationships between the instream SRP:TP or TRP:TP ratio and flow, from which the approximate partitioning of run-off into soluble and particulate (or reactive and unreactive) phases could be estimated.

7. Methods for quantifying internal loading from riverbed sediments have been developed by IFE on behalf of the DoE (see Section 4.3 for further details). Based on work so far, the Equilibrium Phosphorus Concentration appears to be the most useful indicator of the propensity of bed sediments to release phosphorus, if used in conjunction with a further parameter that is related to the sorption affinity of the sediment. A simple way of

measuring this latter parameter is currently being sought, and a standard protocol for the measurement of EPC will then be produced.

**Methods of controlling non-point source loads**

1. Control methods can be divided into soil/nutrient conservation techniques, methods involving the low-risk application of fertilisers, and buffer zones. Conservation techniques include the minimisation of tillage, the incorporation of humus, appropriate crop selection and rotation, the avoidance of soil compaction, suitable livestock densities on grassland and livestock control in riparian areas. Low-risk fertiliser application includes matching inputs to crop requirements, small-scale spatial targeting at the crop and application at times to maximise crop uptake.

2. To these land-based control methods can be added the use of crops that respond to low levels of soil phosphorus, as well as the control of phosphorus in livestock feed. Crops that can exploit the large reserves of relatively inaccessible soil-bound phosphorus now present in most cultivated soils would be a significant advance for non-point source phosphorus control, although development work to create such crops is required. In terms of livestock feed, a large proportion of feed phosphorus is excreted and is therefore not required for animal nutrition, giving rise to scope for reducing the excessive amounts of phosphorus applied to land in animal slurries and manures, or changing livestock feed composition.

3. Owing to the close association of phosphorus with the particulate phase of run-off, erosion control measures are inevitably prime candidates for controlling non-point sources of phosphorus. However, implementation of such measures without due consideration of phosphorus inputs to land is likely to merely shift loads from the particulate to the dissolved phase.

4. Soil phosphorus indices calculated for soils across England and Wales indicate that no crop response to additional fertiliser applications is likely across most of lowland England, particularly in East Anglia and the Cheshire Plain livestock area. It is therefore difficult to understand the continued use of maintenance dressings of phosphorus on such soils, at least in the short term.

5. Buffer zones are different from all other control methods reviewed in that they act to clean up run-off after contamination, as opposed to preventing run-off contamination; in this they can be seen as a curative approach. Whilst numerous workers have reported high retention efficiency of particulates and particulate run-off in short-term studies, the long-term behaviour with respect to phosphorus build-up and the export of soluble phosphorus is unclear. In addition, maintenance is required to ensure effective particulate retention, and even then there are risks of break-through flow if run-off becomes concentrated. In short, whilst buffer zones may provide a good safety net, they should not be the primary control option for non-point sources of phosphorus.

6. There is a fundamental need to target control measures at those areas of land of highest pollution risk. Whilst this may be satisfied using computer models, existing map-based information on land capability may provide useful and easily accessible information for pollution control staff. Computerised databases of basic land characteristics are also available that can assist in the targeting process.

7. Sandy soils are worthy of particular mention in relation to targeting, since they have very low phosphorus adsorption capacities and are thus highly vulnerable to leaching. In relation to erosion risk, it is also worth highlighting that much of the best agricultural land in the south and east of England has soils with very low organic carbon content, presumably due to a dependence upon inorganic (rather than organic) fertilisers. It is likely that much of this land would benefit from an increase in organic matter content, in terms of improved physical stability and infiltration.

8. It is important to consider the implications of control measures for non-target contaminants, since benefits in reducing loads from phosphorus may be offset by the exacerbation of other pollution problems. Integrated land management solutions based upon input minimisation, sound soil and nutrient conservation practices, and integrated pest management are ultimately the key to non-point source pollution control.

**Models for testing control scenarios**

1. None of the models examined are suitable as yet for use by pollution control staff to test nutrient control scenarios. The most relevant of the US models for the task at hand is probably AGNPS, although this may have to be converted to deal with continuous rather than with storm event simulations. This model is more appropriate than other US models simply because it has already been used in the UK. It is also relatively simple compared to most other candidates.

2. MINDER for Rivers appears to be the most appropriate non-US model, as it has a hydrodynamic sub-model and it uses UK GIS data. However, it does not currently deal with specific management practices (such as erosion control measures, fertiliser application techniques, and differences in phosphorus inputs) and at present could therefore only simulate phosphorus control in terms of changing land use.

### A5.3.2 Controlling non-point sources of phosphorus: Recommendations

**Strategic management issues**

1. It is recommended that the NRA work with MAFF in raising the profile of phosphorus in the Codes of Good Agricultural Practices for soil and water, emphasising the impacts on receiving waters and the need to both control soil phosphorus levels (through soil testing and evaluating crop requirements) and minimise soil losses to receiving waters.

2. Following operational trials of the methodologies, it is recommended that refined guidance is developed for operational staff for inclusion in the Pollution Prevention Manual, incorporating the findings of related on-going MAFF and other NRA work. Negotiations should then take place between the NRA and MAFF on how best to deliver detailed guidance on control options to the farming community, in relation to both high priority areas and the wider countryside.

3. It is recommended that a strategy be developed for the use of export coefficient modelling in the assessment of contaminant loads, in order to ensure a consistent and cost-effective approach. This should start with the harmonisation of base datasets, such as land use, the river network, soils, slope and rainfall, many of which are already (or soon will be) available to NRA staff at reasonable spatial resolution (at least for coarse analysis) within the POPPIE system currently under development.

### A5.3.3 Controlling non-point sources of phosphorus: Research requirements

Given the overlapping interests of the NRA and MAFF in the control of non-point source pollution, it is recommended that liaison is undertaken (where relevant) in relation to implementing the research recommendations made below.

**Fate and behaviour of phosphorus in soils and flowing waters**

1. It is recommended that research be undertaken into the compartmentalisation of phosphorus between the dissolved and particulate phases in agricultural run-off. This research would aim to provide simple methods that can predict the likely bioavailability of phosphorus run-off once in the river, both in the short-term and after deposition as bed-sediments.

2. The precise pathways of phosphorus inputs to rivers, from both agricultural land and farmyard areas, requires further attention. Given the increasing levels of phosphorus in most agricultural soils in lowland England, the importance of leaching into under-drainage systems or even aquifers as a transport mechanism (both now and in the future) requires clarification.

**Methods of phosphorus monitoring**

1. An assessment of the significance of differences between Soluble Reactive Phosphorus and Total Reactive Phosphorus should be undertaken at a representative range of riverine sites (to cover a wide range of suspended solids levels and phosphorus sources), in order to evaluate the degree of compatibility between the two parameters.

**Methods of identifying/quantifying non-point source loads**

It is recommended that the catchment-scale model MINDER for Rivers is developed further to provide a high resolution tool for assessing phosphorus loads to high priority rivers and targeting control measures. This work should be undertaken in two phases, with the aim of Phase 1 being to provide a workable system as soon as possible for operational staff.

Phase 1 should comprise:

- modification to provide a variety of output levels, ranging from those with highest reliability (i.e. annual loading of Total Phosphorus) to those with greatest uncertainty (i.e. seasonal loading of SRP or TRP);
- validation on selected catchments, in relation to each output level;
- construction of a user interface that would facilitate its use by staff in the pollution control authorities.

Phase 2 should include:

- more sophisticated consideration of export coefficients, to include phosphorus application rates and perhaps soil phosphorus levels;
- improved assessment of the bioavailability of phosphorus in run-off;
- modification to allow the export from one land cell to become the input to the next.

It is recommended that the national-scale POPPIE system currently under development for the assessment of pesticide risk be extended to incorporate consideration of phosphorus. This would involve the inclusion of a range of export coefficients in line with those required for the MINDER for Rivers model. Such a step would provide an excellent screening model to assist in the identification of catchments requiring controls on non-point sources of phosphorus, which could subsequently be targeted for detailed attention using MINDER For Rivers if appropriate.

**Methods of controlling non-point source loads**

1. It is recommended that the use and efficacy of maintenance dressings be reviewed in the light of the serious water quality implications of accumulating soil phosphorus reserves across the UK. The result of reducing reserves on a variety of crops should be considered, with a view to defining agronomically and environmentally acceptable soil phosphorus levels.

2. The applicability of techniques such as contour ploughing and contour strip cropping to the full range of UK situations requires further investigation, to include an analysis of the potential of existing plant and new plant to cope with operating under such regimes. This would lead to the production of guidelines for their use in different situations.

3. It is recommended that an investigation is undertaken into the availability of crops and crop varieties that can efficiently utilise low levels of available soil phosphorus and can consequently be used to reduce soil phosphorus reserves without compromising agronomic profitability.

4. Investigations are required into the commercial availability and cost of machinery to:

    - target inorganic fertiliser applications at the crop plant;
    - avoid compaction of sensitive soils or soils under conservation tillage regimes.

    The first issue should be tackled in liaison with the Fertiliser Manufacturers Association, who are likely to have useful information on available plant and the limitations on its use.

5. Research is required to accurately predict the short-term and long-term retention of phosphorus in buffer zones under typical loading conditions in arable and livestock areas. This should be accomplished by the NRA ‘new start’ on the establishment and testing of buffer zones.

6. It is recommended that the benefits of livestock control in riparian areas in reducing inputs of phosphorus be assessed by study of livestock behaviour with access to the streambed. Estimates of phosphorus loading from direct defecation should be made, with a view to determining the importance of such contributions to instream phosphorus concentrations, especially during the growing season.

**Models for testing control scenarios**

1. It is recommended that the source code of AGNPS is examined and adapted where necessary to run on UK data. This should then be trialled in a test catchment to assess its performance.

2. If the modifications to MINDER for Rivers recommended in the report are made, consideration should be given to incorporating extra modifying factors to the export coefficients to account for management regime. The model could then be tested against AGNPS in the same catchment to assess relative performance, with a view to selecting the best performer and finalising development.

It is recommended that work be undertaken to simulate instream processes of importance to water column SRP/TRP and sediment phosphorus concentrations, in order to allow reasonable predictions of behaviour following changes in inputs. Such a model could be integrated with management scenario testing models to provide a complete simulation of phosphorus behaviour from application to export from the catchment. The work of the Institute of Freshwater Ecology for DoE, and the Institute of Hydrology on the QUASAR model, is relevant in this respect.

## A6 IMPACT ASSESSMENT

Table A6 lists the projects, where identified, addressing impact assessment in lakes and reservoirs, rivers, estuaries and coastal waters and wetlands. Further information on each project is available from the funding bodies (see Section 2 for contact details).

**Table A6 UK funded eutrophication-related R&D projects addressing impact assessment in lakes and reservoirs, rivers, estuaries and coastal waters and wetlands**

| Ref | Title | End Date | Funding body | Lakes and reservoirs | Rivers | Estuaries and coasts | Wetlands |
|---|---|---|---|---|---|---|---|
| | The sensitivity of upland standing waters to atmospheric nitrogen deposition | | NERC GANE | x | | | |
| | Nitrogen driven lakes: more common than convention claims? | | NERC GANE | x | | | |
| | The artificial fertilisation of gravel pit lakes - its effects and use as a fishery management tool | 2000 | EA Thames | x | | | |
| CV(96)6 | Palaeolimnological investigation of Scottish freshwater lochs | 2000 | SNIFFER | x | | | |
| W(98)03 | Airborne remote sensing for velocity field and algal bloom determination | 2000 | SNIFFER | x | x | x | |
| EID (96)7 | Identification of blue-green algae of the British Isles | 1999 | EA/University of Durham | x | x | x | |

| Ref | Title | End Date | Funding body | Lakes and reservoirs | Rivers | Estuaries and coasts | Wetlands |
|---|---|---|---|---|---|---|---|
| SR 97(08)F | Investigating the design of sampling programmes for standing waters: a scoping study | 1998 | SNIFFER | x | | | |
| P47 | The evaluation of EnviroGuard microcystin plate and tube kits | 1997 | EA | x | x | | |
| 97/DW/07/5 | Algal toxins: occurrence and treatability of anatoxin and microcystins | 1997 | UKWIR | x | | | |
| 96/DW/07/1 | Pilot scale GAC tests to evaluate toxin removal | 1996 | UKWIR | x | | | |
| 96/DW/07/2 | The toxicity and significance of toxins from blue-green algae | 1996 | UKWIR | x | | | |
| 96/DW/07/3 | Synthesis of an internal standard for the determination of anatoxin-a in water | 1996 | UKWIR | x | | | |
| 96/DW/07/4 | The fate of intracellular microcystin-LR during water treatment | 1996 | UKWIR | x | | | |
| PR 271/7/A | Occurrence, fate and behaviour of cyanobacterial (blue green algal) hepatotoxins | 1995 | EA | x | x | x | |
| FR/SC0012 | The toxicity of benthic blue green algae in Scottish freshwaters | 1995 | SO | x | x | | |
| FR0434/Doe 372 | Toxins from blue green algae: toxicological assessment of anatoxin-a and a method for its determination in water | 1994 | FWR | x | | | |
| Note 253 | Lakes: Classification and monitoring - a strategy for the classification of lakes | 1994 | EA | x | | | |
| FR0460 | Levels of anatoxin-a and microcystin-LR in raw and treated waters | 1994 | FWR | x | | | |
| FR0359/DoE | Toxins from blue green algae: toxicological assessment of microcystin-LR and a method for its determination in water | 1994 | FWR/DoE | x | | | |
| FR0363 | An analytical method for annotation-a, a blue green algal neurotoxin, in reservoir water | 1993 | FWR | x | | | |
| PR 113/10/ST | Diffuse pollution from land-use practices | 1993 | EA | x | x | x | x |
| FR0427 | The persistence of anatoxin-a in reservoir water | 1993 | FWR | x | | | |

| Ref | Title | End Date | Funding body | Lakes and reservoirs | Rivers | Estuaries and coasts | Wetlands |
|---|---|---|---|---|---|---|---|
| SR3439/1 | Algal bioassays: a review of their potential for monitoring and managing the trophic status of natural waters | 1993 | SNIFFER | x | x | x | |
| FR0269 | Toxicology of microcystin-LR | 1992 | FWR | x | | | |
| FR0292 | An investigation into the degradation of microcystin-LR | 1992 | FWR | x | | | |
| Note 32 | Review of R&D priorities - Agricultural impacts on water quality | 1992 | EA | x | x | x | x |
| FR0289 | Potential of flow cytometry for routine algal counting and detection of cyanobacteria | 1992 | FWR | x | x | | |
| FR0223 | Detection and removal of cyanobacterial toxins from freshwaters | 1991 | FWR | x | x | | |
| SR 2713/1 | Eutrophication in upland waters | 1991 | SNIFFER | x | x | | |
| P2-127 | Assessment of the impact of nutrient removal on eutrophic rivers | 2002 | EA | | x | | |
| P2A(98) 11 | Nutrient modelling on the river Kennet | 2001 | EA | | x | | |
| P2A(97) 01 | Pilot Catchment study of nutrient sources - control options and costs | 2000 | EA | | x | | |
| 031480 | Pollution of soils and waters through acidification and eutrophication and the associated mobilisation of pollutants | 1999 | BBSRC | | x | | x |
| E1D(97) 09 | Phosphatase activity in rivers | 1999 | EA | | x | | |
| | Phosphorus in rivers: its ecological importance and the role of effluent stripping in the control of riverine eutrophication | 1999 | EN | | x | | |
| P203 | Determining the causes of 'apparent eutrophication' effects | 1998 | EA | | x | | |
| | Eutrophication in controlled waters in the Warwickshire Avon catchment | 1998 | EA | | x | | |
| | Assessment of potential for phosphorus reduction in river waters | 1998 | DETR | | x | | |

| Ref | Title | End Date | Funding body | Lakes and reservoirs | Rivers | Estuaries and coasts | Wetlands |
|---|---|---|---|---|---|---|---|
| | Nutrient budget for the upper reaches of the Hampshire Avon | 1998 | EN | | x | | |
| P72 | Benthic algal mats in river systems | 1997 | EA | | x | | |
| TR E3 | Diatoms as tools for water quality managers | 1996 | EA | | x | | |
| TR E2 | The trophic diatom index: a users manual | 1996 | EA | | x | | |
| Note 341 | Use of diatoms to monitor nutrients in rivers | 1995 | EA | | x | | |
| PR469/11/ HO | Development and testing of GQA schemes: Nutrients in rivers and canals | 1995 | EA | | x | | |
| Note 278 | Survey methodology for algae and other phototrophs in small rivers | 1994 | EA | | x | | |
| NR 3698 | River Eutrophication Risk Modelling: A GIS Approach | 1994 | SNIFFER | | x | | |
| PR 226/2/Y | Foaming in rivers - an initial assessment of the problems in the UK | 1991 | EA | | x | | |
| | Phytoplankton community structure | 2000* | DETR | | | x | |
| P269 | The impacts of nutrients in estuaries Phase II | 1999 | EA/EN | | | x | |
| | Nutrient status of the Glaslyn/Dwyryd, Mawdach and Dyfi estuaries - its context and ecological importance | 1999 | CCW | | | x | |
| E55 | Nutrient and phytoplankton distribution in the North-East Irish Sea during 1997 | 1997 | EA | | | x | |
| TR E30 | The distribution of phytoplankton and nutrients in the NE Irish Sea during 1996 | 1997 | EA | | | x | |
| | Trends in nutrient enrichment of sensitive marine areas in England | 1996 | EN | | | x | |
| 639/1/A | The impacts of nutrients in estuaries - Proceedings of the scoping workshop | 1995 | EA/EN | | | x | |
| PR 150/1/NW | The establishment of a database for trend monitoring of nutrients in the Irish Sea | 1992 | EA | | | x | |

| Ref | Title | End Date | Funding body | Lakes and reservoirs | Rivers | Estuaries and coasts | Wetlands |
|---|---|---|---|---|---|---|---|
| SR 2756 | Coastal water eutrophication - current status | 1991 | SNIFFER | | | x | |
| | The importance of dissolved organic nitrogen in macroalgal dominated coastal ecosystems | | NERC GANE | | | x | |
| | A UK-Netherlands approach to North Sea Eutrophication monitoring | | DETR | | | x | |
| | Benthic diatoms as estuarine water quality indicators | | DETR | | | x | |

* Proposed new starts in the DETR MLIS programme 2000/2001 (see Section 2 for contact details)

## A6.1 Lakes and reservoirs

Much of the research identified in Table A6 deals with one of the impacts of eutrophication in lakes, namely the problem with algal toxins. However, the issues have been dealt with in nuisance attenuation (see Section A1).

Impact assessment in lakes is comprehensively reviewed in Section 4.2. However, the use of algal bioassays in impact assessment (Parr, 1993) and the consequences of artificial fertilisation of gravel pits for fishery management (Barnard *et al*., 1999) do provide suggestions for further research.

### A6.1.1 Algal bioassays: A review of their potential for monitoring and managing the trophic status of natural waters (Parr, 1993)

This report reviews the use of algal bioassays as tools to determine sensitive and less sensitive waters and Nitrate Vulnerable Zones (NVZs).

#### A6.1.1.1 Algal bioassays: Recommendations

1. The issue of phosphorus adsorption onto container walls needs addressing before any method development work is undertaken on freshwater or estuarine bioassays. A project is required to determine whether this is still a problem and if so to what extent are results affected - a method of preventing or compensating for P adsorption must be devised if chemical preservatives are not suitable.

2. The development of a suite of *in vitro* microplate algal bioassays should be continued for water quality management purposes. Standard methods should be developed with guidelines on appropriate modifications that can be made to improve the ecological relevance of the results to individual waters.

3. The use of continuous cultures for providing the algal innoculum to bath cultures should be assessed.

4. Once the standard methods are developed, the bioassays should be used to determine a statistical relationship between bioassay results and other determinants of trophic status, notably chlorophyll *a* and nutrient levels.

5. Greater use of mathematical modelling and greater emphasis on physical factors should be considered when interpreting nutrient (and chlorophyll) data.

### A6.1.2 The artificial fertilisation of gravel pit lakes - its effects and use as a fishery management tool (Barnard *et al.,* 1999)

The West Area of Thames Region has a considerable number (>200) of gravel pits, which can be important fisheries and of significant wider ecological value. Current issues of importance within the area include the development of management plans for gravel pit complexes (e.g. Cotswold Water Park lime-rich communities, SSSIs etc.) and an increasing pressure to develop coarse fisheries.

At present, the artificial nutrient enrichment of gravel pits is one fisheries management tool that has been used with the aim of enhancing coarse fishery performance. Whilst questions have arisen regarding the benefits and impacts of such practices, only limited information is readily available on which to base management decisions. There is therefore a clear need for the available information to be reviewed and for informed guidance to be provided.

WRc were commissioned and funded by Environment Agency Thames Region (West Area) to undertake a review of the available information and to address the following objectives:

- to review the reasons for, and current practice and guidance in relation to, the artificial enrichment of gravel pits for fisheries management purposes;
- to review the impacts of such practices on water quality and nutrient status;
- to review the impacts of such practices on fish populations and wider gravel pit ecology;
- to provide a decision framework identifying information requirements and benefit/risk assessment for management purposes in relation to the Environment Agency;
- to identify additional information and to recommend studies in order to develop understanding and practice in this area.

#### A6.1.2.1 Gravel pit lakes: Suggestions for further work

The currently available work relating to gravel pits, nutrient status and fisheries that has been reviewed and discussed in this report has highlighted several areas that would benefit from further study. These include the rationalisation of management advice; the development of better understanding of the nature of the gravel pit resource; and the focused assessment of any future fertilisation exercises.

**Rationalisation of available guidance**

Formal guidance from the Agency regarding the use of fertilisation as a fishery management tool should seek to present a balanced and informed view, and should highlight the very real (eutrophication) risks that are associated with the practice. These risks are highlighted in the 'Freshwater fisheries and wildlife conservation good practice guide' (Giles, 1998 quoted in Barnard *et al.* 1999). However, other current publications (such as the 'Fisheries habitat improvement guide'; Environment Agency, 1998a) present fertilisation as a management tool without mention of the attendant risks whilst the proposed management strategy on aquatic eutrophication in England and Wales (Environment Agency, 1998b quoted in Barnard *et al.* 1999) actually suggests that 'the damaging and non-sustainable practice of manuring ... to enhance fish growth' should be discouraged.

There is therefore a clear requirement for the Agency to rationalise its current guidance and information literature, especially in situations where advice is provided by different functions (e.g. pollution control and fisheries). Such a task should be undertaken in-house.

**Improvement of knowledge base for gravel pit trophic status**

It is recommended that the Agency develops its knowledge base regarding the nutrient status and underlying ecology of gravel pit lakes. Such data would allow a preliminary classification scheme to be developed, which in turn would permit management advice for a particular gravel pit to be focused, and pertinent to the nature of the site in question.

It would be possible to derive a preliminary classification scheme from a relatively simple dataset (i.e. one that includes only a few variables). Obviously the larger the number of observations within the dataset (i.e. the number of lakes sampled), the more robust would be any classification scheme subsequently derived. Note that it is entirely feasible to undertake this data collation and classification exercise on a regional scale.

To facilitate the development of such a classification system, it is recommended that the Agency collect single water samples from as many gravel pits as possible. These samples should be taken from open water during winter, and should be subsequently analysed for nutrients (TRP, TON, etc.) and other physico-chemical parameters (hardness, pH, etc.). In addition, ancillary data should be collated on a range of background factors, including:

- surface area;
- bathymetry;
- age;
- the underlying geology;
- the nature of pit (whether it was excavated for sand or gravel);
- current use;
- recent management practices.

Simple ordination techniques should be applied to the data to sub-divide the sites into a series of classes on the basis of water chemistry. It is likely that differences highlighted by the ordination process may be accounted for with reference to the ancillary data, so providing an insight into why certain types of gravel pits should be considered separately to others. This classification approach has been tried in Northern Ireland, where a single water sample was collected for hundreds of different waterbodies, analysed for 19 determinands and the results subjected to TWINSPAN analysis. Two upland lake categories (peat-strained and clear water lakes), two medium-altitude categories (man-made and clear water lakes) and five lowland lake categories were derived; the latter distinguished in terms of a trophic status gradient - from grossly enriched to low enrichment. A further three saline lakes were also separated into their own category. Interestingly, man-made lakes were characterised by high magnesium and nitrate levels.

Subsequently, advice or policies that are formulated by the Agency can be better focused; referring to specific classes of gravel pits. Such a process would serve to improve the value of the advice provided by the Agency.

**Assessing perturbations**

Certain mature gravel pit lakes, whilst not being fertilised routinely as part of a fishery management strategy, may nevertheless experience nutrient loading in the form of groundbaiting by anglers. Accordingly, some thought should also be given to assessing the effects that intensive groundbaiting may have on the nutrient status of still water (gravel pit) fisheries, with special reference to eutrophication risk.

**Improved data collation**

From the information reviewed it is apparent that there is a need for the benefits of fertilisation to be more clearly demonstrated. In particular there is a need to quantify the changes through time.

It is therefore recommended that, in instances where fertilisation is being carried out, appropriate monitoring should be set in place to afford robust ‘before’ and ‘after’ data that may be used to assess the effects of the fertilisation program. It would be appropriate to not only monitor nutrient levels, but also to assess subsequent improvements to phytoplankton and fish populations.

## A6.2 Rivers

The impact of eutrophication in rivers can result in a number of effects. A recent review by Hilton and Irons (1998) investigated these effects and proposed ways of attributing them to eutrophication. The critical nutrient responsible for eutrophication in most rivers is phosphorus and Mainstone *et al.* (1999) have reviewed its ecological importance in rivers.

### A6.2.1 Determining the causes of ‘apparent’ eutrophication effects (Hilton and Irons, 1998)

Symptoms of eutrophication are often associated with nutrients from sewage works upstream but there are many other causes that can result in changes to aquatic systems that resemble the effects of eutrophication. The possibility that one of these effects is the cause needs to be considered, and discounted, at an early stage, before proceeding to consider phosphorus control from point or diffuse sources. A simple checklist scheme has been devised to assess the likelihood that any of these alternative causes may be driving the observed effects. In the report, it is recommended that the question and answer scheme be:

- pilot tested in a few areas before redesigning and approving for general use: or

- the scheme is approved for general use but a questionnaire reply form is included, which is filled in by users and returned to a central office.

#### A6.2.2 Phosphorus in rivers - It's ecological importance and the role of effluent stripping in the control of riverine eutrophication (Mainstone *et al.*, 1999)

Eutrophication is one of the largest problems facing the ecology of freshwaters in the UK and elsewhere. The nutrient status of many lakes and rivers has increased dramatically over the past 50 years in response to increased collection and discharge of domestic wastes, increased pressure on collection systems (including the use of phosphate detergents), and widespread agricultural intensification. The importance of phosphorus in lake eutrophication is widely accepted, but there is less understanding of the role of phosphorus in rivers and what steps should be taken to control its effects.

With the highly positive stance of the UK Government and the mechanism of the water industry's Asset Management Planning (AMP) process, there have never been better opportunities to restore the nutrient status of rivers that have suffered from modern development pressure. However, to make the most of these opportunities it is vital that the confusion surrounding phosphorus in rivers is minimised by providing objective and easily digestible information on its behaviour, effects and control. Owing to the complex nature of phosphorus influences, decisions concerning management have to be made in relation to local circumstance. This document therefore serves to arm local decision-makers with the information they require to make the right decisions in a way that is nationally consistent.

The information presented in this document is relevant to a wide audience but is primarily aimed at headquarters and local staff in English Nature and the Environment Agency and at staff in water companies and Government Departments involved in developing phosphorus removal programmes. The main objectives of the document are to:

- provide information on the behaviour and effects of phosphorus in the riverine ecosystem;
- discuss factors obscuring the effects of phosphorus;
- raise awareness of the importance of phosphorus control;
- clarify the contribution that can be made by phosphorus-stripping.

### A6.3 Estuaries and coastal waters

The impact of eutrophication in estuaries and coastal waters is generally less well understood compared to lakes and rivers. Table A6 shows that research is addressing the relationships between nutrients and phytoplankton in coastal waters. Parr and Wheeler (1996) attempted to identify trends in nutrient enrichment of sensitive marine areas for English Nature using existing monitoring data and the limitations of these data gave rise to a number of research suggestions. Scott *et al.* (1999) identified a number of projects that would contribute to the better understanding of the impacts of nutrients in estuaries.

### A6.3.1 Trends in nutrient enrichment of sensitive marine areas in England (Parr and Wheeler, 1996)

This report reviews the biological and chemical data available for the following English Sensitive Marine Areas (SMAs):

- The Colne and Blackwater estuaries.
- Southampton Water, Langstone, Chichester and Portsmouth harbours.
- The Exe Estuary.
- The Dart Estuary.
- The Salcombe-Kingsbridge Estuary.
- Plymouth Sound, Tamar and Yealm estuaries.
- The Fal Estuary.
- The Helford Estuary.
- The Hayle Estuary.
- The Camel Estuary.
- The Severn Estuary.
- The Dee Estuary.

Where possible, changes in the ecology of these SMAs since the 1960s to the present date have been identified from peer-reviewed mainstream and grey literature, with a view to linking this information to recorded changes in nutrients and suspended solids fluvial fluxes, or concentrations within the SMAs themselves. Chemical and river flow data were provided principally by the NRA and were analysed using either the AARDVARK statistical package (WRc plc), or the SAD computer program (WRc plc). A brief review of the factors controlling eutrophication in tidal waters is presented to place the role of nutrients and suspended solids in context with other (principally physical) factors.

Despite initial expectations to the contrary, either the chemical or biological data proved to be insufficient to demonstrate a definitive cause/effect relationship between nutrient levels or loading and ecological changes in any of the SMAs. However, the data illustrate that ecological damage may possibly have occurred in a number of estuaries and embayments as a consequence of changing nutrient/organic status, but that better data, notably biological monitoring data, are required to establish such a relationship with certainty.

#### A6.3.1.1 Nutrient enrichment of SMAs: Conclusions

- The data available are not sufficient to definitively link changes in the nutrient status of any of the SMAs discussed in this report with changes in the ecology of these estuaries and coastal embayments.

- Despite the above reservation, it appears that nutrient and suspended solids riverine loading to most of the SMAs discussed do not appear to have shown a consistent increasing or decreasing trend over the past 5-20 years. Analyses of nutrient and suspended solids concentrations within some of the SMAs themselves have hinted at either increasing or decreasing nutrient status, but as so many factors control variability amongst these concentration data, the results should be used as a potential indicator, not as definitive evidence of changing nutrient status.

- In none of the SMAs reviewed in this study can a change in estuarine ecology definitely be ascribed to either increased fluvial fluxes of nutrients or increased nutrient concentrations within the SMAs themselves. Likewise ecological changes cannot definitely be linked to changes in suspended solids loading nor concentrations.

- The SMA for which the best ecological data are available to demonstrate a progressive change in species abundance and distribution (Langstone Harbour) is also the SMA for which the worst set of water quality data exists. In many of the SMAs reviewed in this report, the spatial variability associated with estuarine water quality, together with spatial variability of the biota themselves, make it extremely difficult to firmly establish a cause/effect relationship between ecological changes and nutrient status. Despite this, large biological changes have occurred in a number of SMAs, which may possibly be related to changing nutrient/organic status (notably the Tamar, Yealm, Fal, Helford and Severn estuaries, in addition to Portsmouth Harbour).

- Further work is required to assess the importance of changing organic status as a causative factor of ecological damage/change in tidal waters.

- Much of the temporal variability associated with estuarine nutrient and suspended solids concentrations is almost certainly a consequence of the sampling and analytical protocols used.

- Sediment nitrogen mineralisation rates appear to be a better predictor of the trophic status of intertidal sediments than nutrient loading rates or concentrations.

- Nutrient loading rates and water column concentrations clearly have a major impact on the trophic status of estuaries, but the associated organic load is probably a more important aspect of eutrophication in many estuaries, in terms of the effect on benthic ecology.

- Annual transect-based biological surveys provide a cost-effective method of monitoring biological changes in tidal waters.

- Eutrophication of estuaries is likely to be observed first in relatively small areas in the vicinity of point source inputs (e.g. nutrient-rich feeder streams or outfalls), rather than as a pan-estuarine process.

- Ecological changes may be taking place in some of these SMAs as a consequence of eutrophication, but the data available are not suitable for demonstrating such changes.

- Increased monitoring of the role of organic nitrogen and total phosphorus would improve our understanding of estuarine nutrient transformation processes and may possibly, as with freshwater lakes, prove to be a more appropriate indicator of the trophic status of tidal waters.

- Of the three nutrients reviewed in the study (N, P and Si), dissolved silicate levels show the greatest fluctuation and are probably least important in terms of being a causative factor of estuarine eutrophication. However, silicon is believed to be a key factor governing phytoplankton periodicity and consequently appears to be important in the occurrence of toxic dinoflagellate blooms.

#### A6.3.1.2 Nutrient enrichment of SMAs: Recommendations

- Identical transect-based biological surveys should be undertaken in each SMA. Where possible, these surveys should be undertaken annually, but biennial or triennial surveys may suffice.

- Where funds allow, increased monitoring of organic nitrogen and total phosphorus should be undertaken at harmonised monitoring sites and within the estuaries themselves.

- Measurement of intertidal nitrogen mineralisation rates in the late spring should be considered as part of an estuarine trophic status monitoring programme.

- Now that a standard national tidal waters sampling programme has been recommended (Rees *et al.,* 1994; Gunby *et al.,* 1995 quoted in Parr and Wheeler, 1996), this should be followed to reduce the variability associated with future sampling trips, thereby making data collected in the future better suited for desk studies of this type. However, any changes in monitoring strategy adopted by the NRA (as part of its General Quality Assessment Scheme, Estuarine Nutrients Module) must be taken into account prior to following this recommendation.

A complementary review to that presented in this report should be undertaken to determine the strength of the relationship between ecological changes in tidal waters and organic enrichment. It is appreciated, however, that substantially fewer data are available on concentrations of dissolved and particulate organic carbon than nutrient levels. Related factors such as BOD levels in the water column and sediment oxygen demand should also be included in this review.

### A6.3.2 Impact of nutrients in estuaries – Phase 2 (Scott *et al.*, 1999)

It is evident from the review of literature that despite the extensive nature of this review on nutrient impacts in estuaries, many aspects of the process of nutrient enrichment and their effects on estuarine species and communities remain unclear. The complexity of the estuarine physical environment and the consequently robust and complex nature of the estuarine communities present major obstacles to understanding the 'cause and effects' relationships between nutrients and biological response and therefore, to the effective management of enrichment in estuarine systems. The present understanding of the subject is also clearly hampered by factors such as the lack of system-wide investigations and the absence of any standard approach to the monitoring of nutrients in estuaries throughout the UK.

The wealth of information that is available however, does provide a good conceptual indication of the potential problems arising from enrichment and identified several key biological responses that can be expected to take place where suitable physical conditions prevail. Most notable among these is the classical concept of successional change in the balance of autotrophic species from k-dominant to r-dominant species, one of the few well-defined potential responses. However, none of the topics reviewed here has complete scientific understanding and thus would benefit greatly from further study; furthermore, while conceptual understanding of many features of enrichment is well developed, any quantitative extension of this is poor.

In addition to the application of estuary classification and monitoring procedures (see Section A3.3 and A4.3), there are numerous studies that can be undertaken to answer specific questions about the ecological impact of nutrients in estuaries. No aspect of this subject can be considered as fully understood and unlikely to benefit from increased scientific investigation but a few specific studies are recommended here which would be of particular interest to the Environment Agency (or English Nature).

**1) An investigation of responses by saltmarshes to changing nutrient levels**

The paucity of information on the responses of saltmarshes to increased nutrients must be a major concern for English Nature. A separate review and study of this subject is recommended.

**2) A review of the ecological status of low-nutrient estuaries in England and Wales**

An assessment of the status of low-nutrient estuaries and an assessment of their potential responses to nutrient enrichment. Firstly the number of such estuaries should be calculated, the habitats reviewed through field studies and the potential response to nutrients estimated using the classification approach. This work needs to be undertaken to demonstrate the value of these sites but care should be taken not to over emphasise the importance of these estuaries in the absence of any detailed information.

**3) A review of the relationship between physical and chemical parameters in UK estuaries**

To complement the work being carried out on the estuary classification scheme it will be necessary to carry out a geomorphological review to describe the relationship between influential physical and chemical factors in estuaries. For example it is necessary to clarify the relationship between freshwater flow, tidal movement and the flushing time of estuaries in order to better predict the response of an estuary to changing freshwater flows and accompanying changes in the nutrient input rate.

**4) An assessment of the relationship between plant tissue nutrient concentrations and the ambient water column nutrient concentrations**

This study would be designed to show whether plant tissue nutrients could be used as a viable indicator of the ambient nutrient levels within an estuary. It is possible that plant tissue nutrients will reflect the nutrient concentrations over the long term and therefore provide a much better measure of the ambient nutrient concentrations than individual water column samples, which will be highly influenced by the variability of the conditions within estuaries. Such a study would involve the measurement of nutrient concentrations in the tissues of several plant types from a range of different estuary systems together with concomitant long-term water column nutrient monitoring.

**5) A study of the impact of macroalgal mats on fish and bird populations.**

Some evidence is available to suggest that the feeding of some bird species can be impaired by the excessive growth of macroalgal mats in the intertidal regions of estuaries. This effect needs to be studied in greater depth to obtain a quantifying measure. An effect on fish feeding is likely but has not been proven probably because of the obvious difficulties associated with the observation of fish feeding activities. As birds and fish are key components in the ecology of estuaries, a study is required into the effects of macroalgal growth and the change in prey palatability following organic enrichment on their feeding activities. Such a study may require fish feeding experiments in laboratory flumes.

**6) Analysis of the effects of nutrients on the formation of water quality barriers to fish migration**

Oxygen depletion in the upper region of estuaries is a characteristic phenomena and the effects of oxygen depletion on fish and benthic species is well documented, what remains unclear however is the effects that nutrient loading has on the creation of water quality barriers to fish migration. This requires a specific examination of the relationship between nutrient and organic mater loading, the morphological characteristics of estuaries and the stability and duration of DO sags in estuaries.

**7) Identification of a viable approach to a national assessment of background nutrient concentrations in estuaries**

A measure of the background nutrient concentrations in estuaries would be a useful component for inclusion within the estuary classification procedures because it would provide a context for assessing contemporary nutrient loading to estuaries and would assist both the Environment Agency and English Nature in assessing areas of potential risks from nutrient enrichment. It is considered that the nutrient export approach represents the most effective way of describing background nutrient inputs to estuaries although its usefulness on a nation-wide basis is constrained by the cost of this procedure. It is recommended that a study should be undertaken to assess the efficacy of applying a simpler and more economical approach. For instance could a few indicators such as catchment area, pre-World War II land use and changing agricultural practices be used to describe historical loads to estuaries.

**8) Broad-scale studies on a range of estuary types**

Once the classification of estuaries procedure has been completed it will be possible to identify a range of different estuary types in respect of their potential response to nutrient enrichment. The instigation of ecosystem-level investigations of nutrient responses will greatly enhance understanding of the cause and effect relationships of enrichment in estuaries.

Among the research topics listed above it is suggested that the first two warrant particular study in the next phase of the Impact of Nutrients in Estuaries project. The investigation of low nutrient estuaries will compliment the work done on the estuary classification project and considering the value of saltmarsh systems a study, or at least a specific literature review, on the impacts of nutrients to these habitats would be useful.

## A6.4 Wetlands

While little research has been directed towards the impact of eutrophication in wetlands, the following information has been provided by Chris Mainstone of English Nature (Mainstone, pers. comm.).

### A6.4.1 Eutrophication research into wetlands (Mainstone *pers. comm*.)

The term wetland is used to describe a wide range of hydrological conditions and hence habitat and vegetation types, from periodically inundated wet meadows (where no peat accumulation occurs), through peat-forming mires, to swamp habitats and in the broader sense all forms of open water. Open water has been dealt with under separate sections, with the ditch systems typically associated with wet meadows and mires having closer process links with lake systems than the meadows and mires themselves.

The focus of this text is peat-forming habitats, which are most commonly associated with the term wetland. Within this broad category, there are base-poor (bogs) and base-rich (fens) types, with further category distinctions being made on the basis of the method of water delivery, landform and other characteristics. Each of these characteristics affects the vulnerability of a wetland to eutrophication, and the way in which nutrient cycling and vegetation reacts to external nutrient loads and other forms of anthropogenic stress.

Both bogs and fens have large nutrient reservoirs, but nutrient availability is low due to hydrological and physico-chemical constraints on microbial decomposition and mineralisation (plus chemical reactions that lock up nutrients). It is therefore important to recognise two mechanisms of eutrophication (Koerselman and Verhoeven, 1995):

- *external eutrophication*, concerning the loading of nutrients from sources outside of the system;
- *internal eutrophication*, concerning physical, chemical and/or hydrological disturbances that lead to changes in nutrient cycling processes and thereby increase nutrient availability.

Both mechanisms are of direct relevance to the Environment Agency and it is important to have a good understanding of both if mires are to be protected and/or restored. As with eutrophication in various types of open water, the underlying mechanism of impact on biological communities is through increased nutrient availability altering the competitive balance between plant species of the unimpacted community and species that are more competitive at higher nutrient levels. Species of the unimpacted community are lost by losing the battle for light and space.

The nutrient limiting growth in mires is generally either nitrogen or phosphorus, although potassium limitation has been observed in certain systems (Koerselman and Verhoeven, 1995). The situation is not that simple for calcareous fens, however, since positive responses to nitrogen additions have been observed in calcareous fens even though phosphorus is generally considered to be the limiting nutrient in such habitats (due to heavy complexation of phosphorus with calcium hydroxides and other mineralisation reactions). The answer seems to be that characteristic plant species of calcareous fens have mechanisms for releasing phosphorus from chemical complexes, but species that are not adapted to the habitat would suffer severe P-limitation under unimpacted conditions. Increasing phosphorus availability therefore does not stimulate growth of characteristic plants, but increasing nitrogen availability does.

External sources of N and P to mires are reasonably well-understood, with precipitation often being an important source of nitrogen, and groundwater and surface water variously important for both N and P. ‘Discharge’ mires (formed from groundwater seepages and springs) are generally less vulnerable to external eutrophication (particularly by phosphorus) owing to filtering processes within the aquifer; however, this depends on the geological circumstances, with calcareous aquifers affording much greater protection than sandstone ones. Recharge fens are generally most susceptible to external eutrophication, although ombrotrophic (rainfall-fed) bogs are highly vulnerable to N-enriched precipitation.

Internal eutrophication is far less well studied and understood. Research on Dutch fens has indicated that, where 'recharge' (as opposed to discharge) fens are dependent upon inundation by river water, pollution can not only increase the nutrient load directly but also contribute to internal eutrophication by unlocking chemically-bound phosphorus. The mechanism is unclear but probably involves the action of sulphate on phosphorus complexes (Koerselman and Verhoeven, 1995). Changes in hydrological conditions, brought about by land drainage, flood defence or abstraction, not only have well-known effects on plant communities through drought and aeration stress (Gowing and Spoor, 1996), but also affect microbial mineralisation processes in ways that can increase nitrogen and phosphorus availability. These interlinked hydrological and chemical processes have been modelled in the Netherlands as a means of trying to predict plant community change (see Mainstone *et al*., 1998).

In terms of restoration strategies, it is clear that both internal and external eutrophication have to be considered fully if ecological objectives are to be met. Co-limitation of plant growth with N *and* P has been suggested as a desirable long-term aim of restoration, to ensure a stable trophic status that does not respond rapidly to variations in a sole limiting nutrient. This is an important message for eutrophication control in open water bodies.

#### A6.4.2 Eutrophication research into wetlands: future research

The indications are that work is required in the UK to clarify the role of internal eutrophication in different wetland types (building on the research undertaken in Europe), and to identify the anthropogenic stresses leading to this mechanism being important.

In general, further research seems to be required into the responses of bog and fen species to increased availability of both N and P, with a view to predicting vegetation changes as a result of changes in the extent of both internal and external eutrophication.

## A7 EUTROPHICATION CONTROL ACTION PLANS (ECAPS) TOOLS

### A7.1 Source apportionment

Table A7 lists the projects, where identified, addressing source apportionment. Further information on each project is available from the funding bodies (see Section 2 for contact details).

**Table A7 UK funded eutrophication-related R&D projects addressing source apportionment**

| Ref | Title | End Date | Funding body |
|---|---|---|---|
| | Organic nitrogen in precipitation: real problem or sampling/analytical artifact? | | NERC GANE |
| | Current and historical nitrogen deposition in the UK and diagnostic indicators of critical load exceedance | | NERC GANE |
| | Atmospheric inputs to the Northern North Sea | | NERC GANE |
| | Landscape analysis of transport, transformation and fate of reactive nitrogen and abatement strategies | | NERC GANE |
| | Application of catchment scale data to the quantification of soluble organic and inorganic N fluxes within and from UK upland soils | | NERC GANE |
| | Nitrates Directive: catchment based study to identify options for reductions in nutrient outflows to sea | 2000* | DETR |
| | Catchment based study to identify options for reductions of nutrient flows to sea II | 2000* | DETR |
| | MAFF Nitrate R&D Programme | | MAFF |
| | MAFF R&D on phosphate loss from agriculture | | MAFF |
| MAF12260 | Optimising soil management to prevent contamination of surface waters by sediment, phosphorus and micro-organisms | 2003 | BBSRC |
| MAF12247 | Scale and uncertainty in modelling phosphorus transfer from agricultural grasslands to watercourses: development of a catchment scale management tool | 2003 | BBSRC |
| 034173 | Atmospheric deposition and its impacts on ecosystems | 2002 | BBSRC |
| P2A(98)11 | Nutrient modelling on the river Kennet | 2001 | EA |
| 031479 | Measure run-off and soil losses, and associated losses of phosphate, other nutrients and pollutants on land liable to erosion | 1999 | BBSRC |
| P2A(97)01 | Pilot Catchment study of nutrient sources - control options and costs | 1999 | EA |
| P269 | The impacts of nutrients in estuaries Phase II | 1999 | EA/EN |
| | Nutrient status of the Glaslyn/Dwyryd, Mawdach and Dyfi estuaries - its context and ecological importance | 1999 | CCW |

| Ref | Title | End Date | Funding body |
|---|---|---|---|
| | Diffuse pollution: sources of nitrogen and phosphorus | 1999 | DETR |
| | Estimation of nutrient loading to the Fleet lagoon from diffuse sources | 1999 | EA South West |
| | A review of ecological models of potential use in environmental forecasting | 1998 | EA |
| | Nutrient budget for the upper reaches of the Hampshire Avon | 1998 | EN |
| | Trends in nutrient enrichment of sensitive marine areas in England | 1996 | EN |
| SR 95(06)F | Hindcasting of in-loch phosphorus concentrations based on land cover classification | 1996 | SNIFFER |
| 639/1/A | The impacts of nutrients in estuaries - Proceedings of the scoping workshop | 1995 | EA/EN |
| Note 320 | Land management techniques | 1994 | EA |
| NR 3698 | River Eutrophication Risk Modelling: A GIS Approach | 1994 | SNIFFER |
| PR 113/10/ST | Diffuse pollution from land-use practices | 1993 | EA |
| Note 32 | Review of R&D priorities - Agricultural impacts on water quality | 1992 | EA |
| FR0316 | The fate of nitrogen resulting from the application of sewage sludge | 1992 | FWR |
| SR 2713/1 | Eutrophication in upland waters | 1991 | SNIFFER |
| P-39 | Review of the effects of afforestation on upland water quality | 1990 | EA |
| P-79 | Nutrient enrichment of Scottish Lochs and reservoirs, with particular reference to the impact of forest fertilisation | 1990 | EA |
| PRS 2468M/1 | The impact of land use on water quality - a review of available models | 1990 | EA |
| P2-014 | Land management techniques - Phase 3 | | EA |

* Proposed new starts in the DETR MLIS programme 2000/2001 (see Section 2 for contact details)

Source apportionment includes methods for identifying nutrient sources (point and diffuse) within a catchment and for estimating relative contributions to overall nutrient loads and eutrophication impacts. One of the key diffuse sources of nutrients is from agriculture and MAFF have supported two very large research programmes on nitrate and phosphate loss from agriculture (MAFF 1996, 1999a and b). These research programmes have also addressed some issues relevant to source measures (see Section A4) and control techniques (see Section A7.5). All of the issues concerned with diffuse sources of nitrogen and phosphorus have recently been reviewed by Parr *et al.* (1999a) for DETR. The implications of diffuse sources of nitrate for groundwater have been considered by Chilton *et al.* (1996) for the Environment Agency.

Source apportionment is a key step in the construction of nutrient budgets and a number of operational projects include nutrient budgets: Fleet Lagoon (Mainstone and Parr, 1999), upper Avon (Parr *et a.,l* 1998), Welsh estuaries (Parr *et al.,* 1999b).

The National Environment Research Institute (NERI) in Denmark completed an Integrated Environmental Assessment (IEA) of eutrophication (NERI, 1997) on behalf of the European Environment Agency (EEA) which proposed some further work on source apportionment.

Summary information from these key research programmes/projects is provided in the following sections.

### A7.1.1 MAFF Nitrate R&D programme

For more than 10 years, MAFF have funded an extensive programme of R&D aimed at optimising the use of nitrate in agricultural practices to minimise the loss of nitrate to the environment from agricultural diffuse sources. The programme was reviewed in 1996 (MAFF 1996) and synthesised in 1999 (MAFF, 1999b). It is currently funded at £4million per annum.

MAFF have funded a total of 87 individual projects in 8 keys areas with end-dates ranging from 1996 to 2000 (MAFF, 1996). The outputs from the projects are in the form of published papers in the open literature, popular articles in the industry press and advice/guidelines in various forms for farmers including the revision of appropriate parts of the Codes of Good Agricultural Practice. MAFF produced a bibliography of references arising from the nitrates programme in 1999. The 8 key areas of research were:

1. Efficiency of nitrogen fertiliser use for arable and horticultural crops;
2. Assessment of nitrate losses from arable and horticultural crops;
3. Use of manures;
4. Fate of organic nitrogen;
5. Guidelines for reduction of nitrate leaching from grassland and forage crops;
6. Application of models;
7. Whole system studies;
8. Minimising total losses of nitrogen from agriculture.

The MAFF Nitrate programme was synthesised under the following headings in MAFF (1999b) assimilating results and conclusions from research in the 8 key areas. These relate to Eutrophication Focus Areas as follows:

- Source measures (see Section A5)
  - Development of improved advice for farmers and advisors
- Source apportionment (this section)
  - Nitrate leaching from arable and horticultural land;
  - Nitrate leaching from grassland and potential abatement strategies;
  - A modelling framework for evaluating nitrate losses at national and catchment scales
- Control techniques (see Section A7.5)
  - Strategies to encourage better use of nitrogen in animal manures – Control techniques (see Section A7.5).

#### A.7.1.1.1 Nitrate leaching from arable and horticultural land

The aims and objectives of the arable and horticultural part of the Nitrate Programme have been to:

- quantify the losses of nitrogen from a range of crops and soils and relate these to management and the weather;
- obtain a better understanding of the nitrogen cycle, especially key processes such as mineralisation that control nitrogen availability to crops and losses;
- incorporate this knowledge into better recommendations for fertiliser and manure use, including predictive models, and generate practices that sustain production but minimise nitrate/nitrogen losses.

The conclusions and practical outcomes of the research have been to:

- better understand the amounts and causes of nitrogen loss to the environment,
- define best management practices to minimise leaching from land growing arable and horticultural crops as follows:
  - choose a high-yielding variety to maximise the use of the available nitrogen;
  - maintain green cover as much as practicable - use a cover crop if necessary and drill autumn sown crops early;
  - calculate fertiliser requirements using the best recommendation system available, allowing for soil mineral nitrogen residues and nitrogen in manures;
  - use starter fertilisers and banding for vegetables;
  - apply autumn nitrogen only to those crops that need it - avoid unnecessary early applications in spring;
  - use split applications and apply fertiliser at the appropriate time;

- apply fertilisers and manures carefully - well away from watercourses - with a properly calibrated spreader;

- use appropriate controls to minimise pest, disease and weed infestation;

- irrigate carefully where required to support crop yield and using a scheduling system that takes account of crop nitrogen use and the weather.

- understand that best management practices will reduce emissions only slowly and gradually. Large and rapid reductions can only be achieved by a radical change from arable and horticultural cropping to extensive unfertilised grass.

- appreciate that the use of buffer strips between agricultural land and watercourses or boreholes can reduce the leaching of nitrate, phosphate and pesticides where the hydrological pathways have been identified and can be intercepted.

- understand that a change in farm system (i.e. organic farming, Integrated Farming Systems (IFS)), can reduce nitrate losses although requiring significant start-up costs.

- considerably improve the advice given to advisors, farmers and growers and have been incorporated in the management of NVZs.

The continuing needs identified from this area of research were:

- to encourage farmers to take responsibility for the losses of nitrogen from their farms and to use the improved recommendation systems and supports.

- to further understand the balance between reducing nitrate losses to surface waters and increasing losses of nitrous oxide to the atmosphere (pollution swapping - eutrophication for global warming) and to devise strategies to reduce total environmental impact.

**A7.1.1.2 Nitrate leaching from grassland and potential abatement strategies**

The aims and objectives of this part of the Nitrate Programme were to:

- establish the extent of nitrate losses from grassland systems and, in particular, from grazed pastures;

- improve predictive capabilities by modelling the nitrogen cycle in grassland systems.

The main outputs of the research were:

- clear demonstration of the extent of nitrogen leaching losses, especially those from grazed pastures under intensive management;

- improved recognition of how the soil nitrogen cycle interacts with the whole farm nitrogen cycle and acknowledgement that leaching losses should not be considered in isolation;

- demonstration of the key role that mineralisation of nitrogen from soil organic matter has in contributing to the pool of available nitrogen in grassland soils and of the need to better account for this in future methods to define nitrogen requirements;

- development of user-friendly models of nitrogen cycling which can be used to make predictions of the annual effects of changes in husbandry for fertiliser nitrogen and manure additions, and the incorporation of this approach into catchment models;

- development of the conceptual and practical basis for new approaches to fertiliser management;

- adoption of new approaches to determine the consequences of modifying nitrogen flows and losses;

- demonstration that practical options to limit nitrate leaching and other nitrogen losses can be achieved using current information;

- demonstration of effects and possible options for immediate uptake by farming communities through visits, talks and roadshows resulting in a rising awareness of the need for improved nitrogen management.

The potential abatement strategies arising from recognition of these results have been used both within and outside Nitrate Vulnerable Zones and for improvements in the Codes of Good Agricultural Practice. They include:

- controlling rates and timing of manurial application rates in relation to fertiliser inputs;

- manipulation of grazing management to avoid critical periods for leaching;

- improved fertiliser timing to better meet the needs of the current demands of the grass crop;

- improved protocols after swards have been reseeded;

- potential to reduce nitrogen inputs to intensive management systems, especially dairy enterprises.

The continuing needs identified from this area of research were:

- identification of the rate of nitrogen storage in grassland soils and the impact this has on supplies of available nitrogen from ‘native’ sources and whether this can be used to explain the still large ‘unaccountable’ component of the farm nitrogen budget;

- continued improvement to the Decision Support Systems for nitrogen use in fertilisers and manures;

- need to provide better advice for maize production and its nutrient requirements;

- improved modelling of parts of the farm system that are associated with the phase of production during which farm animals are housed;

- improved understanding of the grassland nitrogen cycle in relation to emissions of ammonia and nitrous oxide.

### A7.1.1.3 A modelling framework for evaluating nitrate losses at National and Catchment Scales

The objective of this area of research was to provide MAFF with a method of estimating nitrate exports to groundwater and surface water catchments. The essential attributes of such a system were established as:

*accurate* - reflecting observed data both at plot and catchments scales;

*correctly responsive to change* - so that the impact of any reduction strategies or change in conditions can be assessed;

*based on data available for 'unknown' catchments* - not dependent on detailed information that is not available at the catchment scale;

*easy to u*se - so that MAFF staff could answer simple queries directly and explore a range of scenarios at both field and catchment scales;

*readily updated and expanded* - so that new models could be added or loss estimates adjusted as necessary, and the output from different models compared.

The resulting modelling framework called MAGPIE (Modelling Agricultural Pollution and Interactions with the Environment) was built based on data for the whole of England and Wales.

The conclusions and practical outcomes of the development of the modelling framework were:

- The MAGPIE model has been shown to give satisfactory agreement with measured nitrate concentrations and flow in rivers, both in terms of annual totals and time course at the catchment level;
- MAGPIE has proved valuable in demonstrating the relative importance of diffuse inputs from land, compared with point discharges, in determining peak nitrate concentrations;
- The model system forms the basis of current discussions within Europe (OSPAR) on harmonisation of methods for the assessment and reporting of nutrient inputs to the North East Atlantic, including the North Sea;
- The database built for nitrate modelling is proving invaluable as a basis for work on related environmental policy issues;
- Other pollution models including ammonia loss, nitrogen balance and phosphorus loss are planned to be built into the same framework, thereby exploiting the considerable investment in building the agricultural and environmental databases.

The continuing needs for enhancements to improve the predictions and outputs from MAGPIE include:

- integration with models of in-river processes and non-agricultural inputs/outputs;

- inclusions of groundwater/surface water interactions;
- improved allowance for the effects of rapid flow through soil cracks and field drains;
- incorporation of more detailed survey information (i.e. timing and application rates of farm manures).

### A7.1.2 MAFF Phosphate Loss from Agriculture R&D Programme

MAFF have funded an extensive programme of R&D aimed at the assessment of 'the contribution of agricultural practices to phosphate loss, and to devise management strategies to meet likely future national and international requirements for the control of phosphate inputs from agriculture to surface and underground waters as they occur' (MAFF 1999b). The programme began in 1992, was reviewed in 1995 and again in 1999 (MAFF, 1999b).

MAFF have funded a total of 38 individual projects with end-dates ranging from 1994 to 2003. The 1999 review considered 24 projects for which significant progress had been made in the period 1995 to 1999 grouped into 3 key areas: Field scale measurement, Catchment scale measurement and Coefficients of phosphate loss. The following brief sections summarise the objectives, conclusions to date and possible future work for each of the projects within these key areas.

#### A7.1.2.1 Field scale measurement

**i Phosphorus co-ordination project (ADAS)**

*Objectives:*

- To ensure the successful integration and completion of projects within the MAFF R&D programme on 'Phosphorus loss from agriculture,' advise on new R&D opportunities and contribute ideas towards policy;
- To co-ordinate an EU COST Action 832 'Quantifying the agricultural contribution to eutrophication' (see Section 5.2.2);
- To co-edit a special issue of Soil Use and Management on agricultural phosphorus loss to water.

*Conclusions:*

- Results of the phosphorus loss programme to date indicate that the concentrations and loads of phosphorus leaving agricultural fields are sufficiently large to cause eutrophication problems but further information is needed on both the fate of these transfers as they move to the catchment outlet and their impact on entering the receiving water.
- In terms of control, diffuse P loss is best viewed as a total P loss problem.
- Accelerated P loss may occur due to changes in land management affecting storm run-off and erosion rates, in the way manures and fertilisers are stored and/or applied, and/or due to an increase in soil P status.

- Flow is the main driver for P loss and a better understanding of the interaction between flow rate and soluble and particulate P loss from soils will improve quantification of the significance of agriculture as a cause of eutrophication problems.

- Nutrient budgeting remains as priority issue since excessive accumulation of P in the soil cannot be rectified quickly. Diffuse P loss is a catchment specific problem and mitigation options are best targeted at those areas which are at highest risk and generate the most loss.

*Future work:*

- Significance of agriculture as a source of diffuse P in different UK regions;
- Interaction between rate of flow and phosphorus loss from soils;
- Sources and pathways of P loss in different sized catchments - the scaling up issue;
- Effectiveness of control measures and their integration at the catchment scale;
- Impacts of diffuse P concentrations and loads on water quality.

**ii Phosphorus retention at the field and catchment scale: a review (ADAS)**

*Objectives:*

- To identify the potential mechanisms by which transported phosphorus is retained within fields, small catchments and large catchments;

- To quantify phosphorus retention by the different mechanisms.

*Conclusions:*

- As P is transported from the field to the catchment outlet, P export rates commonly decline with distance from the source and as catchment size increases;

- Sediment transport has a dominating influence on P fluxes within agricultural catchments;

- Deposition and storage of sediment associated P within fields, river channels and the flood plains are the major mechanisms of P retention;

- Most detached sediment is redistributed in the field and not lost to the watercourse;

- Hedgerows and riparian zones have a large potential to store P;

- In-stream deposition represents only a small proportion of the total P flux through a catchment;

- Floodplains are important storage zones retaining up to 50% of suspended sediment;

- Suspended particulate P is most probably associated with very fine colloidal material and is most likely to enter into sorption reactions with soluble P.

*Future work:*

- Further work is required to test the individual and combined influence of storage zones within catchments on phosphorus transfer, and create modelling opportunities around their relative distribution.

**iii Phosphorus loss from manures (ADAS)**

*Objectives:*

- To quantify the risk of phosphorus loss following land application of manures;
- To identify farm management practices likely to reduce phosphorus losses.

*Conclusions:*

- High risk of particulate P loss from maize fields and an increased risk of incidental P loss where slurry is applied to the surface;
- Ploughing in slurry or tyne cultivation before application of slurry significantly reduces the risk of P loss;
- Leaching is a significant pathway for P loss from high P status soils.

*Future work:*

- Cultivation practices to reduce P loss may have implications for increased risk of N loss through mineralisation and leaching over the winter period after the maize harvest.

**iv Phosphorus leaching from a sandy soil receiving regular applications of poultry litter or phosphate fertiliser (ADAS)**

*Objectives:*

- To monitor, by soil analysis to depth, the migration of P from the cultivation layer to the deeper subsoil;
- To undertake soil solution sampling to quantify the depth of any P movement from the topsoil;
- To identify the P threshold at which P movement becomes significant.

*Conclusions:*

- Losses of P to lower layers became significant where P applications increased Olsen soil P status above 100 mg/kg (i.e. P index 6 and above);
- Leaching on a structureless sandy soil will not be a significant loss pathway for phosphorus and adopting good agricultural practices should avoid the build up of soil P status to levels that will increase P leaching.

*Future work:*

- Confirmation of soil P thresholds for significant leaching of P from poultry litter applications;

- Monitoring responses of soils and crops in P rich areas to withholding further P additions.

**v Phosphorus losses to surface water following manure application to agricultural land (ADAS)**

*Objectives:*

- To improve understanding of phosphorus losses via surface run-off, following organic manure applications to agricultural land;

- To identify appropriate management strategies likely to reduce such losses.

*Conclusions:*

- Losses of total and soluble P recorded during four years of monitoring were insignificant in agronomic terms but peak concentrations of P during a run-off event could be of considerable concern in sensitive catchments and could make a significant contribution to accelerated eutrophication on entry to watercourses and inland waters;

- Restricting slurry application rates to those consistent with good agronomic practice offers the simplest and most cost-effective control measure against this potentially important source of diffuse pollution.

*Future work:*

- Investigate critical thresholds for slurry solid loading over a range of soil types and conditions;

- Investigate the physical clogging of pores at the soil surface by slurry solids by different types of slurry (i.e. pig and cattle slurry).

**vi Phosphorus losses from drained clay soils receiving organic manures (ADAS).**

*Objectives:*

- To quantify P losses following the application of farm manures to a drained clay soil;

- To identify appropriate land management practices likely to reduce P losses.

*Conclusions:*

- Pig slurry application increased P losses in the first drainage season but not in the other two seasons. This may have been due to either the recent installation of the drainage system or the short time between the pig slurry application and the first drainage event (c. 6 weeks) compared with the other two seasons (c. 13 weeks);

- Solid manure and inorganic fertiliser P additions did not increase P losses in drainage water.

*Future work:*

- Evaluate interactions between the timing of slurry applications and P losses in drainage water and the effects of slurry incorporation into the soil compared with ploughing down as a technique to reduce P losses. (Work commissioned in project on the measurements of phosphorus loss from manures).

**Phosphorus losses from a lowland dairy farm (ADAS)**

*Objectives:*

- To quantify P losses in subsurface flow from land used for lowland dairy farming in a low rainfall area;

- To measure P concentrations (MRP, total dissolved P and total P) in subsurface flow from two drained fields over three winter drainage seasons;

- To quantify annual P losses from the fields in relation to soil P status and field management practices.

*Conclusions (provisional):*

- Total P losses from the two experimental grassland fields in Worcestershire were similar to losses from a similar clay textured soil at Brimstone (Oxon) under annual cultivation and arable cropping;

- A greater proportion of the total P was in the MRP form from these grassland fields (55%) compared with arable management (c. 20%) which may be related to grassland surface P additions via slurry and grazing livestock, and rapid water movement through the mole and tile drainage systems.

*Future work:*

- Evaluation of the interaction between soil surface P additions and soil hydrology, and the magnitude and form of P losses from drained grassland soils.

**Phosphorus transfer from grassland soils (IGER)**

*Objectives:*

- To extend current understanding of rates and mechanisms of P loss from poorly drained grassland soils;

- To further understand interactions between P losses, environmental conditions and management factors;

- To further understand the potential for P loss over a wider range of inputs and soil types;

- To address the scaling-up issue by taking measurements at small plot, field, lysimeter and farm scales in relation to catchment information;

- To further develop budgets for P loss from grassland.

*Conclusions:*

- Background phosphorus export coefficients from grassland are in the range 0.3 - 1.3 kg TP $ha^{-1}$ $yr^{-1}$ and are smaller on drained soils. Methods of calculation affect the estimated value. Concentrations in drainage are such that they will contribute to eutrophication (<100 TP $l^{-1}$);

- Processes involved can be categorised as: solubilisation (leaching), physical detachment (particles and colloids) and incidental mechanisms (direct transfer of fertiliser and slurry);

- Accelerated incidental transfers represent an important component with much potential for mitigation;

- P responses downstream can be related to upstream transfers in the field;

- Budget modelling exercises have demonstrated that P is accumulating in grassland farm soils and if current management continue, there is the potential for total soil P concentrations to double in 30 years.

*Future work:*

- Establish ways of reducing incidental transfers;

- Identify a mechanism for tracking the connectivity of P in storm discharges through catchments.

**Quantification of P transfers from soil following tillage and reseed of grassland swards (IGER)**

*Objectives:*

- To monitor and quantify the P discharges from tilled and reseed plot lysimeters;

- To compare the effect of sward presence/absence on particle/colloid sizes and forms of P transfer and determine inputs;

- To determine the effect of threshold rainfall values on P transfer pathways using soil block experiments;

- To determine the implications for improved grassland management recommendations for the protection of water.

*Conclusions (provisional):*

- Accelerated P transfer can occur when reseeding is followed by intensive rainfall particularly on undrained grassland;

- Accelerated P transfer may be particularly prevalent on grassland soils which, in contrast to arable soils, receive greater amounts and intensity of rainfall, often on sloping land;

- After sward re-establishment on undrained soils, concentrations and loads of P transfer are higher on reseeded grassland;

- Drained soils appear to be less susceptible that undrained soils to changes following reseeding.

**Phosphorus mobility in arable soils (IACR)**

*Objectives:*

- To investigate the suitability of the 'change point' as a routine tool for predicting the potential risk of P leaching from the plough-layer in arable soils.

*Conclusion:*

- The 'change-point' could provide a useful indicator of the approximate soil Olsen P concentration at which environmentally significant quantities of P are measured in drainage water.

*Future work:*

- Investigate the relationship between soil P change-points and common soil properties;

- Investigate relationships between soil P concentrations and P in drainage water in the field.

**Brimstone Phase IV: reducing phosphorus losses from arable soils (IACR)**

*Objective:*

- To quantify the phosphorus losses from the arable soils of Brimstone Farm plots;

- To quantify the influence of different treatments applied to the plots on P loads (fertiliser application late, drainage restrictions, mole drain spacing).

**A7.1.2.2 Catchment scale measurement**

**Phosphorus losses from agriculture/Additional measurements of P loss from Trent and Rosemaund (ADAS).**

*Objectives:*

- To quantify the diffuse losses of P in small catchments;

- To develop a GIS based predictive model to determine the impact of land use changes on P loss at the small catchment scale;

- To monitor P loss from three additional tile drains.

*Conclusions:*

- At the small catchment scale, P export varied with rainfall;
- Tile drains can be an important route by which P, including particulate forms, is lost from agricultural land;
- Losses of P from upland grassland was less than from lowland arable/mixed farming.

*Future work*:

- Understanding the problem of different magnitudes of P loss measured at different scales.

**Measurements of phosphorus loss at the farm and catchment scales (ADAS)**

*Objectives:*

- To continue to intensively monitor the transport of particulate phosphorus, dissolved phosphorus and suspended sediments in stream flow and land run-off from the Trent and Rosemaund catchments;
- To quantify the contribution of phosphorus loss from individual farms within the Cliftonthorpe sub-catchment to the pattern of loss measured at the catchment outlet;
- To develop methodologies for prediction of phosphorus loss at the field/farm and small catchment scale.

*Conclusions (preliminary):*

- Monitored tile drains were major pathways for P loss bypassing the stream margin and delivering particulate P into the watercourse;
- Heavy applications of farm yard manure led to large losses of P when rainfall occurred soon after application (i.e. one badly timed farm scale activity generated more loss in a few days that that occurring during the rest of the year).

*Future work:*

To be addressed within the project after further monitoring:

- Develop methodologies for identifying critical source areas within the catchments;
- Calculation of P balance sheets for P inputs to each farm within the Cliftonthorpe catchment;
- Develop process-based model of phosphorus loss from small catchments.

**Measurements of phosphorus stored in stream biomass and sediment at Rosemaund and Trent (ADAS)**

*Objectives:*

- Determine the amount of P held in the biomass at key locations within the study catchments at ADAS Rosemaund and Trent;
- Determine whether the changes in P status of the sediment have an impact on flux out of the catchments;
- Evaluate whether bed sediment is a sink or a source of P in the study catchments.

*Conclusions:*

- Within the study catchments, the impact of changes in macrophytes and macroinvertebrate populations on P fluxes are small;
- Temporal variations in microinvertebrate populations may be sufficient to produce large variations in measured particulate P concentrations;
- P stored on the stream-bed that can be remobilised is relatively small compared to overall P loss.

**Identification of high risk soils for sediment-associated phosphorus loss in subsurface flow and an assessment of its contribution to catchment sediment budgets (ADAS, Coventry University and Exeter University)**

*Objectives:*

- To identify for the Trent and Rosemaund catchments, the origin within the soil profile of particulate P lost in tile drain flow;
- To quantify, within the Trent and Rosemaund catchments, the contribution of particulate material transported in subsurface flow to catchment sediment budgets;
- To develop sediment budgets for the study catchments and develop suitable mixing models to describe sediment loss from agricultural catchments.

*Conclusions (preliminary):*

- Tile drains provide a rapid route by which sediment reaches the stream at Cliftonthorpe;
- Sediment transported in the tile drain flow at Rosemaund is derived from the top 30 cm of the soil profile.

**Phosphorus inputs to large river systems: quantifying the diffuse export coefficients for the River Swale catchment (ADAS, IFE).**

***Objectives:***

- To quantify the diffuse export of phosphorus from different land uses within the River Swale catchment;
- To develop the phosphorus export coefficient methodology based on the River Swale.

*Conclusions (preliminary):*

- The contribution of the Upper Swale to MRP and particulate P fluxes in the Lower Swale appears to be small due to the dominance of sewage effluent inputs in the Lower Swale;
- Inputs of sediment from agriculture in the Lower Swale provide a source of particulate P although adsorption of sewage derived MRP onto suspended particulates during transport may enhance the amount found;
- Losses of MRP to bed sediment occur in the Lower Swale during low flow conditions whilst gains occur during medium flow conditions making the net effect of the bed sediment small;
- Losses of particulate P occur during out-of-bank flow, this is assumed to be due to deposition on the floodplain.

**Field and farm scale investigation of the mobilisation and retention of sediment and phosphate (ADAS)**

*Objectives:*

- To investigate the processes of sediment and P mobilisation/retention at the field and farm catchment scales to identify best farm management practices for the mitigation of losses to river systems;
- To develop an Erosion Risk Management Strategy for the farm based on analysis of a Digital Terrain Map (DTM) for the area to identify sites of net erosion and deposition of material within and between fields.

#### A7.1.2.3 Coefficients of P loss

**Phosphorus loss from agriculture (SSLRC)**

*Objectives:*

- An examination of critical soil processes affecting P transfer and phosphorus supplying capacity of soils;
- Development of P export coefficient datasets;
- Spatial modelling, mapping and extrapolation of datasets using GIS techniques.

Conclusions:

- Agricultural use of the land plays an important role in soil P status and P mobilisation, and can also modify pathways of P movement from the land;
- Hydrological processes dominate movement of P across and from the land both in particulate and dissolved states;
- Excess rainfall is the primary trigger after which water follows a number of pathways depending on soil hydrology although the contribution of spring and summer rainfall to P transfer is not well understood at this time;
- Systematic modelling of P transfers and their interactions with soil, climate, slope and land use offer a means, at different scales, for targeting abatement actions and by identifying the pathways showing which techniques are most promising.
- Primary export coefficient values, pertinent to individual soils and hydrological pathways, were determined which, when extrapolated across east and west, produced a mean value of 1.18kg TP $ha^{-1}$ $yr^{-1}$ (range: 0.02-8.66 kg TP $ha^{-1}$ $yr^{-1}$).

*Future work:*

- The model invites application at the catchment and farm scale using DEM, detailed soil maps and appropriate land use information.

**A systematic approach to national budgets of phosphorus loss through soil erosion and surface runoff at national soil inventory (NSI) nodes (SSLRC)**

*Objectives:*

- To produce a systematic assessment of the scale of P transfer from agricultural land in England and Wales, as contributed to by water erosion and surface runoff;
- Refinement of the Hydrology of Soil Types (HOST) classification, contributing to P transfer modelling;
- An evaluation of the scale, nature and circumstances of soil erosion by water, based on a statistically valid and appropriate monitoring strategy;
- A collection of data on P loss to surface waters from eroding land at selected sites in order to validate P budgeting and modelling;
- An assessment of the impact of cultivation practices and environmental circumstances from the standpoint of remedial action towards soil and water conservation.

*Conclusions:*

- On arable land, a systematic survey shows soil erosion occurring not only on light soils and steep slopes but on land classified in the ‘negligible’ erosion risk category (important because this category covers 50% of the land area of England and Wales and the role soil erosion plays in P transfer);

- 39% of sites in the uplands have some soil erosion with soil erosion progressing at about 3.5% a year on actively eroding sites. Total P transfers in the uplands are of comparable order to those established from the more serious examples of arable erosion;
- Losses by channelled erosion from established grassland are, by comparison, trivial;
- The survey is likely to have underestimated transfers in overland flow away from erosional channels in all the landscapes surveyed.

*Future work:*

- Investigation of the efficacy of soil erosion abatement measures and implications for P loss;
- Assessment of the frequency and scale of unchannelled overland flow;
- Further analysis of existing data to address environmental and agricultural circumstances of soil erosion and runoff.

**Quantification of national P loss from agriculture to water (University of Reading)**

*Objectives:*

- To quantify the P loss from agriculture to water from England and Wales using modelling.

*Conclusions:*

- Output from the project has provided an updated prediction of present P loss from diffuse agricultural sources to water bodies in England and Wales
- The relative contribution of agriculture to P enrichment of water bodies in England and Wales over the pat 60 years of agricultural intensification and expansion has also been quantified.
- Valuable information has been provided from which indicators of sustainability with respect to P loss from agriculture may be derived.

*Future work:*

- Development of the two approaches used in this project into a single modelling package would provide a tool which might be used to isolate the critical source areas and the critical transport pathways controlling the efficiency of P loss from agriculture to water;
- Such a tool might be used to indicate the extent to which control of P loss from agriculture might be achieved with minimal impacts upon agricultural productivity through landscape scale planning, relocating high risk land uses away from critical source areas and transport pathways.

**A national estimate of P loss from agricultural land based on land use export coefficients/Quantification of national P loss from agriculture to water (ADAS, SSLRC)**

*Objectives:*

- To develop a framework for quantifying the loss of phosphorus from agricultural land at the national scale

- To provide a national estimate of P loss from England and Wales based on phosphorus loss export coefficients

*Conclusions:*

- The proportions of the total P loss occurring from permanent grassland, tillage/ley and the uplands were 35%, 53% and 10% respectively;

- The significant contribution to national P loss estimates of underdrainage (33%) and fresh P inputs (23%) was highlighted;

- There is a fundamental difficulty in separating out the influence of fresh P inputs compared to those of soil P from previous P applications and in separating out values appropriate to different scales.

*Future work:*

- Addressing the selection of appropriate phosphorus loss export coefficients

- Better calibration with water quality data at sub-national level.

**Strategies to control phosphorus loss from agricultural land: a review (ADAS, IGER)**

*Objectives:*

- To identify control strategies for phosphorus loss from agricultural land to water

- To appraise the cost-effectiveness of mitigation options for phosphorus loss

*Conclusions:*

- Strategies to minimise agricultural P loss at the field and farm scale need to include both source (nutrient management) and transport (land management) control;

- Specific mitigation options (nutrient budgeting, input management, soil conservation, land use management and the establishment of riparian buffer zones) for P vary in their effectiveness depending on accurate identification of contributing areas and the level of P reduction achievable in relation to site hydrological conditions;

- The variable nature of diffuse P loss indicates that the best approach to control is through integrated management at a range of scales;

- There is a potential conflict between controlling the rate of eutrophication and requirements to meet production targets and/or to minimise the loss of other nutrients (e.g. N);

- Requirements of nutrient control for individual waterbodies differ and consequently the mix of solutions need to be site specific and their successful adoption requires an appreciation by farmers of the importance of minimising agricultural P loss both as individuals and collectively within a catchment;

- Critical control concepts at the farm level include targeting those areas which contribute the most loss, maintaining P loading rates within recommended limits to minimise surface run-off losses and matching P inputs to meet minimum requirements for sustainable production.

*Future work:*

- Evaluate the effectiveness of land and soil management practices to reduce manure and soil phosphorus losses under different site conditions in England and Wales both at the field scale and when combined with other land management practices as part of an integrated catchment approach;

- The impact of P loss control measures on nitrogen losses needs to be better identified and quantified.

**Brimstone farm: systems to minimise the loss of nutrients, especially phosphorus, to drainage water from a structured clay soil (ADAS)**

*Objectives:*

- To provide hydrological support to IACR Rothamsted for developing sustainable agricultural practices and reduce the risk of nutrient pollution of surface waters;

- To establish the influence of reduced drainage on soil-water status and the impact on cropping.

*Conclusions:*

- Manual manipulation of drainage by restriction-type systems and cultivations under wet field conditions markedly affected water movement and led to a potential change in nutrient losses compared to the situation with good sub-surface drainage;

- Farmers and landowners place emphasis on maintaining sub-surface drainage as part of sustainable farm management and that sub-soiling has become important in recent years as an on-farm management technique in heavy clay soils;

- Changed drainage status as a result of a lower standard of mole drainage (farmer maintained) in conjunction with frequent subssoiling is likely to have influenced the pattern of water movement in these soils and the potential for nutrient losses.

### A7.1.3 Diffuse Pollution: sources of N and P (Parr *et al.*, 1999a)

This review has recently been completed for DETR. The report follows the DPSIR (Driving forces, Pressures, State of the Environment, Impact, and Responses) structure favoured by organisations such as the European Environment Agency. The emphasis of the review is to identify the relative importance of all diffuse sources of nutrients, make an assessment of their contribution to national nutrient budgets and discuss the options for controlling/reducing nutrient export from these sources.

#### A7.1.3.1 Diffuse pollution: Conclusions

- Diffuse sources make up about half of the total phosphorus load and 70% of the total nitrogen load to surface waters in the UK.
- Agriculture is by far the largest diffuse source of both N and P to surface waters.
- Recommended phosphorus fertiliser application rates are designed to maintain the soil P content at a critical level required to achieve maximum crop yield. Recommended N fertiliser application rates are designed to meet the requirements of the crop being grown, while taking account of soil reserves from previous crops.
- The current P index scheme used to classify the phosphorus status of UK soils is coarse. These indices indicate the relative amount of nutrients in the soil that are available to the crop, and range from 0 (deficient) to 9 (very large). However, P indices 2 and 3 cover the critical range of soil phosphorus concentrations for most (if not all) agricultural crops. A case is made to divide P index 3 (26-45 mg Olsen P $l^{-1}$) into two indices containing a narrow ranges of P concentrations, *viz* P index 3a (26-35 mg Olsen P $l^{-1}$) and P index 3b (36-45 mg Olsen P $l^{-1}$).
- In terms of surface runoff (the major pathway of phosphorus loss from soil to water), the P content of soils is an appropriate measure of export risk, particularly when used in conjunction with an assessment of erosion risk (e.g. the universal soil loss equation). However, for export via leaching, percentage saturation of the P adsorption sites within the soil is a much better indicator. Sandy soils, in particular, are at increased risk of phosphorus loss via leaching.
- Animal manure and slurry has a lower N:P ratio than that required by the majority of crops.
- Over-fertilisation with organic fertilisers is a problem in areas of the country where intensive livestock farming is practised. The major factor preventing the application of this manure to land further away from these areas is the high transport cost of slurry relative to that of inorganic fertilisers and the variable nutrient content of manures. Slurry and manure are a very valuable source of nutrients for grassland and arable crops, but a source which requires better management (probably involving a regional approach), better marketing and better awareness of its nutrient content.
- MAFF guidance to farmers in terms of fertiliser application rates is often weak in terms of its environmental consequences. However, nutrient balance studies show the UK to be substantially better than the majority of other European countries.

- The wider adoption of farm-based nutrient management plans is to be supported. Indeed, MAFF agree with such a policy, but did not specifically recommended their wider use in their 1988 consultation document on sustainable agriculture. As yet, only farm waste management plans are recommended by MAFF in the Code of Good Agricultural Practice for water.

- Atmospheric deposition (itself derived principally from agricultural and industrial sources) is probably the next largest diffuse source of nitrogen, but while the atmospheric N load to land can be modelled, the proportion of this which is exported to surface waters is not clear.

- Atmospheric deposition of P onto land is a minor source of phosphorus when considered nationally, but direct deposition to water may be an important source for some nutrient-poor lakes.

- Natural/background loading (some of which is derived from atmospheric deposition) is the second largest diffuse source of phosphorus. A range of values for natural phosphorus loads have been reported in the literature, ranging from 0.07 to 0.65 kg $Pha^{-1}yr^{-1}$, but in many upland catchments with igneous geology, true background phosphorus loads may be even less than the lowest value in this range. Less work has been undertaken to estimate natural nitrogen loading rates, probably because the use of quasi-pristine rivers to estimate this load is fundamentally flawed.

- In the UK, during the past 10-15 years, the phosphorus load to sewers and septic tanks is likely to have decreased by some 20% as a result of changes in detergent formulations. While estimates are available for the N and P loads from septic tanks that reach water, it is not clear how reliable such estimates are. Educated guesses are currently the only option for assessing nutrient loads to water from sewer leakage, albeit that this may be a relatively minor source of nutrients.

- Within the national context, leaking water mains are likely to be an even smaller source of phosphorus to surface and groundwater than leaking sewers. This does not represent a diffuse source of nitrogen.

- Surprisingly little information has been published on urban runoff as a diffuse source of nutrients, particularly with regard to the UK. However, as the area of drained urban land is small in comparison with the area of agricultural land, this is unlikely to be a large source of nutrients within the national context.

- Groundwater is undoubtedly a major pathway for diffuse source nitrogen loading to surface waters, but is much less important for phosphorus. However, leaching of phosphorus to groundwaters and to surface waters are major problems in some European countries. Phosphorus levels in some UK groundwater are surprisingly high, but available results suggest that this is a localised problem.

- Aquifer geology (soil, gravel, chalk) and hydrology is likely to make an enormous difference to the amount of phosphorus which is exported from groundwater sources.

- The marine load of phosphorus to some UK estuaries (primarily associated with suspended solids) may be of a similar order of magnitude to the land-derived phosphorus load. The marine-derived nitrogen load is likely to be much lower than the land-derived load in all estuaries.

- Sediments should not really be considered as a diffuse nutrient source, since they function as a delaying mechanism for the release of nutrients at a later date. However, sediments can be regarded as an important nutrient source on a seasonal basis.

- Sufficient information is available in the grey literature to make an assessment of the nutrient status of rivers and tidal waters, but much less information is available for lakes. However, much of the more detailed and useful data (particularly for rivers) is now 7 years old. The traditional view that UK freshwaters are P-limited and coastal waters are N-limited should be addressed. The situation is often more complex than such simple statements suggest.

- In targeting catchments for nutrient control/reduction strategies, both point and diffuse sources of nutrients should be considered. In addition to water quality and nutrient loads, ecological considerations should also be included in the prioritisation process. However, issues such as cost-effectiveness and uptake/implementation need to be addressed.

- Techniques for controlling nutrient export from diffuse sources are well understood, and have been for some years.

- From a legislative point of view, the Nitrates Directive is probably the most effective piece of legislation for reducing export of both N and P from agriculture to surface waters. However, the IPPC Directive may play an important role in some catchments by requiring treatment of animal waste from large rearing units.

- Economic instruments, such as taxes on commercial fertilisers, generally have weak incentive effects and achieve objectives indirectly. Taxation of on-farm nutrient surpluses appears to have considerable advantages that warrant more detailed examination.

- Direct payments/subsidies are widespread, as are cost sharing schemes. They are, however, inconsistent with the polluter pays principle and often conflict with other interventions such as product price support. Cross-compliance (the linking of environmental and non-environmental regulations) is pursued in a number of countries. Much less experience has been gained with tradable rights - despite their theoretical advantages.

#### A7.1.3.2 Diffuse pollution: Recommendations

- A field-based monitoring investigation is required to determine the ratio of urban runoff nutrient loads (to sewer) to domestic nutrient loads (to sewer) in selected urban catchments.

- An assessment of the contribution of sewer leakage to catchment-based nutrient budgets should be undertaken in two or three contrasting trial catchments. A part-modelling/part monitoring approach is recommended for such studies.

- A thorough review of agricultural nutrient balances for different crop and soil types using recommended fertiliser application rates and likely crop yields (including grass) should be undertaken. This information will be held primarily by Government-funded agricultural research organisations.

- The likely effects of dividing soil P index 3 into two sub-indices should be investigated in a desk study. This should include an assessment of the likely long-term water quality (surface and groundwater) effects of changing fertiliser application rates based on knowledge of critical P levels and corresponding crop N requirements. Use of current N and P export models will be required for this.

- A study should be undertaken to assess the feasibility of using on-farm nutrient surplus studies as an input to regional slurry management centres. Options for funding the operation of such centres (including transportation costs) to assure a more even distribution of organic manures to agricultural land throughout the country should be investigated. One of the options for funding should be taxation of on-farm nutrient surpluses. This study should be complementary to the proposed MAFF-funded study (CTE 9901) to develop a framework to evaluate farm practices to meet multiple environmental objectives in pollution control. Close co-operation between the contractors undertaking these two studies would be required.

- Three pilot UK studies should be funded to test the feasibility of catchment-based nutrient trading within the UK legal framework. Work undertaken overseas, primarily in the USA (which includes several demonstration studies), should be used as the basis of these studies. One of these studies should be a point source↔point source trade, another should be a point source↔diffuse source trade and the third a diffuse source↔diffuse source trade.

- A national nutrient export model should be developed, building on national expertise. This should be GIS-based and have a modular format, such that as advances are made in nutrient modelling techniques in the future, they can be retrofitted by replacing a single module. A scoping study is required as the first step in this process to determine which organisations would use such a model and what the model would be used for.

- A qualitative risk assessment of phosphorus loads to aquifers from both point and diffuse sources is required. This project should investigate whether the current situation is likely to worsen.

- A desk-based study is required to identify which estuaries are most susceptible to large nutrient loads from the marine environment and to determine which of the most susceptible estuaries have high land-derived areal nutrient loading rates. (The latter information is available from an on-going DETR-funded project.) A monitoring study on one of the most ‘at risk’ estuaries to measure/model nutrient inputs from all sources should be undertaken to gain a ‘worst case’ reliable quantitative assessment of marine nutrient loads to UK estuaries.

- Further work on determining nutrient limitation to aquatic macrophytes should be undertaken, notably in terms of measuring C:N:P ratios in plant tissue, together with bioavailable N:P ratios in sediment and overlying water. Sampling should be taken on a monthly basis for a full year at a range of locations covering the range of nutrient concentrations found in the UK. The study should include freshwater and saltwater sites.

- A review of recent Environment Agency nutrient data should be undertaken. This should include an assessment of phosphorus concentrations in groundwater, further investigations into likely N or P limitation in tidal waters, a re-assessment of the nutrient status of English and Welsh rivers, and an assessment of the degree of change.

- Environment Agency GQA water quality data should also be used for trend analysis of water quality over the past 10 years. Ideally such a study would link with MAFF agricultural census data, soil phosphorus concentration data and catchment geology data (to include a HOST-type classification). This would allow a classification of those agricultural activities that predominate in areas where water quality has changed most dramatically in recent years. Information on changes in point source discharges over the same period would also be required for such an assessment.

#### A7.1.4 Identification and Quantification of Groundwater nitrate pollution from non-agricultural sources (Chilton *et al*, 1996)

Nitrate has been identified as an important diffuse pollutant in all the major aquifers in England and Wales. The specific objectives of this study were to firstly to produce a literature review of the present state of knowledge with respect to non-agricultural sources of nitrate in groundwater, and secondly to design and evaluate methods for quantifying non-agricultural sources of nitrate. Based on this review, leaking sewers and other urban sources appeared likely to be the most important. Other sources of importance included land application of sewage sludge, influent rivers containing sewage treatment effluent, highway drainage, landfills and septic tans. Recreational fertiliser use (e.g. golf courses, public and private gardens), atmospheric deposition, airfield de-icing, and agricultural point sources such as silage clamps and slurry storage appeared to be less important.

A recommended approach to nitrogen source evaluation was given.

#### A7.1.5 Estimation of nutrient loading to the Fleet lagoon from diffuse sources (Mainstone and Parr, 1999)

The Fleet Lagoon on the Dorset coast constitutes some 60% of the total area of saline lagoon in Britain, a priority habitat under the EU Directive on the conservation of natural habitats and wild fauna and flora (the ‘Habitats’ Directive). The site is of very high conservation priority, being a candidate SAC under the Habitats Directive, a SSSI, a SPA under the EU Birds Directive, and a ‘Ramsar’ site. Concerns over the possible effects of nutrient enrichment on the special interest of the site have led to a number of projects being undertaken. As part of this larger work programme, the Environment Agency commissioned WRc to undertake a brief investigation into the contribution of diffuse sources to the nutrient loads entering the Fleet.

Annual nutrient budgets have been constructed for both nitrogen and phosphorus, based on Agricultural Census information on crop areas and livestock numbers in conjunction with point source load estimates. Although there are concerns over the reliability of a number of aspects of the available data, agricultural sources are undoubtedly very important in relation to both nutrients. They have been estimated to contribute around 80% of the annual load of total nitrogen and over half the annual load (perhaps over 70%) of total phosphorus (estimates excluding background loads from rainfall and natural soil weathering).

On the basis of this assessment, it is clear that agricultural activities need to be addressed in any nutrient control strategy. Initially, the identification of practical control measures across the catchment can be achieved by using catchment walk-overs to identify critical practices and run-off pathways. More detailed modelling has been recommended to gain a better understanding of the spatial and seasonal distribution of loads and the effects on water quality within the Fleet. Further modelling will eventually help to focus attention on high risk areas and will help to predict the likely effect of control measures on nutrient status and eutrophication risk.

Estimated loads from Abbotsbury Swannery and populations of other key birds species on the Fleet are small in relation to nutrient sources contributing to the lagoon as a whole. However, considering the lack of flushing within the Fleet, particularly at the western end where the swannery is located, there is potential for local enrichment effects on both the water column and sediments.

Improved information is required on the loads entering the Fleet via point sources, feeder streams, direct run-off and groundwater seepage, and the extent of internal loading from lagoon sediments. Monitoring has been recommended to address this information shortfall.

#### A7.1.5.1 Fleet lagoon: Conclusions

1. Despite uncertainties in the nutrient budget (see below), agricultural sources are undoubtedly important in delivering nutrients to the Fleet, contributing an estimated 80% of the annual load of total nitrogen and over half (possibly over 70%) of the annual load of total phosphorus.

2. Although no within-catchment discrimination of loads has been possible, it is likely that phosphorus loads (including those from domestic sources) to the West Fleet are greater than those to the East Fleet, whilst nitrogen loads to the East Fleet are likely to be greater than those to the West Fleet.

3. The export coefficients that have been used to convert data on livestock numbers and crop types to nutrient loads to the Fleet lie near the national average, with most of the land in the catchment being of moderate gradient and possessing slowly permeable soils.

4. Available information on flows and nutrient concentrations in the feeder streams was poor, generating unreliable estimates of instream loads that hampered the production of a sound nutrient budget. This was largely due to the fragmentation of the riverine load to the Fleet into a number of minor watercourses that would not normally receive much monitoring attention.

5. It was not considered sensible to calibrate export coefficients against instream estimates of loads, due to the low confidence associated with instream loads. Agreement between modelled loads and instream loads was good for nitrogen, but modelled phosphorus loads were somewhat lower than instream estimates. It may therefore be that the coefficients used for phosphorus are too low and that they should be modified upwards, generating a higher estimated agricultural contribution.

6. Available information on the loads from the two major sewage treatment works gave widely differing estimates, emphasising the importance of adequate monitoring of effluent flow and nutrient concentrations.

7. No data were provided by MAFF on the numbers of pigs and poultry in the catchment, the former due to reasons of data confidentiality, the latter due to concerns over data reliability. No assessment is therefore possible of the importance of these two livestock types to nutrient loads to the Fleet.

8. Uncertainty over the size of the atmospheric nitrogen load is of concern, with the two methods used to estimate it giving answers an order of magnitude apart. Depending on the method used, the load could be as large as that from livestock, or as small as that from point sources.

9. The limitations of annual budgets of total nitrogen and phosphorus in reflecting the ecological importance of contributions from different sources have to be recognised. Consideration of the spatial distribution of loads, nutrient bioavailability, season of load delivery and nutrient cycling within receiving waters are all necessary to properly understand the influence of different sources.

**A7.1.5.2 Fleet lagoon: Recommendations**

1. Monitoring of nutrient loads from Abbotsbury and Langton Herring sewage treatment works should be undertaken more intensively to provide reliable estimates for future assessments. This should involve monthly recording of effluent flow and simultaneous sampling for Total Phosphorus and Total Nitrogen over a period of at least a year.

2. Monitoring of nutrient loads in all feeder streams should be undertaken to improve the reliability of instream load estimates. This should involve monthly recording of effluent flow and simultaneous sampling for TRP, Total Phosphorus, TIN and Total Nitrogen over a period of at least a year, preferably 3 years.

3. Groundwater movements and water quality should be assessed with a view to determining the importance of groundwater other than in feeder stream baseflow in influencing the nutrient status of the Fleet.

4. The size of the non-sewered population should be assessed and the likely load evaluated, including consideration of the proportion of septic tanks delivering nutrient loads directly to the Fleet rather than via feeder streams.

5. A survey should be undertaken of the sedimentary nutrient reservoir within the Fleet, including detailed work on phosphorus concentrations and redox potential in the vicinity of the Abbotsbury Swannery (where significant accumulation of organic material may occur).

6. If budgets allow, agricultural and other loads should be modelled with improved spatial discrimination, using remotely sensed data supported by limited field surveys of agricultural activities (particularly livestock husbandry). Results should be used to identify high risk land areas and to feed a eutrophication model of the Fleet, simulating both local and general effects on nutrient status and eutrophication risk through the year.

7. Further modelling should recognise the inherent uncertainties in simulating diffuse nutrient loads, and the need for catchment walk-overs focused on high risk areas to highlight critical management activities and run-off pathways that need to be targeted in subsequent control strategies.

8. The recommendation for further modelling should not obstruct practical action to reduce diffuse loads through consideration of agricultural management regimes and run-off pathways in the field. Estimated diffuse loads and observed nutrient concentrations in feeder streams and groundwater are of sufficient concern to warrant such action without more detailed modelling work. Further modelling would eventually serve to help direct practical action and to provide some indication of its likely benefit.

### A7.1.6 Nutrient budget for the upper reaches of the Hampshire Avon (Parr *et al.*, 1998)

Whilst measures to reduce phosphorus inputs from point sources are likely to be agreed in the lower reaches of the Hampshire Avon catchment, elevated nutrient levels in the upper reaches are also of ecological concern. This report details the construction of a nutrient budget for the rivers upstream of Salisbury STW, including consideration of both diffuse and point sources. A summary of the budget is given below:

| Source | Nitrogen (tonnes $yr^{-1}$) | Percentage of total N load | Phosphorus (tonnes $yr^{-1}$) | Percentage of total P load |
|---|---|---|---|---|
| Livestock | 328.2 | 16.5% | 18.7 | 21.0% |
| Inorganic fertiliser | 1344.1 | 67.5% | 19.8 | 22.2% |
| Atmospheric N deposition | 199.9 | 10.0% | - | - |
| Background P export | - | - | 12.5 | 14.0% |
| Cress farms | - | - | 0.1 | 0.2% |
| Fish farms | 12.3 | 0.6% | 2.5 | 2.8% |
| STWs | 107.8 | 5.4% | 35.5 | 39.9% |
| **Total load** | **1992.3** | **100.0%** | **89.1** | **100.0%** |

Environment Agency water quality/flow data were used to validate the above nutrient budget estimates. Analysis of these data show that the calculated annual loads can vary by a factor of up to three (in the case of phosphorus) and four (in the case of nitrogen), albeit that such wide variability was demonstrated only in one tributary - the River Bourne. Year-to-year differences in loads are largely accounted for by differences in annual flow, and years with lowest loads are potentially the most ecologically damaging since they are low flow years and provide little dilution of continuous point sources through the growing season.

The annual budget indicates that the largest phosphorus contribution is derived from diffuse sources, even though a relatively small proportion of the nutrient load applied to land appears to be exported to the river network. However, analysis of flow and water quality data indicates that SRP concentrations peak through the growing season and appear to be essentially dictated by point source loads and the extent of available baseflow for dilution. Much of the diffuse load is transported by the river outside of the growing season under high flows, although a proportion will be retained in sediment and will be available to growing plants through root uptake or via internal loading into the water column. Some groundwater SRP levels in the catchment are alarmingly high (>0.2 mg SRP $l^{-1}$), although they may be indicative of localised problems only.

If progress is to be made in reducing riverine phosphorus levels towards background levels (and thereby reducing the risks of detrimental effects upon the macrophyte community and fauna dependent upon it), an integrated approach to phosphorus control is required that involves action in controlling both point and diffuse sources. Whilst a better understanding of internal sources and sinks of phosphorus is essential to properly understand the system, it is unlikely that water column concentrations of SRP will be reduced to target levels without better control of point sources. Further analysis of water quality and flow data are recommended, as well as more comprehensive point source modelling to include the major tributaries. Observed groundwater contamination should be examined in more detail to assess its current and likely future importance in delivering nutrient-rich baseflow.

#### A7.1.6.1 Hampshire Avon nutrient budget: Conclusions

1. It has been estimated that around 43% of the phosphorus load to the river network of the upper Avon catchment is derived from point sources, with 57% originating from diffuse sources. Sewage treatment works are responsible for the vast majority of the point source phosphorus load.

2. Only 6% of the nitrogen load to river is derived from point sources and 94% from diffuse sources.

3. SRP:TIN ratios vary seasonally, with typical values of 40-60. Nitrogen is never limiting to algal growth.

4. Only about 1.5% of the phosphorus and 8% of the nitrogen applied to land as inorganic fertiliser or animal manure is exported to river owing to the permeability of the soils and geology of the catchment.

5. Whilst the largest contributor of phosphorus is diffuse sources, limited water quality analysis suggests that continuous point sources are the major influence on water column concentrations through the growing season. This finding contrasts with that of parallel work undertaken by the Environment Agency, which suggests that point sources have only a limited spatial impact.

6. The threat of long-term contamination of groundwater sources with phosphorus, from intensive agricultural practices and effluent recharge, is of great concern. Elevated concentrations in groundwater that are likely to be anthropogenic in origin may already make significant contributions to growing season concentrations in some parts of the river system, but the extent and source of this contamination is not clear.

7. Targeting point sources of phosphorus is likely to have the greatest effect on water column SRP concentrations during critical times of the year, but an integrated control strategy tackling both point and diffuse sources is required to restore an appropriate

nutrient status for the river system as a whole, including both sediments and water column.

8. The application of suitable minimum acceptable flows would help to control water column phosphorus concentrations in the growing season, since ambient concentrations are essentially a product of the influent load and the river flow available for dilution. However, this would in no way obviate the need for integrated control of point and non-point source phosphorus loads to the river system.

#### A7.1.6.2 Hampshire Avon nutrient budget: recommendations

1. It is recommended that further point source modelling of the upper Avon is undertaken, as well as further analysis of the relationship between SRP and flow at a range of sites, so that the discrepancy between the findings of this assessment and the Agency's modelling study can be investigated further. Part of the problem may be that the Agency's modelling work focused on the main Avon river, whilst the current study only assessed water quality and flow data from the major tributaries (Nadder, Wylye and Bourne). The gathering and incorporation of data on phosphorus loads in MoD discharges should be an integral part of future modelling exercises.

2. Investigations are recommended into the role of riverine sediments and plant biomass in the uptake and release of phosphorus to and from the water column. This is currently a grey area that may well contribute to the contrasting findings of the two studies. IFE have recently developed a technique for assessing phosphorus fluxes into and out of riverine sediments (involving the determination of the Equilibrium Phosphorus Concentration of the sediment), which is likely to prove very useful in such an assessment.

3. It is recommended that a more comprehensive collation of groundwater phosphorus data is undertaken than was possible in the current study (including information on depth of sampling and aquifer properties), in conjunction with an assessment of soil phosphorus concentrations and aquifer characteristics. The work should also identify the locations of effluent recharge and long-term sludge disposal. This appraisal would provide an initial indication of natural geological sources, the extent of current contamination and the likelihood of future problems, assessing the need for more detailed modelling work.

4. Areas of particularly high diffuse pollution risk can be identified at a finer level of spatial resolution than has been possible in this brief assessment, which could act as a focus of future management attention. Models such as WRc's MINDER for Rivers can be applied to remotely sensed land use data of 30 metre resolution, estimating SRP concentrations in the river through the use of more complex export coefficients and river flows generated across the catchment by a catchment-response framework. It can also incorporate point sources of phosphorus and thereby provide a truly integrated assessment of pollution sources.

### A7.1.7 Nutrient status of the Glaslyn/Dwyryd, Mawddach and Dyfi estuaries - its context and ecological importance (Parr *et al.*, 1999b)

This report places the nutrient status of the Glaslyn/Dwyryd, Mawddach and Dyfi estuaries in context with other UK estuaries and discusses their ecological sensitivity to a change in nutrient status. Water quality, nutrient loads and biological data are reviewed, and nutrient budgets derived for the three estuaries.

The three estuaries discussed in this report are included in the Pen Llyn a'r Sarnau candidate SAC because of their important conservation status. It is unclear how the ecological status of the estuaries is related to their nutrient status and how sensitive individual species and communities are likely to be to a change in nutrient status. The latter is required so that those species/communities that are most at risk of impact/change can be monitored for use as an early warning system of changing trophic status.

To develop a nutrient control strategy it is first necessary to undertake a source apportionment study to determine the relative importance of different sources and to determine the likely effect on water quality of controlling one or more sources.

#### A7.1.7.1 Nutrient status of Welsh estuaries: Conclusions

**Classification**

1. Harmonised Monitoring Site data, suggest that the three estuaries are of moderate nutrient status when data are expressed in terms of nutrient load per area of catchment. However, nutrient concentrations in the main rivers feeding the Glaslyn/Dwyryd, Mawddach and Dyfi estuaries are extremely low when compared to other lowland Welsh and English rivers, and TRP concentrations in adjacent coastal waters are also extremely low. Furthermore, these three estuaries have very large surface area:catchment area ratios, so when nutrient loading data are expressed in terms of the annual load per area of estuary (a more robust indicator of nutrient status than those described previously), the estuaries are shown to be amongst the most pristine in Britain.

2. Under the Classification of Estuaries Working Party (CEWP) estuary classification scheme the estuaries are predominantly class A, with a small section near Porthmadog in the Glaslyn/Dwyryd Estuary of class B. Data are not available to classify the estuaries according to the proposed nutrients in estuaries GQA classification scheme, but the Dyfi was highlighted as a likely class A estuary by the authors of the classification scheme report. The Dyfi Estuary (and to a lesser extent the Mawddach) is of such a low nutrient status predominantly because of the large tidal prism and rapid flushing times.

3. Contrary to popular belief, three large areas of English and Welsh coastal waters appear to be phosphorus-, rather than nitrogen-limited. These regions extend from north of the Humber to the Essex estuaries, from the Solent to Dartmouth and around the Severn Firth from Padstow to Oxwich. Northeast Cardigan Bay also appears to be P-limited around the mouth of the Glaslyn/Dwyryd Estuary.

**Ecological impacts of changing nutrient status**

1. It is very difficult to separate the ecological impacts of organic enrichment from the effects of nutrient enrichment.

2. The estuarine infauna does not appear to be particularly sensitive to a change in nutrient status, since most species are found in more nutrient-enriched estuaries. Community status appears to be determined primarily by physical rather than chemical factors. However, the

primary productivity of the sediment flora is dependent on the nutrient status, and thus the secondary productivity of the benthos will almost certainly be linked.

3. The estuaries contain a number of rare or endangered species (whose ecology we know very little about, e.g. Welsh mudwort), which may be sensitive to localised or relatively minor whole-estuary changes in nutrient status. Any increase in nutrient loading to the estuaries should therefore be strongly opposed.

4. Changes in the positioning of nutrient entry to the estuaries (e.g. building of new outfalls to replace old ones) must be considered on a case-by-case basis - ecological change or damage will not necessarily occur. Particular attention should be paid to the role of organic nitrogen (and total phosphorus).

5. The establishment of *Spartina* beds is likely to increase the trophic status of sediments, even if nutrient loads to the estuaries do not change.

**Nutrient budgets**

1. Current agricultural land use data (MAFF) for Wales is of very poor spatial resolution. The information is available on a county basis, of which there are only nine, typically occupying 3,000-6,000 $km^2$ each. For comparison, English agricultural data is available on a 'superparish' basis. The mean area of a superparish is 92.7 $km^2$. Because of this, the calculated agricultural nutrient loads (from fertiliser application and livestock waste) should be viewed with caution (especially considering the concerns over validation of the modelled data).

2. Use of remotely sensed land use data should provide an improved estimate of nutrient export from fertiliser application, but agricultural census data would still be required for estimating the nutrient export from livestock farming.

3. Validation of modelled instream N loads using concentration/flow data is impossible because the Environment Agency do not monitor total nitrogen; only the components of total inorganic nitrogen.

4. Nutrient retention (including biological uptake) within the river system has not been included in the load modelling procedure, but may be important, particularly in determining the seasonality of nutrient delivery to the estuary.

5. The nutrient load to the estuaries is probably dominated by inputs from the marine environment. In addition, it appears that the deposition of marine-derived suspended particulate matter within the estuaries is a major source of phosphorus, which may be of a similar order of magnitude to all other phosphorus sources to the estuary. In other words, there may be no net movement of phosphorus between the coast and estuaries, in which case the estuaries act as a major sink for phosphorus. This supports the suggestion that salt marsh macrophyte communities are likely to be nitrogen-limited.

6. Validation of modelled catchment-derived nutrient loads is potentially subject to large sources of error, since less than half of the three estuary catchments is upstream of the water sampling sites at which instream loads are calculated (28, 34 and 43% for the Glaslyn/Dwyryd, Mawddach and Dyfi estuaries, respectively). Of further concern is the fact that the gauging station sites were not sampled; instead, water quality data from the

nearest sampling site (with different sized catchment areas to the gauging stations) had to be used. The inappropriate limit of detection for phosphorus that was used until about three years ago resulted in very large confidence limits for the calculated instream loads. No validation of the nitrogen load was undertaken since neither total nitrogen nor Kjeldahl nitrogen concentration were measured by the Agency. Nutrient export monitoring is almost always undertaken in terms of total nitrogen and total phosphorus.

7. Use of harmonised monitoring data to estimate nutrient loading to estuaries should be used carefully.

**Monitoring**

1. Only within the last 3 years has an appropriate limit of detection been used for phosphorus analysis. The value of earlier phosphorus data is very much reduced because of this. Monitoring of total phosphorus is undertaken by the Environment Agency, but monitoring of total nitrogen is not. All nutrient export modelling predicts the load of total nutrients exported from a catchment. As such, total nitrogen is an essential parameter to monitor if nitrogen export budgets are to be validated.

2. Salinity should always be measured when sampling estuaries for nutrients. No concomitant salinity data were available for the Glaslyn/Dwyryd, Mawddach or Dyfi estuary nutrient data.

3. In addition to conventional chemical monitoring of the trophic status of estuaries, three other approaches may offer advantages in some estuaries:

   - Monitoring of the organic nitrogen mineralisation rate in intertidal sediments during late spring - particularly important where STW outfalls provide a large proportion of the nitrogen load to estuaries.

   - The development of an intertidal (attached) sediment diatom index related to sediment and water quality appears to offer a practical method of monitoring the trophic status of estuaries. However, electron microscopy may possibly be required for species identification, and much of the basic taxonomic information required for the development of such a UK index is still to be collated. A simpler index to that developed by the Environment Agency for river epipelic[4] communities may suffice. Diatoms appear to be very sensitive to changes in salinity, so such an approach may only be suitable for sites where diurnal fluctuations in salinity are relatively small.

   - Monitoring of plant tissue C:N, C:P and N:P ratios appears to provide a pragmatic guide to the nutrient status of sediments. The ratios are likely to vary on a seasonal basis, so tissue sampling should be undertaken at approximately the same time every year (early in the 'growing season').

4. Although estimates of nutrient inputs to the Dyfi Estuary from marine-derived particulate matter have been made, these estimates are based on a number of assumptions and scant

[4] Definition: Used of those aquatic organisms moving over the sediment surface or living at the sediment/water interface.

data. Improved data on sediment accretion rates within the estuaries (not just associated with the salt marsh) and data on the nutrient content of coastal suspended particulate matter is required.

#### A7.1.7.2 Nutrient status of Welsh estuaries: Recommendations

1. A more thorough analysis of the Environment Agency's marine baseline survey data should be undertaken, in conjunction with river flow and nutrient concentration data to determine the extent of P-limitation in Welsh and English coastal waters. The seasonality of N- and P-limitation should also be investigated.

2. A survey of basic diatom taxonomy in intertidal sediments, combined with a water/sediment quality monitoring programme is required to assess whether the development of an estuarine episammic[5] diatom trophic index is practicable.

3. Surveys of C:N and C:P ratios in dominant salt marsh species from estuaries covering a wide range of trophic status should be undertaken. This should be linked to the nutrient content of sediment cores collected from the same sites. If sufficient funds are available, a range of different parts of the plants should sampled throughout the year. If funds are limited, the sampling programme should concentrate on sampling tissue early in the growing season and total nutrient concentrations in the sediment.

4. A more complete comparison of the estuarine invertebrate taxa of the three Welsh estuaries with other UK estuaries should be undertaken. This should be based on invertebrate density data, not just species presence (as in this study).

5. More attention should be given to monitoring sediment accretion rates and movement within these estuaries. A study on the nutrient content of suspended particulate matter (SPM) and fluxes of SPM across the estuary mouths should be undertaken. This study should be based around the BSI (1973) methodology for measuring flow in tidal channels and should include seasonal surveys to provide year-round estimates of fluxes.

6. Considering the very poor spatial resolution offered by current MAFF Agricultural Census data, and bearing in mind the fact that that there is no evidence of an overall trend in nutrient loading to any of the three estuaries, it is recommended that the diffuse source nutrient export modelling be repeated using 1989 Agricultural Census data. Alternatively, the 1989 data could be used to estimate the loads from livestock farming, and more recent remotely sensed data could be used to estimate the load from arable farming.

7. Consideration should be given to the monitoring of total nitrogen at harmonised monitoring sites.

8. Salinity should always be recorded when measuring aquatic nutrient concentrations in estuaries.

[5] Definition: attached to sand particles.

#### A7.1.8 Integrated Environmental Assessment (IEA) on Eutrophication (NERI, 1997)

See Section 5.2.3 for information on the use of IEA at the European Environment Agency.

##### A7.1.8.1 IEA: Objectives

- to identify and test some ways forward for the EEA in the use of IEA;
- to identify gaps in data coverage and knowledge for addressing eutrophication as an environmental issue;
- to identify appropriate methodologies and policies.

##### A7.1.8.2 IEA: Recommendations

- Based on information on crops grown and nitrogen application rates, nitrate leaching from the root zone of agricultural land can be estimated. However, the mechanisms of transport from the root zone to loading into surface waters are poorly understood. An approach relating information on agricultural pressure information directly to the concentration in surface waters offers advantages in terms of fewer data requirements and overall simplicity.
- The process of phosphorus run-off due to agricultural activities is rather complicated and at present reliable models for predicting the effects of changes in agricultural pressures to run-off of phosphorus are not available - however, information on soil erosion risk together with phosphorus balances for agricultural soil may be useful to determine whether the pressure is increasing or decreasing.

## A7.2 Cause-effect relationships

Table A8 lists the projects, where identified, addressing cause-effect relationships in lakes and reservoirs, rivers, estuaries and coastal waters and wetlands. Further information on each project is available from the funding bodies (see Section 2 for contact details).

**Table A8 UK funded eutrophication-related R&D projects addressing cause-effect relationships in lakes and reservoirs, rivers, estuaries and coastal waters and wetlands**

| Ref | Title | End Date | Funding body | Lakes and reservoirs | Rivers | Estuaries and coasts | Wetlands |
|---|---|---|---|---|---|---|---|
| | The sensitivity of upland standing waters to atmospheric nitrogen deposition | | NERC GANE | x | | | |
| | Nitrogen driven lakes: more common than convention claims? | | NERC GANE | x | | | |
| P2B(96)03 | Effectiveness of eutrophication control by phosphorus reduction | 2001 | EA | x | | | |
| E1D(97)-8 | Development of an expert system for predicting growth and distribution of macrophytes in shallow eutrophic lakes | 2000 | EA, Broads Authority University of Amsterdam | x | | | |
| | The artificial fertilisation of gravel pit lakes - its effects and use as a fishery management tool | 2000 | EA Thames | x | | | |
| CV(96)6 | Palaeolimnological investigation of Scottish freshwater lochs | 2000 | SNIFFER | x | | | |
| | A review of ecological models of potential use in environmental forecasting | 1998 | EA | x | x | x | x |
| SR 97(08)F | Investigating the design of sampling programmes for standing waters: a scoping study | 1998 | SNIFFER | x | | | |
| SR 95(06)F | Hindcasting of in-loch phosphorus concentrations based on land cover classification | 1996 | SNIFFER | x | | | |
| SR 2713/1 | Eutrophication in upland waters | 1991 | SNIFFER | x | x | | |
| P-39 | Review of the effects of afforestation on upland water quality | 1990 | EA | x | x | | |
| P-79 | Nutrient enrichment of Scottish Lochs and reservoirs, with particular reference to the impact of forest fertilisation | 1990 | EA | x | | | |
| P2A(98)11 | Nutrient modelling on the river Kennet | 2001 | EA | | x | | |
| P2A(97)01 | Pilot Catchment study of nutrient sources - control options and costs | 2000 | EA | | x | | |

| Ref | Title | End Date | Funding body | Lakes and reservoirs | Rivers | Estuaries and coasts | Wetlands |
|---|---|---|---|---|---|---|---|
| 031480 | Pollution of soils and waters through acidification and eutrophication and the associated mobilisation of pollutants | 1999 | BBSRC | | x | | x |
| | Phosphorus in rivers: its ecological importance and the role of effluent stripping in the control of riverine eutrophication | 1999 | English Nature | | x | | |
| P203 | Determining the causes of 'apparent eutrophication' effects | 1998 | EA | | x | | |
| | Eutrophication in controlled waters in the Warwickshire Avon catchment | 1998 | EA | | x | | |
| Note 346 | Nitrification rates in rivers and estuaries | 1994 | EA | | x | x | |
| NR 3698 | River Eutrophication Risk Modelling: A GIS Approach | 1994 | SNIFFER | | x | | |
| | The importance of dissolved organic nitrogen in macroalgal dominated coastal ecosystems | | NERC GANE | | | x | |
| | Marine ecosystem modelling workshop | 2000* | DETR | | | x | |
| | Scientific support for the management of nutrients - modelling | 2000* | DETR | | | x | |
| P269 | The impacts of nutrients in estuaries Phase II | 1999 | EA/EN | | | x | |
| | Nutrient status of the Glaslyn/Dwyryd, Mawdach and Dyfi estuaries - its context and ecological importance | 1999 | CCW | | | x | |
| TR P14 | Biogeochemical controls on phosphorus cycling between sediment and water in estuaries (JONUS II) | 1997 | EA | | | x | |
| TR E30 | The distribution of phytoplankton and nutrients in the NE Irish Sea during 1996 | 1997 | EA | | | x | |
| 639/1/A | The impacts of nutrients in estuaries - Proceedings of the scoping workshop | 1995 | EA/EN | | | x | |
| SR 2756 | Coastal water eutrophication - current status | 1991 | SNIFFER | | | x | |

* Proposed new starts in the DETR MLIS programme 2000/2001 (see Section 2 for contact details)

Cause-effect relationships between nutrient inputs and eutrophication effects have been widely investigated and the current challenge appears to be to model these relationships in different waterbody types. The successful production of such models will have benefits in the management context by linking them with catchment-based models predicting inputs of nutrients from the environment.

Mainstone *et al.,* (1998) undertook a review of ecological models of potential use in environmental forecasting and this review included models of cause-effect relationships in eutrophication in the main water body types.

### A7.2.1 Lakes and reservoirs

#### A7.2.1.1 Review of ecological models: Lake models (from review by Mainstone *et al.*, 1998)

Ecological models specific to lakes are mostly targeted at eutrophication issues (such as PCLake, LAVSOE, LEEDS and PROTECH), some dealing only with eutrophication risk (in terms of threshold nutrient concentrations) and others being more complex and dealing with simulations of various biological components (such as phytoplankton, zooplankton, macrophytes and fish).

The Dutch dynamic model **PCLake** simulates changes in-between the two alternative stable states of the lake ecosystem (one comprising phytoplankton-dominated turbid water and the other comprising clear water dominated by submerged macrophytes). Modelling of alternative stable states is now a key component of lake modelling in relation to eutrophication and restoration, and is not accommodated by traditional eutrophication models. PCLake is currently being linked to a water transport model DUFLOW so that catchment problems can be investigated (pers. comm. L. van Liere, the Dutch National Institute of Public Health and Environmental Protection - RIVM), and links to PCDitch are also being developed.

**PROTECH** (developed by IFE) is currently available to the Environment Agency as a standard lake eutrophication model. This goes further than basic nutrient/chlorophyll regression analyses (e.g. OECD 1982 quoted in Mainstone *et al.,* 1998), since it predicts chlorophyll levels associated with functional groups of phytoplankton throughout the year. It does this by updating information on growth conditions in 10 cm horizons throughout the water column. Thus, it is able to predict chlorophyll *a* levels at any time of year and to predict what group of algae is likely to dominate. The downside of such a model is that it is data-hungry, requiring bathymetric, biological, hydrological, chemical and meteorological inputs. PROTECH may be used in conjunction with PACGAP - a simple expert system that uses data on lake morphology, biology, retention time and nutrient concentrations to predict the most suitable eutrophication control method(s).

The forecasting of blue-green algal problems is a particularly important issue for the Agency. PROTECH is able to predict the likely times of dominance and the standing crops of the functional groups containing toxic blue-green algae, but modelling of toxin production is altogether different. There is a two-thirds chance of a potentially toxic blue-green algal bloom being toxic, but the factors controlling toxin production appear not to be sufficiently well understood for the process to be accurately modelled, although such models have been attempted. However the effects of light-driven buoyancy on blue-green algal populations (mediated by gas vacuole inflation/deflation) have been successfully modelled (albeit in a nutrient-saturated isothermal water column - Belov and Giles (1997 quoted in Mainstone *et al.,* 1998). This model requires further validation and a user-friendly front end before it could be used by non-modellers, but the general model of Belov and Wiltshire (1995 quoted in Mainstone *et al.,* 1998) could be very useful in predicting the likely effect of mixing system operation on blue-green algal populations, and hence be of use to both the Environment Agency and water companies.

### A7.2.2 Rivers

#### A7.2.2.1 Review of ecological models: Models for rivers (from review by Mainstone *et al.*, 1999)

MINDER for Rivers and CECOSECOM (Coupled ECOlogical and Socio-ECOnomic Model) deal with the prediction of eutrophication problems in rivers as a result of enhanced nutrient inputs. Both deal in eutrophication risk, rather than direct prediction of biological changes. **MINDER for Rivers** has been applied to the Don catchment in Scotland and adapted to utilise environmental data available in Eastern Europe. It was then applied to river systems in Romania, Slovakia and Hungary. However, it would require further development before it could be termed properly operational. **CECOSECOM** brings together the forecasting of human activities with the simulation of ecological consequences in order to analyse future scenarios of eutrophication risk, covering both river reaches and coastal areas associated with the Rhone River basin. It considers factors such as agricultural production, overall population, intensity of urbanisation and industrial activity, but the output parameters are unclear from available information. The project was scheduled to end in 1996 so it assumed that the model is complete.

**BINOCULARS** (BIogeochemical Nutrients Cycling in LArge River Systems) is another nutrient-based river model that is geared towards analysing land use scenarios in river basins. Although it is unclear from the information available how model outputs are expressed, it does consider impacts on the ecological functioning of the river as well as predicting changes in nutrient status. The aim of model development was to assist in the formulation of policies on integrated river basin management, and as such is of potential relevance to the Agency in environmental forecasting. It has been built on 7 case study catchments in Europe (including the Axe, in England).

### A7.2.3 Estuaries and coastal waters

#### A7.2.3.1 Review of ecological models: Models for estuaries and coastal waters (from review by Mainstone *et al.*, 1998)

The review has identified a number of models dealing with the simulation of phytoplankton and/or macroalgal populations that are of potential use in forecasting human-induced change. These include a predictive model for *Phaeocystis* blooms, which are a major feature of coastal areas of England and Wales. Phytoplankton simulation models have been developed in Norway, France, Germany and Italy, whilst **EROS 2000** is a collaborative European model that deals with eutrophication in coastal areas. **COHERENS** is a management-orientated dynamic model of coastal ecosystems, developed by Belgium and the UK, that is particularly worthy of further investigation.

**ERSEM** and **MIKE21 EU** both simulate carbon and nutrient cycling processes through the food web in the North Sea. Their applicability to the analysis of eutrophication problems has been compared by Baretta *et al*. (1994) (quoted in Mainstone *et al.,* 1998), concluding that both are relevant at different geographical scales. MIKE21 EU has a high spatial resolution (18.5x18.5 km), whereas ERSEM is mechanistically more complex (with 70 state variables) but of coarse spatial resolution. MIKE21 EU is therefore more appropriate for identifying problem areas, whilst ERSEM is better suited to analysing the mechanisms and nature of likely changes.

The EU-funded JEEP-92 (Joint European Estuarine Project) Project has produced a model of ecological processes in European estuaries that may be of value in environmental forecasting. The ecological model **MOSES** simulates basic pelagic and benthic processes relevant to carbon and nutrient cycling, including primary production, degradation processes, zooplankton grazing and macrobenthic feeding (Heip and Herman, 1995 quoted in Mainstone *et al.,* 1998). The model is said to be sufficiently generic to apply easily to other estuaries, and has potential applications in simulating the impacts of possible future changes in the loads of organic material and nutrients. MOSES is linked to a hydrodynamic model that calculates loads to the system.

Several OECD-type empirical models (linking chlorophyll *a* levels to nutrient concentrations) have been produced for coastal waters (e.g. Lack *et al.,* 1990; Gowen and Ezzi, 1992; Gowen *et al.,* 1992; Giovanardi and Tromellini, 1992 quoted in Mainstone *et al.,* 1998), the first of which includes the use of site-specific flushing factors to account for phytoplankton loss from dynamic systems. This substantially improved the accuracy of the model for use in Hong Kong coastal waters, but the approach is not known to have been used in estuaries.

The loss of eel-grass beds is of concern in some UK coastal areas, and a European model has been developed under the EU 3rd Framework Programme to simulate the mechanisms causing transition from *Ulva* (sea lettuce) to eel-grass that may be of value to the Agency.

Few models of anthropogenic impact exist that deal with mudflats, despite the high ecological importance of mudflat ecosystems. **ECOFLAT** is a collaborative European model that simulates the ecological effects of global environmental change, and may be of future use to the Agency.

### A7.2.4 Wetlands

#### A7.2.4.1 Review of ecological models: Modelling wetlands (from review by Mainstone *et al.,* 1998)

Large amounts of effort have been invested in wetland modelling by organisations in the Netherlands, particularly in relation to the effects of anthropogenic alterations to the height of the water table. There are many Dutch models, some of which appear to overlap heavily in the nature of their application.

- **ICHORS** (Influence of Chemical and Hydrological factors On the Response of Species) uses site-specific data on the distribution of plant species and various (about 25) associated abiotic variables (such as water depth above or below ground level, pH and soil/sediment content of parameters including magnesium and bicarbonate), computing probability functions for selected plant species in relation to the most important abiotic factors (selected by multiple regression). In this way, it may be compared to the PHABSIM model for rivers, with its probability functions being similar to Habitat Suitability Curves. Unfortunately, the large number of parameters it uses makes it expensive to apply, and when scenario-testing many parameters are very difficult to predict.

- **WSN** (Water-Site-Nature conservation value) is based on the first Dutch ecohydrological model WAFLO (WAter-FLOra) and concentrates on water management issues. It uses Ellenburg's scales of wetland character, which are based on soil moisture, acidity and nutrient availability and are applied to individual wetland plant species. These are used to identify ecological species groups (together with potential conservation value) under different combinations of the three abiotic variables, and physico-chemical models are used to predict changes in the abiotic environment. Where predictions of abiotic change take a site from one species group to another, the site is reclassified and a new potential conservation value is assigned.

- **MOVE** (Model for the Vegetation) combines the statistical approach of ICHORS with Ellenburg's indicator values. The Ellenburg scales are calibrated to abiotic site factors, such as soil moisture and pH, which are predicted in scenario testing using dynamic models such as SMART2. MOVE and SMART2 are both incorporated into the decision support system Nature Planner.

- **DEMNAT-2.1** is a national-scale model that uses national datasets on soils, groundwater and plant species distributions to develop empirical relationships that are then used in scenario-testing, considering changes in soil moisture conditions, nutrient availability, acidity and salinity.

The two models of greatest apparent applicability are DEMNAT and MOVE, with the former seeming to be of more utility in terms of environmental forecasting simply due to its large scale of application. This allows more strategic, national-level predictions of change, although it does rely on certain national datasets being available in an appropriate format. Although both models are used by RIVM to analyse water management scenarios, there is some concern that MOVE is not ready for operational use (*pers. comm*. F. Witte, RIVM). A PC version of DEMNAT has recently been produced which is to be sent to the regional water boards of the Netherlands for operational applications.

The Projektzentrum Oekosystemforschung in Germany is developing a similar modelling approach for managing wet grasslands (Schrautzer *et al*., 1996 quoted in Mainstone *et al.,* 1998), consisting of an expert system, a database of 1300 sites and autecological information on 200 plant species. Rules concerning autecological preferences, vegetation types and likely succession stages are built into the expert system and used to simulate likely biological changes as a result of possible alterations to environmental conditions. Whilst the system seems to be more orientated towards determining what changes are required to achieve a pre-defined target vegetation type, it can presumably be used to determine what floristic changes would occur if environmental conditions were altered in different ways. It differs from Dutch models in having no abiotic modelling capability (although this is planned for the future), and is largely geared to identifying meadow restoration options.

**PCDitch** is a Dutch model that has been developed to simulate the adverse consequences of nutrient enrichment in the drainage networks typically associated with wetland systems. Enrichment of ditch systems, and the consequent loss of the typically diverse assemblages of submerged macrophytes, is an important issue and one that has been poorly researched to date. This model, whilst requiring further development, provides an opportunity to place ditch management on a more objective footing.

## A7.3 Cost-benefit and effectiveness

Table A9 lists the projects, where identified, addressing cost benefit and effectiveness. Further information on each project is available from the funding bodies (see Section 2 for contact details).

**Table A9 UK funded eutrophication-related R&D projects addressing cost-benefit and effectiveness**

| Ref | Title | End Date | Funding body |
|---|---|---|---|
| | Strategic cost analysis of nutrient input reduction | | DETR |
| | Economics of nitrogen pollution | | DETR |
| | Nitrates Directive: economic analysis of nutrient control | 2000* | DETR |
| P2A(97)01 | Pilot Catchment study of nutrient sources - control options and costs | 2000 | EA |
| P269 | The impacts of nutrients in estuaries Phase II | 1999 | EA/EN |
| | Diffuse pollution: sources of nitrogen and phosphorus | 1999 | DETR |
| 639/1/A | The impacts of nutrients in estuaries - Proceedings of the scoping workshop | 1995 | EA/EN |

* Proposed new starts in the DETR MLIS programme 2000/2001 (see Section 2 for contact details)

The relative costs and benefits of measures to combat eutrophication are an increasingly important consideration in decisions on the implementation of management options. This issue is currently being actively researched by DETR in ongoing or proposed projects.

## A7.4 Collaboration mechanisms

Table A10 lists the projects, where identified, addressing collaboration mechanisms. Further information on each project is available from the funding bodies (see Section 2 for contact details).

**Table A10 UK funded eutrophication-related R&D projects addressing collaboration mechanisms**

| Ref | Title | End Date | Funding body |
|---|---|---|---|
| 639/1/A | The impacts of nutrients in estuaries - Proceedings of the scoping workshop | 1995 | EA/EN |
| P269 | The impacts of nutrients in estuaries Phase II | 1999 | EA/EN |

Research into collaboration mechanisms includes projects that seek to promote collaboration among interested parties (including regulators) to implement measures to control eutrophication. This has received little attention to date though co-funded R&D projects between regulators are increasingly common.

## A7.5 Control techniques

Table A11 lists the projects, where identified, addressing control techniques. Further information on each project is available from the funding bodies (see Section 2 for contact details).

**Table A11 UK funded eutrophication-related R&D projects addressing control techniques**

| Ref | Title | End Date | Funding body |
|---|---|---|---|
| | Landscape analysis of transport, transformation and fate of reactive nitrogen and abatement strategies | | NERC GANE |
| | Application of catchment scale data to the quantification of soluble organic and inorganic N fluxes within and from UK upland soils | | NERC GANE |
| | Nitrates Directive: catchment based study to identify options for reductions in nutrient outflows to sea | 2000* | DETR |
| | Catchment based study to identify options for reductions of nutrient flows to sea II | 2000* | DETR |
| | MAFF Nitrate R&D Programme | | MAFF |
| | MAFF R&D on phosphate loss from agriculture | | MAFF |
| MAF12260 | Optimising soil management to prevent contamination of surface waters by sediment, phosphorus and micro-organisms | 2003 | BBSRC |
| MAF12247 | Scale and uncertainty in modelling phosphorus transfer from agricultural grasslands to watercourses: development of a catchment scale management tool | 2003 | BBSRC |
| P2-127 | Assessment of the impact of nutrient removal on eutrophic rivers | 2002 | EA |
| E11490 | Biological phosphorus removal from wastewaters: a novel approach | 2002 | BBSRC |
| P2B(96)03 | Effectiveness of eutrophication control by phosphorus reduction | 2001 | EA |
| P2-123 | Soil erosion and control in maize | 2001 | EA, MAFF |
| D08080 | Colloidal organic matter and phosphorus transfer in grassland hydrological pathways | 2000 | BBSRC |
| P2-128 | Development and piloting of an agricultural integrated best practices manual | 2000 | EA |
| P2A(97)01 | Pilot Catchment study of nutrient sources - control options and costs | 2000 | EA |

| Ref | Title | End Date | Funding body |
|---|---|---|---|
| 24303010 | Leaching and ion transport in grassland soils | 1999 | BBSRC |
| P269 | The impacts of nutrients in estuaries Phase II | 1999 | EA/EN |
| | Diffuse pollution: sources of nitrogen and phosphorus | 1999 | DETR |
| | Phosphorus in rivers: its ecological importance and the role of effluent stripping in the control of riverine eutrophication | 1999 | English Nature |
| P203 | Determining the causes of 'apparent eutrophication' effects | 1998 | EA |
| | Eutrophication in controlled waters in the Warwickshire Avon catchment | 1998 | EA |
| HO-06/98-5K-B-BCJL | Diffuse pollution from agriculture - a field guide | 1998 | EA |
| | Assessment of potential for phosphorus reduction in river waters | 1998 | DETR |
| | Eutrophication control via nutrient reduction in rivers: Literature Review | 1998 | EA Anglian |
| P20 | Agricultural waste minimisation | 1997 | EA |
| P78 | Sustainable systems of outdoor pig production - runoff from outdoor pig production | 1997 | EA |
| P2-553 (P26) | Farm effluent treatment | 1997 | EA |
| TR P17 | Alternative farming methods. A study of the effects of an integrated arable management system on levels of herbicide and nutrients reaching 'controlled waters.' | 1997 | EA |
| 639/1/A | The impacts of nutrients in estuaries - Proceedings of the scoping workshop | 1995 | EA/EN |
| Note 320 | Land management techniques | 1994 | EA |
| Note 239 | Measures for protecting upland water quality - assessment of forestry buffer strips | 1993 | EA |
| Note 108 | Nitrate reduction for protection zones - the role of alternative farming systems | 1992 | EA |
| FR0253 | Guide on nutrient removal process selection | 1992 | FWR |
| FR0216 | Review of nutrient removal processes | 1991 | FWR |
| P2-014 | Land management techniques - Phase 3 | | EA |

* Proposed new starts in the DETR MLIS programme 2000/2001 (see Section 2 for contact details)

Research into control techniques includes source controls (improved sewage treatment nutrient removal), farm waste management, agricultural buffer zones, *in situ* control of nutrient effects and the environmental impact of applying control measures.

The issue of farm waste management has been addressed in the MAFF Nitrate R&D Programme. The potential for recovering phosphorus from sewage and animal wastes was the subject of a recent conference organised by the Centre Européen d'Etude des Polyphosphates (CEEP, 1998). The effectiveness of nutrient removal in controlling the effects of eutrophication in rivers has been addressed by a number of recent studies, including Whitton and Kelly (1998), Mainstone *et al.* (1999), House *et al.* (1998) and Coventry University Centre for Environmental Research and Consultancy (1998).

### A7.5.1 MAFF Nitrate R&D programme

#### A7.5.1.1 Strategies to encourage better use of nitrogen in animal manures

The objectives of the research on manure nitrogen in the Nitrate Programme were to:

- quantify nitrate leaching losses following manure applications to a range of crops and soils, and relate them to manure type and management, and the weather;

- obtain a better understanding of the key processes controlling manure nitrogen losses and availability to crops, especially ammonia volatilisation and organic nitrogen mineralisation;

- evaluate the ability of existing and improved farm machinery to apply manures accurately and evenly at agronomically required rates;

- incorporate the knowledge into better recommendation systems to help farmers to use manure nitrogen more effectively, while minimising nitrate and other nitrogen losses to the wider environment.

The conclusions and practical outcomes of research in this area have been used to formulate new guidelines on the efficient use of manure nitrogen included in the manure management practices in Nitrate Vulnerable Zones and recommendations in the Code of Good Agricultural Practice for the Protection of Water:

- Where possible avoid applying manures containing large amounts of available nitrogen (i.e. slurries and poultry manures) to free-draining soils in the period from autumn to early winter to reduce nitrate losses;

- Manure applications should be kept to agronomically required rates for efficient utilisation and to reduce pollution risks up to 250 kg total N $ha^{-1}$ $yr^{-1}$;

- Existing machinery has been shown to be capable of applying manures evenly on grassland and to arable stubbles but requires an accurate estimate of application rate and the matching of spreading widths. However, where growers wish to top-dress slurries to growing arable crops from tramlines, they will need to invest in trailing-hose (boom) applicators to apply even dressings without crop damage.

- The much-improved understanding of manure nitrogen losses and availability following land application has been summarised in published form (i.e. the MAFF Fertiliser

Recommendations booklet). Where growers require more detailed guidance on the fertiliser nitrogen replacement values of manures the computer-based decision support system MANNER can be used;

- To help growers make the most of manure the improved guidelines are being communicated to the agricultural industry via:

  - Managing Livestock manures booklets;
  - Fertiliser Recommendations booklet;
  - Code of Good Agricultural Practice for the Protection of Water;
  - Nutrient Demonstration Farms.

The continuing needs identified from this area of research were:

- Developing a better understanding of the processes controlling ammonia volatilisation and denitrification losses following land application and the complex interactions that exist between the different nitrogen loss pathways. The development of strategies to limit manure nitrogen loss from one route may indeed exacerbate losses from another;

- The contribution that mineralised organic nitrogen makes to crop nitrogen requirements and nitrate leaching losses, and benefits of the associated organic matter additions to soil quality;

- The continued development of MANNER to synthesise new knowledge on nitrogen availability and losses, and to transfer this knowledge in terms of improved nitrogen advice to farmers and their advisors.

### A7.5.2 CEEP International conference on phosphorus recovery from sewage and animal wastes (CEEP, 1998)

The quantities of phosphorus present in sewage and animal waste are significant compared with the needs of the detergent and high-grade phosphate industry. EC regulations and local environmental objectives are making phosphorus removal from wastewaters increasingly widespread. These two factors mean that in the future phosphorus recovery for recycling could become economically viable.

The conference concluded that phosphate recovery and recycling must involve the high-grade phosphate industry (represented by CEEP), but also the fertiliser and animal feed industries all of whom use phosphate rock as a raw material. Recovered phosphates will be most appropriately recycled through one or more industries, depending on the site of production, local markets and the recovered product type.

#### A7.5.2.1 CEEP conference: Recommended research

The following research areas are identified:

- economics of P recovery;

- economic study of existing P recovery plants;

- establishment of an economic model of cost and paybacks for P recovery in different situations;
- study of the chemistry of the two currently developed P recovery pathways (calcium phosphate and struvite formation) to obtain a better understanding of their application;
- effect on phosphate product formation of potential inhibitors likely to be present in waste waters e.g. organic molecules, metals;
- research into other P recovery routes in particular ion exchange;
- technical and economic feasibility of the use of different recovered phosphate products by the phosphate and fertiliser industries;
- use of struvite and potassium struvite as a fertiliser;
- construction of a demonstration scale, mobile P recovery installation.

#### A7.5.3 Phosphorus in rivers – Its ecological importance and the role of effluent stripping in the control of riverine eutrophication (Mainstone *et al*., 1999)

One of the objectives of this project was to clarify the contribution of phosphorus stripping to the control of eutrophication in rivers (see Section A6.2.2).

#### A7.5.4 Eutrophication Control via Nutrient Reduction in rivers: Literature Review (Whitton and Kelly, 1998)

- Storm events have an important influence on nutrient loads, both by enhancing inputs from diffuse sources and by mobilising bed sediments – water quality sampling programmes in catchments subject to marked variation in flow should take account of extreme rainfall events.
- Need for a critical assessment of the EA’s procedure for sample storage and analysis of water samples, particularly in the case of phosphate and chlorophyll.
- More detailed understanding of the process of denitrification in rivers, wetland treatment systems and buffer zones to enhance nitrate removal and to minimise that component of the process which terminates in nitrous oxide.
- Vitamins might influence the biomass of some algae like *Cladophora.*

#### A7.5.5 Assessment of the potential for phosphorus reduction in river waters (House *et al.*, 1998)

There are uncertainties about how rivers will respond to reductions in phosphorus discharges from sewage treatment works and the timescale for the biological symptoms of eutrophication to be reduced. This study develops a better understanding of how waterbodies will respond, in particular how reductions in discharges of phosphorus could be counterbalanced by phosphorus release from bed sediments of rivers. The outcome is the development of criteria for predicting the response of sediments to reduced concentrations of phosphorus in river waters. There is a recommendation for further development of the Equilibrium phosphate concentration method (EPC) for sediments (see Section A5.3 for further details).

### A7.5.5 Eutrophication in controlled waters in the Warwickshire Avon catchment (Coventry University Centre for Environmental Research and Consultancy, 1998)

The Avon has shown signs of accelerated eutrophication in recent years by the presence of attached and planktonic algae, and the presence of nuisance blue-green algal blooms. Such characteristics are undesirable from both a water quality management and recreation/resource perspective.

Consequently, the River Avon was designated a Sensitive Area (Eutrophic) under the UWWTD in 1994. This project was designed to:

- Identify present nutrient levels in the Avon catchment;

- Estimate likely effects of phosphate removal;

- Estimate possible further improvements by extending phosphate removal to smaller STWs.

Monitoring aims to provide a baseline for assessing any improvements resulting from phosphate treatment at the major STWs commencing at the end of 1998.

### A7.5.51 Eutrophication in Warwickshire Avon: future research

A number of areas may require additional investigative work in order to improve the understanding of nutrients in the Warwickshire Avon, including:

- Investigating the impact of P removal in the Avon catchment;

- Calculating nutrient loads - A guidance note on the most appropriate load methods to use under various scenarios is required;

- More detailed investigations are required in some subcatchments to determine the accuracy of budget estimates and to identify other potential point and diffuse sources of P;

- Export coefficient modelling and testing - Most of these models are based on land use specific loss coefficients expressed as kg/ha/yr and vary in their sophistication from lumped approaches to those which attempt to weight particular land use types depending on their proximity to stream channels. More sophisticated models which take into account seasonal and annual variations in rainfall, could be used with detailed land use information to provide better estimates of the potential diffuse source inputs of N and P;

- The role of wetlands as sediment and nutrient sinks, and as phytoplankton re-seeding areas;

- Phytoplankton and eutrophication - further research effort should be directed towards biological assessment, with the aim of identifying the relative contribution of green and blue-green algae and diatoms to the chlorophyll *a* record;

- Rural sewage pollution - for premises not connected to the sewer network, there is a need to quantify impact on local watercourses and groundwater;

- Climate change and eutrophication - long term changes in rainfall patterns (e.g. reduction in rainfall may alter dilution capacity of point sources) may be of significance in eutrophication issues.

## A7.6 Monitoring framework

Table A12 lists the projects, where identified, addressing monitoring framework. Further information on each project is available from the funding bodies (see Section 2 for contact details).

**Table A12 UK funded eutrophication-related R&D projects addressing monitoring framework**

| Ref | Title | End Date | Funding body |
|---|---|---|---|
| | A UK-Netherlands approach to North Sea Eutrophication monitoring | | DETR |
| | Benthic diatoms as estuarine water quality indicators | | DETR |
| E1C(95)06 | Sensors for nutrients - Phase 2 | 2000 | EA |
| W(98)03 | Airborne remote sensing for velocity field and algal bloom determination | 2000 | SNIFFER |
| E54 | Trial classification of lake water quality in England and Wales: a proposed approach | 1999 | EA |
| P269 | The impacts of nutrients in estuaries Phase II | 1999 | EA/EN |
| SR 97(08)F | Investigating the design of sampling programmes for standing waters: a scoping study | 1998 | SNIFFER |
| TR E3 | Diatoms as tools for water quality managers | 1996 | EA |
| TR E2 | The trophic diatom index: a users manual | 1996 | EA |
| 639/1/A | The impacts of nutrients in estuaries - Proceedings of the scoping workshop | 1995 | EA/EN |
| Note 341 | Use of diatoms to monitor nutrients in rivers | 1995 | EA |
| PR 469/11/HO | Development and testing of GQA schemes: Nutrients in rivers and canals | 1995 | EA |
| Note 253 | Lakes: Classification and monitoring - a strategy for the classification of lakes | 1994 | EA |
| Note 278 | Survey methodology for algae and other phototrophs in small rivers | 1994 | EA |
| SR3439/1 | Algal bioassays: a review of their potential for monitoring and managing the trophic status of natural waters | 1993 | SNIFFER |
| FR0289 | Potential of flow cytometry for routine algal counting and detection of cyanobacteria | 1992 | FWR |

Monitoring for nutrients and other measures of eutrophication is carried out routinely by the Environment Agency. Research in making this monitoring more cost-effective is ongoing with the use of sensors for nutrients and the potential of remote sensing for algal blooms being addressed. Much monitoring is carried out in support of classification schemes and where these have been proposed for lakes, rivers and estuaries and coastal waters the implications for monitoring is addressed. The development of new measures (chemical or ecological targets (see Sections A3 and A4 respectively) can also have implications for future monitoring.

## REFERENCES


Barnard, S., Parr, W. and Mainstone, C.P. (1999) The artificial fertilisation of gravel pit lakes - its effects and use as a fishery management tool, WRc Draft Technical Report.

Centre Européen d'Etude des Polyphosphates (CEEP) (1998) International Conference on phosphorus recovery from sewage and animal wastes, Warwick University, 6-7 May, 1998, (http://www.nhm.ac.uk/mineralogy/phos/co nf12.htm).

Chilton, P.J., Stuart, M.E., Wagstaff, S.J., Coleby, L.M., Bennett, J. and Jones, H.K. (1996) Identification and quantification of groundwater nitrate pollution from non-agricultural sources. Environment Agency R&D Technical Report P32.

Coventry University Centre for Environmental Research and Consultancy (1998) Eutrophication in controlled waters in the Warwickshire Avon catchment, Volume 1 - Report and executive summary.

Gowing, D.J.G. and Spoor, G. (1996) The effect of water table depth on the distribution of plant species on lowland wet grassland. RSPB Symposium of Floodplains, held in London. RSPB.

Hilton, J. and Irons, G.P. (1998) Determining the causes of "apparent eutrophication" effects. Environment Agency R&D Technical Report P203.

House, W.A., Denison, F.H. and Irons, G.P. (1998) Assessment of the potential for phosphorus reduction in river waters. Report by IFE to DETR, IFE Report No. RL/T11059J1/19.

Kelly, M.G. (1996) Use of diatoms to monitor nutrients in rivers, EA R&D Project Record E1/i618/5.

Koerselman, W. and Verhoeven, J.T.A. (1995) Eutrophication of fen ecosystems: external and internal nutrient sources and restoration strategies. In: Restoration of temperate wetlands. Eds. B.D. Wheeler, S.C. Shaw, W.J. Fojt and R.A. Robertson. John Wiley and Sons, Chichester.

MAFF (1996) Review of MAFF's Nitrate R&D Programme. Review and Scientific reports.

MAFF (1999a) Review of MAFF's R&D on Phosphate loss from agriculture. Review document. 28 June 1999.

MAFF (1999b) Tackling Nitrate from Agriculture. Strategy from Science. MAFF Publications, London.

Mainstone, C.P., Clarke, S. and Parr, W. (1998) A review of ecological models of potential use in environmental forecasting. Report to the Environment Agency. WRc, Medmenham.

Mainstone, C.P., Davis, R.D, House, A. and Parr, W. (1996) A review of methods for assessing and controlling non-point sources of phosphorus, WRc Report No. NR 3897.

Mainstone, C.P. and Parr, W. (1999) Estimation of nutrient loadings to the Fleet lagoon from diffuse sources. WRc Report No. CO 4708.

Mainstone, C.P., Parr, W. and Day, M. (1999) Phosphorus in rivers: its ecological importance and the role of effluent stripping in the control of riverine eutrophication, Draft report to English Nature, WRc Medmenham.

Mainstone, C.P., Weddepohl, J. and Woodrow, D. (1994) Land management techniques. NRA R&D Note No. 320.

NERI (1997) Integrated Environmental Assessment on Eutrophication: A pilot study, National Environmental Research Institute (NERI), Denmark, ISBN: 87-7772-347-3.

Parr, W., Andrews, K., Mainstone, C.P. and Clarke, S.J. (1999a) Diffuse pollution: sources of N and P, Final Report to DETR, WS 128/1/115 (ASP 34000044).

Parr, W. (1993) Algal bioassays: A review of their potential for monitoring and managing the trophic status of natural waters, WRc Report No. SR 3439/1.

Parr, W., Mainstone, C.P. and Morgan, N. (1998) Nutrient budget for the upper reaches of the Hampshire Avon, WRc Report No. 4426/2.

Parr, W. and Wheeler (1996) Trends in nutrient enrichment of sensitive marine areas in England, WRc Report No. CO 4055 to English Nature.

Parr, W., Wheeler, M. and Codling, I. (1999b) Nutrient status of the Glaslyn/Dwyryd, Mawddach and Dyfi estuaries - its context and ecological importance, WRc Report No. CO 4704 to the Countryside Council for Wales.

Scott, C.R., Hemingway, K.L., Elliot, M., De Jonge, V.N., Pethick, J.S., Malcolm, S. and Wilkinson, M. (1999) Impact of nutrients in estuaries - Phase 2. Environment Agency Project Record P2/i639/1. Cambridge Coastal Research Unit, University of Cambridge and CEFAS.

Whitton, B.A. and Kelly, M.G. (1998) Eutrophication control via nutrient reduction in rivers: Literature review. Research report produced by Durham University on behalf of the Environment Agency Anglian Region.