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Land Management Techniques

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EXECUTIVE SUMMARY

Diffuse pollution from agricultural sources is of great concern in the U.K. 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 the NRA to take action against this form of pollution would result in a continuance of current problems at best, and significant deteriorations in existing water quality at worst. Owing to a lack of practical tools to combat such pollution, the National Rivers Authority has commissioned WRc to conduct a scoping study (NRA Project Reference 453) to identify and outline suitable research. This R&D Note summarises the findings of the work and outlines recommended research. A comprehensive account of the study can be found in the associated Project Record (Nº 453/5/Y).

Practical methods of controlling pollution risk, including both in-field (soil conservation measures, application practices and Integrated Pest Management strategies) and end-of-field (buffer zone) techniques, have been 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 farmer. 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 U.K. and abroad have been 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, have been developed on the basis of this review.

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

KEYWORDS: Land management, diffuse pollution, agriculture, pollution risk, best agricultural practices, buffer zones.

1. INTRODUCTION

1.1 Background

Concern over the effects of modern agricultural practices on the environment and human health has increased over recent decades, in both public and political spheres (Edwards 1987, Logan 1990, Vereijken and Viaux 1991, NRA 1992). This has arisen mainly from an intensification of farming activity and an associated increase in the potential for environmental degradation.

Pollution of receiving waters from diffuse agricultural sources presents many difficulties in the areas of monitoring and control. Identifying effects, and subsequently relating cause to effect, is hampered by the temporal and spatial variability of contamination, and the identification of ameliorative measures is confounded by the vast array of possible land management practices and the complex behaviour of contaminants prior to reaching receiving waters. For these reasons, water quality management has in the past largely concentrated on point-source problems, which are most easily controlled. There is now an urgent need to address diffuse pollution problems if significant improvements in water quality are to be achieved in rural areas.

Owing to the monitoring difficulties posed, the scale of diffuse pollution in the U.K. is not readily quantifiable. Reported pollution incidents are often cited, but they are likely to represent only a small fraction of those occurring. Moreover, the more insidious effects of diffuse pollution are not accounted for in such statistics. Agriculture in general accounts for around 12% of all reported pollution incidents (NRA 1992), although most of these are caused by point sources around the farm yard (mainly slurry stores and silage clamps), rather than diffuse sources. Routine chemical monitoring is generally not suited to detecting diffuse pollution problems or pin-pointing sources. Discrete sampling has little chance of detecting intermittent (typically rainfall-generated) problems, the range of parameters monitored is often too limited (especially for pesticides), there is little basis upon which to target monitoring effort, and many headwaters (often at high risk) are unclassified and therefore not within the routine monitoring framework. Non-routine investigations in selected catchments have revealed diffuse problems not detected by routine monitoring (NRA 1992). Work by WRc in headwater streams has shown that organic pollution problems in areas of high livestock intensity can be extensive (Rutt and Mainstone 1992).

Several pieces of legislation require the NRA to act to combat pollution from diffuse sources. The 1991 Water Resources Act requires the NRA to identify Nitrate Sensitive Areas and also enables the establishment of more general Water Protection Zones for areas sensitive to any type of diffuse contamination. The introduction of Statutory Water Quality Objectives, also under the 1991 Water Resources Act, will require all sources of contamination to be addressed within an integrated framework. The EC Nitrate Directive, soon to be enacted under U.K. legislation, requires the identification of vulnerable zones. The North Sea Treaty and Paris Convention require that the load of certain substances (including Red List substances and phosphorus) be reduced to target levels within specific timescales, targets that may be difficult to achieve through point-source control alone. Lastly, the recent acknowledgement by EC ministers that further action is required to control groundwater contamination from diffuse sources (ENDS 1992), and forthcoming EC legislation in the form of the proposed Ecological Directive, will further increase pressure to tackle diffuse problems in an effective way.

There is a requirement for practical measures that can be used to identify and subsequently control diffuse agricultural pollution. In developing such measures, an integrated approach is required in order to ensure that environmental problems are eliminated rather than shifted from one part of the system to another. The NRA has commissioned WRc to review possible measures with a view to formulating a work programme for a major study into agricultural pollution and its control. More specifically, the requirement is for suitable methods of assessing diffuse pollution risk from agricultural activity, and land management techniques that minimise pollution risk. This R&D Note provides a summary of the findings of this scoping study, together with recommendations for future work. A full account of all information reviewed during the course of the study is given in the associated Project Record (Nº 453/5/Y).

1.2 Objectives

The overall objective of the work was:

To examine the scope of a project to develop land management techniques for the prevention of diffuse pollution of controlled waters and develop tools/procedures for rural catchment-based pollution risk assessment.

This overall aim was broken down into the following specific objectives:

1. To identify existing databases/modelling approaches and their availability with regard to rural catchment risk assessment modelling and assess the application of GIS in pollution risk assessment.

2. To produce a specification for the development of risk assessment tools.

3. To identify appropriate land management techniques, from reviews and studies carried out elsewhere, for reductions of levels and risk of diffuse pollution.

4. To recommend and prioritise future research and development needs to enable land management techniques, including the use of buffer zones and farm management plans, to be developed and produce a detailed costed strategy.

5. To develop a project plan for further research into land management techniques.

During the course of the study, objectives 4 and 5 were modified to allow broader recommendations to be made concerning future research. These recommendations would then be discussed at a technical workshop that would aim to agree the future direction of NRA research in this area.

2. METHOD

Information on land management techniques was gathered by computerised literature search and telephone discussions with a number of agricultural experts at WRc and other organisations. Effort was focused on research that had demonstrated the effectiveness of a technique in reducing contamination (by sediment, nitrogen, phosphorus, pesticides and organic material) of run-off or receiving waters. Techniques that involve the reduction of inputs to land (and the reduction of risk by implication - see Section 3) were assessed on the basis of the reduction in usage achieved in relation to the effect on crop yield and quality. Where information was available, the economic implications of the techniques described have been discussed.

Details of available diffuse pollution risk models and databases were obtained by computerised literature search and from WRc's experience in catchment modelling. The resulting list was compared with what was known about the NRA's requirements, both from earlier reports on environmental modelling commissioned by the NRA and from limited discussions with NRA staff.

3. MAIN ISSUES ARISING FROM THE STUDY

3.1 Land management techniques that minimise pollution risk

A vast amount of literature is available on research into the minimisation of diffuse pollution risk through the modification of land management practices. However, relatively little was found on the use of such techniques in commercial, or commercially realistic, situations. Relevant activities that can be divided into two management tiers:

a. Specific management practices that individually result in reduced transport of a contaminant to receiving waters.

b. Integrated management of practices on a farm or catchment scale that minimises pollution risk whilst maintaining farm profitability.

3.1.1 Specific management practices

Table 3.1 summarises the issues covered in the review of specific management practices. It is not possible to list the actual techniques and their benefits and disadvantages in this document (which is intended to provide a brief resumé of the project); a full account is given in the Project Record (Report Nº 453/5/Y). During the course of the review, it became apparent that management techniques with the potential to reduce pollution risk to receiving waters can be broadly separated into two types (although there is considerable overlap):

a. those that minimise the usage of potential contaminants (pesticides, inorganic fertilisers and organic fertilisers or animal wastes) and therefore reduce risk at source;

b. those that reduce the likelihood of potential contaminants in or on the soil reaching receiving waters.

Techniques that fall into category (a) would include those that seek to target the application of pesticides and fertilisers more accurately at the place and time that they are required, rather than the more typical modern practice of blanket broadcast spraying across the whole field on specific calendar dates. Temporal targeting may involve the use of pest forecasting systems, manual "scouting" of crops or soil nutrient testing (for both nitrogen and phosphorus), whilst spatial targeting may involve new application techniques and/or new formulations.

More fundamental than these approaches are techniques that seek to maximise the potential of the crop and its husbandry, the ecology of agricultural systems, and natural nutrient cycles in order to minimise, or in some cases eliminate, the use of artificial inputs. A list of such techniques would include pest control methods that are based on enhancement of natural control organisms, those that increase crop resistance or crop diversity (both in space and in time), cultural and mechanical techniques that suppress pest populations, and a host of soil and nutrient conservation measures.

Techniques falling into category (b) would include many of the soil conservation measures that help to minimise external inputs to land, such as the depth and frequency of tillage, choice of crop and the use of rotations, maintenance of soil humus and the avoidance of soil compaction. All of these techniques involve the containment of potential contaminants at or near the site of generation or application. Buffer zones serve the same broad purpose of preventing the migration of contaminants to receiving waters, but allow migration from the site of generation/application to the buffer zone via surface or sub-surface run-off. Buffer zones may therefore be viewed as a curative measure, rather than a preventative measure, in that they act primarily by cleaning up run-off after it has been contaminated.

There is a good deal of optimism concerning the use of riparian buffer zones and other buffer areas for the amelioration of run-off quality and in the avoidance of direct overspray or drift (particularly pesticides) into watercourses. Reductions in contamination of receiving waters using buffer zones can occur in three ways:

i. by reducing the likelihood of direct overspray;

ii. by physical entrapment of sediment and sediment-bound contaminants;

iii. by direct adsorption of dissolved contaminants.

In addition, their potential for enhancing the ecological quality of the river corridor in intensively farmed areas, through the extensification of management alongside riverbanks, is clear. It is important, however, to recognise that buffer zones are not a solution to the root cause of agricultural contamination of receiving waters, which is related to certain in-field agricultural practices that produce poor run-off quality. Buffer zones should be considered as a safety net, with potential for improving poor run-off quality when sound, low-risk farm management occasionally fails. In the short-term, greater reliance may need to be placed upon buffer zones until a full range of low-risk agricultural practices are available and integrated.

The available results on the effectiveness of buffer zones show buffering capacity of individual contaminants to be variable, largely reflecting the diversity of conditions in which they operate. In addition, the effectiveness of removal under fixed conditions varies between contaminants, depending upon their chemical characteristics. The majority of buffer zone research has been conducted in the U.S. on the efficiency of sediment retention, which can be high when conditions are optimal; less research has been conducted into the retention of dissolved contaminants. Nitrate can be retained effectively and exported to the atmosphere through denitrification processes (in waterlogged soils with an adequate carbon source); however, whilst phosphorus can be retained effectively in the short- and even medium-term (mainly through the trapping of sediment particles), longer-term export would appear inevitable once the phosphorus adsorption capacity of the buffer zone is saturated. Although no information was found on the use of buffer zones to ameliorate pesticide run-off, the ability of buffer zones to retain pesticides will vary greatly depending upon the physico-chemical properties of the pesticides concerned. However, for most pesticides an increase in soil-contact time will reduce concentrations in run-off, particularly if the soil organic matter content is high.

Table 3.1 **Summary of issues covered in the review of specific management practices.**

Practices associated with soil/nutrient conservation

Tillage
Crop rotation
Cropping patterns
Cover crops
Arable field size
Timing of autumn sowing
Avoidance of soil compaction
Tramlines
Maintenance of soil humus
Mulching
Grassland management
Water table control
Straw incorporation

Practices involving the application of potential contaminants to land
(pesticides, inorganic fertilisers and organic fertilisers)

Form of applied material
Method of application
Rate of application
Timing of application

Alternative management techniques

Pest control
Enhancement of native control organisms
Exotic predator/parasite introduction
Autocidal techniques
Use of pest-resistant crops
Cultural control techniques
Mechanical weed control techniques
Use of pest attractants/repellants
Use of biological pesticides

Crop fertilisation
Crop development for reduced fertiliser inputs

Buffer zones

Effects on run-off quality
Conservation value
Effects on flood alleviation
Buffer zone design: Physical dimensions
Management
Hydrology
Alternative buffer areas

3.1.2 Integrated management of practices

Introduction

Integrated farm management in the context of water pollution control concerns applying a compatible set of management practices to suit the specific conditions on the farm, in terms of soil type, topography, climate and hydrology, that minimises pollution risk with due allowance for the financial constraints on the farmer. There are several key stages in this process.

i) Identification and integration of cost-effective practices that minimise the input of external resources (essentially artificial fertilisers and pesticides) and contamination of receiving waters.

ii) Identification of where and when to apply which practices, considering local conditions.

iii) Assessment of the implications of changing farm practices on farm income and subsequent optimisation of environmental and financial benefits.

iv) Development of a management plan to implement changes.

Implicit in this thinking is that the use of external resources above the minimum requirement represents an unnecessary pollution hazard. In practical terms, this means efficient recycling of resources on the farm, the use of non-chemical pest control techniques where feasible, and the accurate targeting of necessary nutrient and pesticide inputs to minimise excess.

Integration of practices to minimise overall pollution risk

Low-risk agricultural practices are often developed for one contaminant of interest with little or no consideration of the implications for receiving water quality as a whole. This can lead to a situation where the benefits of reducing pollution risk from one contaminant are nullified by an increase in risk from others; situations may also arise where risk from one contaminant is merely transferred from one type of receiving water (eg rivers) to another (eg groundwater). There is therefore a need to consider the effect on all potential contaminants of land practices designed to minimise pollution by one contaminant to one type of receiving water.

Edwards (1990) concludes that some of the interactions between practices are understood and some can be predicted, but many are poorly understood and the relative importance of all interactions still needs to be assessed. In addition to this, low-risk practices need to be integrated with the ecology of agricultural systems; practices that avoid disturbance of field-nesting birds during the breeding season should be favoured, as well as targeted pesticide and fertiliser application techniques that minimise effects on the plant and animal communities of field margins.

In the area of pest control, good progress is being made towards the integration of non-chemical and chemical control methods for the minimisation of pesticide usage (i.e. Integrated Pest Management, IPM). The amount of pesticides used could be considerably reduced on a number of U.K. crops through the widespread adoption of effective non-chemical practices, using chemical applications only when necessary.

Application of practices in relation to local conditions

It is recognised that it will often not be possible to eliminate practices carrying a high intrinsic pollution risk from agricultural management. However, this is not necessarily critical if these practices are restricted to appropriate areas. The application of low risk practices on land of high vulnerability (owing to its physico-chemical characteristics) and high risk practices (if unavoidable) on land of low vulnerability is essential to effective non-point source pollution control. Identification of the intrinsic vulnerability of the land to release contaminants to receiving waters is therefore a basic requirement. Superimposed upon this vulnerability is existing land management, the combination of which dictates pollutant transport to receiving waters. Lastly, the value of the receiving water (as determined by its designated Water Quality Objective) should be considered to complete the picture of pollution risk. In determining what action must be taken where, all three factors should be considered in tandem.

It should be remembered that the pollution risk associated with a specific area of land and its management varies considerably depending upon the type of receiving water in question. An area of land posing a low risk to surface waters may pose a high risk to groundwaters and vice versa. Restriction of unavoidable high risk practices to areas of low surface water pollution risk may therefore exacerbate groundwater problems. Consequently, it is important to consider pollution risk holistically if overall risk is to be minimised.

Regarding buffer zones specifically, a great variety of influencing factors combine to dictate the suitability of an area for buffer zone establishment. It can be assumed that some conservation benefit will accrue from buffer zone establishment anywhere in the U.K., as long as management is appropriate to the ecological and landscape character of the area; however, benefits are likely to be greatest in areas where land use is most intense and habitats are therefore scarcest. In terms of water quality improvement, the key issues are the distribution of pollution risk, i.e. contaminant loadings and physico-chemical factors affecting contaminant transport, and physico-chemical factors affecting buffer zone function. In practice, the factors affecting contaminant transport are largely the same as those influencing buffer zone function, the principal ones being hydrology (including the presence of under-drainage), soil chemistry, topography and climate.

There is potential for at least some of these features to be mapped on a national scale, in order to assess the applicability of buffer zones across England and Wales on the basis of current knowledge. However, it should be remembered that certain factors, such as hydrology, can be manipulated in order to increase buffer zone efficacy, so that the extent of applicability can be artificially increased. In the U.S., non-point source models have been developed (see Section 3.2) that can assess the effect of buffer zone design on retention efficiency under different conditions; however, the majority of effort has so far been concentrated on sediment run-off and information on validation exercises are not readily available.

3.1.3 Optimisation of costs and environmental benefits

Of over-riding importance to the success of "low-risk" techniques is the cost of implementation, since farmers are unlikely to voluntarily change their management regime unless there is a valid economic justification. Moreover, the economic benefit often has to be considerable to overcome the farmer's uncertainty and aversion to the risk of changing practice (Guttierez 1987). In relation to pesticide application, farmers invariably consider the cost of treatment as a necessary insurance "premium" to ensure the crop's success (Mumford and Norton 1987, Guttierrez 1987).

Changing a specific farming practice can have widespread repercussions across the farm, as the changes have to be accommodated within a complex management framework. Studies in the U.S.A. have found that the Best Management Practices (BMPs) that are most effective at decreasing non-point source pollutant losses from agricultural land are not necessarily the most economical. In addition to difficulties associated with the complex inter-dependencies of farm management, the feasibility and cost of changing farming practices varies with local conditions, including not only environmental but also economic factors.

The cost of implementing a low-risk practice can be artificially altered by the application of incentives for "low-risk" management and disincentives for "high-risk" management; alternatively, the farmer can be statutorily restricted in the practices he can adopt. However, it should be recognised that the adoption of low-risk practices without any economic or legislative intervention is preferable and, indeed, far simpler in practice. This said, a number of highly environmentally desirable land management activities are unlikely to ever be financially attractive without some sort of economic intervention. An example of this is the use of floodplains as pastureland: many floodplain pasture landscapes have been drained for arable use in recent decades, with considerable financial gain for the farmer. Increases in erosion risk and the use of fertilisers and pesticides on such land has increased the pollution risk to adjacent surface waters considerably, whilst the ecological value of the wet meadow habitat has been lost. A reversion to wet pasture in such areas is highly unlikely without external financial support; this is being provided under the Environmentally Sensitive Areas scheme, but this currently only applies to a few designated areas.

If the financial implications of adopting low-risk practices are to be properly assessed, farm economics need to be modelled in a detailed way. This can either be done with due consideration for the effects of change on pollution risk, ie true optimisation, or in isolation from such effects. The former approach has the potential to yield the best information, but is complicated in practice owing to the large range of management options available to the farmer, each of which would have to be quantified in terms of its effect on pollution risk (accounting for land characteristics). The latter approach would involve using only the basic characteristics (ie soil type, topography, rainfall, etc) of a land area, which would be targeted for attention on the basis of pollution risk, and testing the relative performance of low-risk practices in terms of the effects on farm income only. Using this latter approach, reductions in pollution risk would have to be inferred or only very broadly evaluated, but operation and interpretation would be simpler.

Models (largely U.S.) that have been used to assess the cost-effectiveness of agricultural practices under specified conditions, as a means of assessing the cost of reducing pollution risk, have been reviewed in this study (see Section 3.2). Of particular interest are studies that have compared the cost-effectiveness of: a) altering in-field agricultural practices to ensure high run-off quality (ie prevention); and b) establishing end-of-field buffer zones to ameliorate run-off quality (ie cure). Whilst model simulations have estimated that in-field measures allow better retention of sediment and sediment-bound contaminants, riparian buffer zones have generally been estimated to be more cost-effective in terms of the effects on farm income and the logistics of enforcement. However, these results were based on the control of sediment loss and may not hold for the export of dissolved contaminants, particularly in the long term.

It should be stressed that the choice of approach to diffuse pollution abatement is not necessarily as stark as indicated by such model simulations In-field practices associated with input minimisation and soil conservation can be practised in parallel with buffer zone establishment, particularly if they are found to have no financial disdvantages in the short-term. In discussing the control of sediment loss to surface waters in the U.S., Williams and Nicks (1993) recommend that buffer zones are installed only after all necessary conservation treatments are applied to adjoining fields that the buffer zone serves.

In terms of in-field measures alone, long-term research into integrated arable farming systems for input (fertilisers and pesticides) minimisation in the Netherlands has shown that such systems can be as profitable as modern high-input agriculture (Wijnands 1990). Results from an experimental farm between 1985 and 1988 showed that although yields under the integrated system were lower than the high-input system, the reduced costs of pesticides and fertilisers allowed the integrated system to achieve a similar net revenue. This work has led to commercial trials of the system by experienced arable farmers (supported by expert advisors on integrated farming), which aim to modify the system according to local conditions. It is envisaged that sufficient knowledge of local considerations will be gained from this exercise to introduce integrated arable farming on a widespread basis.

3.1.4 Farm-level decision-making

For integrated farm management to work, decision-support systems will need to be available to the farmer to highlight the options available and the situations in which they should be used and combined. These could either be operated by the farmer himself, or be operated by regulatory authorities (NRA, MAFF or third parties) who would provide outputs and discuss implications with the farmer. Much relevant information could be extracted from catchment-scale risk models, in conjunction with outputs from farm economic models. However, other tools are likely to be necessary to give adequate detailed guidance to the farmer.

Edwards (1990) concludes that there is considerable scope for decision-support systems. A "hypothesis-driven expert system" has been developed in Pennsylvania to support "user-initiated" land management decisions related to nutrient budgeting (Cronc *et al.* 1990). The user is the farm operator, with the system producing a number of appropriate management options that seek to minimise nutrient losses to receiving waters.

Sound information upon which to base fertiliser applications is crucial to proper nutrient budgeting. Jarvis (1992) calls for the combination of databases on climatic, soil and drainage conditions to allow accurate predictions of crop growth and hence nutrient utilisation to be made. Horticultural Research International are currently developing nutrient budget models on behalf of MAFF to minimise nutrient usage.

The generation of slurry spreading schedules for individual farms, based on a knowledge of crop nutrient requirements and the conditions leading to run-off of organic material, is one particular aspect of farm management that could be addressed (Mainstone *et al.* 1993). Schedules could be produced by regulatory authorities or farming advisors and agreed through on-farm discussions.

Decision-support in Integrated Pest Management is crucial to reducing pesticide inputs to land. A pest forecasting facility is available for certain crops, but there appears to be little overall guidance on methods to reduce pesticide usage, such as targeted applications and the use of alternative control measures, including suitable crop rotations, biological control and the use of resistant cultivars. A shortage of experienced IPM advisors and the distance between farms make the supply of sound advice to farmers difficult (Mumford and Norton 1987). This leads to the adoption of standard control procedures using calendar, broadcast applications of pesticides. Decision-support systems using "expert system" technology would allow local decision-making based upon specialist knowledge (Mumford and Norton 1987).

In a farm survey of the Ouse catchment, Ward and Munton (1992) found that when deciding upon pest control measures, the pesticide merchant's representative was the most important source of advice for over half of all farmers. This advice is based purely on economic risk assessment, balancing the risk of crop failure against the cost of the pesticide, with the general assumption that if a pesticide has been licensed then it must be environmentally safe to use within the constraints of the manufacturer's recommendations. Application rates advised by merchant's representatives are often thought by farmers to be too high, but are usually adhered to since there is no come-back possible if the farmer uses a lower rate and the treatment fails. Such reliance on advisors with a vested interest in maximising pesticide usage is worrying, and needs to be countered by sound advice from impartial advisors, or decision-support systems based upon impartial advice.

3.2 Assessment of diffuse pollution risk

A enormous array of non-point source pollution models have been developed in both Europe and the U.S., ranging in complexity from simple loading functions to detailed process simulation models. Some have been designed to simulate the behaviour of specific contaminants, whilst others deal with a range of

Table 3.2 **U.S. EPA and European environmental models useful for rural catchment risk assessment**

U.S. EPA	European
Surface water contaminant fate	**Surface water contaminant fate**
ACTMO	QUASAR
AGRUN	MIKE11
ARM	TOMCAT
CEQUALR1	SIMCAT
CEQUALRIV1	STREAMS
CEQUALW2	ADZ
CHNTRN	MINDER
CTAP	RESERVOIR NITRATE
DYNTOX	FARMS
EUTRO4	SARA
EXAMS	
GEMS-EXAMS	
MICHRIV	
QUAL2E	
SERATRA	
SLSA	
WASP4	
Groundwater contaminant fate	**Groundwater contaminant fate**
ASM	AQUA
AT123D	FELFLO
BEAVERSOFT	FELPAR
BIO-1D	MAGIC
BIOPLUMEII/OASIS	MAITHREE
CADIL	MODPAC
CFEST	NO3
CHAIN	SUTRA
CHEMFLO	TGSL
CHEMRANK	TRADE
CONMIG	WRc LANDFILL
CRACK	JURY,FOCHT,FARMER
DPCT	
EPA-VHS	
EPA-WHPA	
FEMWASTE (with FEMWATER)	
FRONTTRACK	
GLEAMS	
GROWKWA	
GS2	
GS3	
GWTR3D	
HELP	
ISL-50	

Table 3.2 cont.

U.S. EPA	European
Groundwater contaminant fate (cont)	
MMT	
PESTRUN	
PLUME	
PLUME2D	
PRINCETON	
PRZM	
RUSTIC (PRZM, SAFTMOD and VADOFT)	
RWH	
SBIR	
SESOIL	
SOLUTE PKG	
SUTRA	
TETRANS	
VAM-2D	
VAM-3D	
Multi media	**Multi Media**
GEMS	SHE
MINTEQA2	
SARAH2	
Non-point source transport & environmental fate	
CREAMS	
GLEAMS	
HELP	
HSPF	
MRI	
NPS	
PESTRUN	
PRZM	
STREAM	
SWMM (Urban)	
Run-off simulation	**Run-off simulation**
STORM	HYRROM
SCS	FSR
	MINDER

contaminants. Most are designed to operate on a catchment scale, and many consider the effect of specific crop husbandry practices (such as method of tillage) on run-off quality. Some are linked to cost-optimisation models, that can (with appropriate data) answer 'what-if' questions concerning the cost-effectiveness of implementing various 'low-risk' practices. Table 3.2 lists models from Europe and the U.S. respectively that have potential for assessing diffuse pollution risk in the U.K.. Brief accounts of their characteristics are provided in the associated Project Record (N° 453/5/Y).

The selection of a model or model(s) that will satisfy NRA requirements for assessing diffuse pollution risk needs to be undertaken with due consideration for the applications to which the model(s) will be put. It is clear that to enable a comprehensive assessment of risk, all major diffuse contaminants from rural land will need to be covered by the models chosen. It would also appear that to provide a complete picture of the spatial distribution of risk, a low-resolution tool that covers the whole of the NRA's area of jurisdiction is required in addition to a high resolution tool that can aid management decisions in specific high risk areas. Such an approach would offer an objective and transparent way of: a) focusing effort at a national or regional level at high risk catchments; and b) within these catchments, focusing operational effort at areas in most need of management attention. From limited discussions with NRA staff, it would appear that this approach would suit the NRA's needs.

An outstanding issue that cannot be resolved within this scoping study is the extent to which the NRA require, at a catchment level of resolution, absolute estimates of contaminant loads and, subsequently, estimates of receiving water quality. Such information would clearly be of use in assessing the effect of land management upon compliance with Statutory Water Quality Objectives. However, it should be pointed out that models with the capacity to produce such estimates are necessarily complex and data-hungry, and therefore expensive to operate. In addition, the complexities of contaminant behaviour are incompletely understood in relation to the plethora of land management practices that are available, leading to large uncertainties in estimates of contaminant loads and concentrations, particularly when applying 'what-if' scenarios. Estimates can be improved considerably by local calibration data, but this inevitably increases the effort and cost associated with operating the model. The need for, and usefulness of, such estimates should be seriously considered before the decision is made as to whether to adopt such models.

Irrespective of the models used, Geographical Information Systems are felt to be a flexible vehicle for accepting and storing a diversity of spatially distributed datasets, linking with models as required, interfacing with existing databases and providing user-friendly map outputs.

4. CONCLUSIONS

4.1 General

Diffuse agricultural pollution is a significant problem in the U.K. that has to be addressed in a comprehensive and integrated manner. Although MAFF are very active in this area, the NRA need 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 deteriorations in existing water quality at worst.

4.2 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 hazardous inputs and others through better retention of potential contaminants within the soil. These include practices in the areas of soil conservation, material application (form, rates, timing, location) and Integrated Pest Management. 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:

a) a lack of farmer knowledge of the options available and where they should be applied;

b) concern about possible reduced yields and/or farm income;

c) reluctance on the part of impartial advisors to endorse reduced inputs for fear of liability for yield loss;

d) the use by the farmer of pesticide manufacturers as major advisors on suitable crop protection measures and pesticide application rates.

Development of promising techniques is probably further constrained by reluctance on the part of pesticide/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 has to be recommended against a background of a large MAFF R&D programme already in existence concerning land management practices for the protection of water. As has been pointed out by Thompson *et al.* (1992), the NRA R&D commitment to the land management research area is modest in relation to the MAFF programme, and this has to be recognised when planning future NRA-funded work. Information on phosphorus and agriculture in the U.K. is lacking at present, although this is now being addressed by a major MAFF programme of research. Erosion management is also receiving increased attention from MAFF through its soil protection R&D programme. A large amount of research effort is being invested by MAFF into identifying methods of minimising pesticide usage, although it is not clear to what extent results are being fed to the farmer in the form of clear guidance notes on pesticide application (BCPC, 1992) and, more importantly, Integrated Pest Management.

In general, the majority of MAFF-funded work is highly process-orientated and aimed at producing general guidance for the farmer. However, monitoring of both the uptake of guidance and the extent of actual benefits (in terms of improvements in environmental quality) seems to be lacking (BCPC 1992).

Two main areas of work may therefore be identified:

a) detailed, process-orientated research into developing best practices;

b) implementation of best practice and assessment of overall benefits.

Regarding best practice development, the NRA are already funding certain specific projects on slurry and dirty water application to land, areas where more detailed advice for the farmer is required. Other research areas that the NRA could support are investigations into the integration of best practices designed for individual contaminants, rather than for overall water quality improvements.

Regarding the latter work area, 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.

4.3 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 U.K. 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 may be very effective in some specific situations, 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.

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.

4.4 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.

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, and implementing alternative crop protection measures and IPM strategies.

4.5 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.

5. RECOMMENDATIONS

5.1 General

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.

5.2 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 lobby 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 (see Section 5.4). Best practices would include Integrated Pest Management strategies, soil conservation practices, nutrient budgeting, targeted application methods and properly scheduled slurry spreading.

The economic and operational viability of the low-risk practices reviewed in this report should be properly assessed prior to demonstration, in order to ensure favourable results (both economically and environmentally). Importantly, this should include a review of commercially available IPM strategies and those that are ready for field validation.

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 U.K. or where success is likely. In terms of land use, study catchments would ideally be located in: a livestock-dominated area, 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.

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 (ie initial background monitoring of study catchments) or a spatial control (ie 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 (eg 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 a MAFF/SOAFD-driven partnership with industry on research into Integrated Farming Systems (Wall 1992). The stated objectives of this project are as follows:

1. To integrate the latest results coming from research into an arable production system which will optimise the use of inputs compatible with production needs, profitability and environmental concerns.

2. To make valid comparisons between the integrated system of production and conventional practice for profitability, energy balance and environmental effects.

3. To investigate scientifically the interactions between component parts of the system.

The work is based on a number of sites, reflecting the range of climatic zones, soil types and agronomic practices in the main farming belt of the U.K.. A variety of environmental assessments are being made, none of which currently relate to the aquatic environment. This is clearly a good opportunity for collaboration, particularly since the intention of the project is to form a 'work-bench' upon which other studies may be bolted. The expected outcomes will be:

1. Reduced enregy inputs
2. Enhanced biological diversity
3. Optimised use of pesticides and nutrients
4. Integrated alternative control measures for insect pests, diseases and weeds
5. Enhanced rural environments
6. Increased protection of water supplies

Other relevant projects currently being undertaken are LIFE (Low Input Farming and Environment) and TALISMAN (Towards A Lower Input System Minimising Agrochemicals And Nitrogen). Both studies are aimed at reducing the cost and increasing the environmental safety of arable farming in the U.K. through the development of integrated farming systems (Jordan *et al.* 1990). 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.

5.3 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. As a minimum requirement, study catchments should lie within areas of high pollution risk as identified by the recommended risk assessment tools outlined in Section 5.4.

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 U.K.. 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 only covers nutrients and sediment, so NRA involvement in pesticides monitoring should be considered (if pesticide usage in the study catchments is sufficiently high). Further discussions should be undertaken with MAFF as soon as possible, in order to agree any collaborative work.

Land acquisition for buffer zone establishment is likely to be a major financial consideration. Possibilities for utilising EC Set-Aside funds for water-fringe habitats within the recommended study should be explored.

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 from buffer zones to be established in the near future, 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.

5.4 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. Outputs from the national/regional tool would be of great value in strategic and political terms, whilst the catchment/farm tool would provide information for catchment planning and farm visits. Specifications and costs for national/regional and catchment/farm scale tools are given in Appendix D. 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.

5.5 Development of decision-support systems

In conjunction with recommended work outlined in Section 5.2 and relevant work being carried out by agricultural research organisations, it is recommended that studies are undertaken to produce decision-support systems for rational slurry spreading (to include consideration of topography, soil type, proximity to watercourse, rainfall, timing of application, rate of application and method of application), nutrient budgeting and the use of IPM techniques. 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 (see Section 5.4).

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APPENDIX A - SPECIFICATION FOR RECOMMENDED RISK ASSESSMENT TOOLS

A1. INTRODUCTION

Owing to the availability, reliability and speed of current computing hardware and software, coupled with improved techniques for data analysis and visualisation, and simulation modelling, the most logical approach to satisfying the needs of the NRA lies in a computer-based system.

A GIS is recommended as a basis for supporting this task for the following reasons:

- The factors which affect pollutant loads and their transport from land to surface waters are spatially complex.
- A GIS can readily restructure or interpolate data from a wide range of sources and sampling frameworks to a common basis for analysis.
- A GIS is designed to store high resolution data over a wide geographical area.
- A GIS can be used to combine spatial information about basic parameters and present it in a form more relevant to management support.
- A GIS is an ideal tool for assimilating the data required by diffuse source pollution models and provides tools for visualising model outputs.

It is proposed that two risk assessment tools are developed, covering two scales of detail.

- national/regional scale
- catchment/farm scale

Analysis at the national/regional scale would highlight areas or catchments where use of the catchment/farm scale tool should be focused.

The chosen software and hardware package would reflect the needs of the NRA with respect to the number of users of the system and the current IT policy. The chosen package could be workstation- or PC-based within the constraints of meeting the functionality requirements of the system. As part of the selection process, WRc would advise the NRA on the appropriate options in accordance with any IT strategy which exists.

Prime candidates for workstation systems would include Tydac workstation SPANS; Genasys GENAMAP + GENACELL; Intergraph MGE + MGA, and ARC/INFO. PC-based candidate systems include Tydac PC SPANS, but it should be noted that PC run-times will be considerably longer.

A2. NATIONAL/REGIONAL SCALE RISK ASSESSMENT

A2.1 Objectives

The objective at this scale is to produce a system for use by NRA Head Office and Regional Headquarters staff, providing outputs for strategy support. The system would enable inter-catchment analysis but would be at sufficient resolution to target areas of high risk within the catchment of a major river.

A2.2 Resolution

The resolution is dictated by processing overheads and storage, and the availability of suitable data. Processing and storage become a problem at resolutions much finer than a 1 km grid for national analyses. To achieve the objectives of a national assessment system using available data within current software and hardware limitations, a grid-based system of 2-3km cell size is recommended.

In many parts of the UK, a 1 km grid is already too coarse to represent the river network. However, by using a river network represented by a vector structure, a relationship between coarse grid cells and the network may be established. This is based on river lengths included within each cell.

A2.3 System overview

Only steady-state conditions would be represented, using mean annual figures taken from the most appropriate recent timescale. Although calculation of contaminant concentrations in receiving waters is desirable in order to assess the likelihood of SWQO compliance under the current management regime, a tool that holds all of the relevant information to produce meaningful answers (which would include specific farm management considerations) would be extremely complex, time-comsuming and expensive to develop, at least at this scale. In addition, many of the factors affecting fate and behaviour are not well understood, so considerable assumptions would have to be made. The approach here is therefore to concentrate on those factors that are easily quantifiable at the national scale, and assess pollution risk in a relative way. Detailed investigation of agricultural management practices would be a separate activity, with attention being focused upon areas identified as being most at risk.

The system would comprise four main modules:

- **Land vulnerability** - This module considers the characteristics of land that determine the likelihood of contaminant transport to receiving waters. These are relatively unaffected by man's activities and therefore stable through time. Because different contaminants react to various land characteristics in different ways, separate land vulnerability classifications are required.

- **Existing land use** - This module considers the use to which the land is currently put and would be updated annually with information from the agricultural census. This serves to modify basic land vulnerability and allows distributions to be derived of land vulnerability specific to current land use.

- **Existing contaminant inputs** - This module considers the loading of potential contaminants to the land. Annual changes recorded in the census with respect to land use and livestock densities will produce changes in loadings; therefore this map will also be updated annually.

- **Receiving water quality** - This module considers the vulnerability of the receiving water in terms of its existing quality and long-term quality objective. National datasets of river quality should be available on a 5-yearly basis (perhaps yearly). Quality objectives will not be available in the near future, but can be incorporated at a later date.

Information from the first three modules would be combined to produce an overview of existing pollution risk for different contaminants. Information from individual modules can be used to investigate the nature of the risk, and to what extent it can be altered by changing land use or cropping patterns. A variety of mapped outputs and areal statistics would be available from each module and combinations of modules. Outputs could be produced on a grid cell basis or aggregated into river catchments.

A2.4 System elements

Module A - Land vulnerability

The basis of this module is a Hydraulic Export grid with Standard Percentage Run-off and Base-flow Index values being derived for each grid cell using the SSLRC/IoH Hydrology of Soil Types (HOST) soil classification. These indicate the long-term average proportions of rainfall that are exported from the cell via surface flow and that reach the river through groundwater respectively. Combining this information with average annual rainfall for each grid cell yields a potential hydraulic export grid. No correction is made for evapo-transpiration at this stage (which would create an **actual** hydraulic export grid), since this is a function of existing land use (Module B).

For each contaminant type, the following stable land characteristic factors are considered important and would be used to assess contaminant-specific land vulnerability.

Sediment and sediment-bound contaminants

Hydraulic export
Soil erodability
Rainfall erosivity
Topography

Soluble pesticides

Hydraulic export
Soil organic carbon
Topography

Soluble nitrogen

Hydraulic export
Soil organic carbon
Soil saturation*

Soluble phosphorus

Hydraulic export
Topography

Organic material

Hydraulic export
Topography

* This would not be compensated for land drainage activity since this is an existing land use (ie Module B) and, in addition, it could not easily be addressed at this resolution.

Module B - Existing land use

This would allocate grid cells to the following land use types:

Cultivated
Improved pasture
Unimproved pasture
Woodland
Urban
Inland water

Cultivated land would be further sub-divided into crop type to assist in the determination of contaminant inputs to land and to produce distributions of:

o evapo-transpiration rates (to refine the hydraulic export grid in Module A)

o erosion hazard due to existing vegetation type

o nitrate leaching hazard due to existing vegetation type

Information on land use and crop types would be obtained from the most recent annual MAFF Census.

Module C - Existing contaminant inputs

Nutrients

Nitrogen would be estimated as mass loadings from inorganic fertilisers and livestock wastes, without consideration of form. Phosphorus would be estimated in the same way.

Estimates of inorganic fertiliser application rates would be obtained from the Farmstat database for major crop types, and combined with information on crop distribution to yield information on loadings. Estimates of livestock waste production would be obtained from annual MAFF Census data on livestock, with estimates of waste output weighted by livestock type and age.

Organic material

This would be estimated as BOD and volumetric loadings from livestock waste production, derived as above.

Pesticides

Pesticides are different from other contaminants in that they are a collection of different chemicals with widely different properties, which fundamentally affect the hazard posed. A mechanism for standardising the measurement of hazard posed by their input (equivalent to mass for the other contaminants considered) is required. It is proposed that two hazard indices are used:

Drinking water hazard - this would focus on the properties of pesticides tending to cause high water column concentrations. Factors considered for each chemical would be:

o Usage (kg per grid cell)
o Environmental half-life
o Octanol-water partition coefficient (K_{ow})

Ecological hazard - this would focus on properties that would tend to cause: a) high concentrations in the water environment; and b) high probability of ecological impact, through toxicological considerations. Factors would be:

o Usage
o Environmental half-life
o K_{ow}
o Toxicity (probably acute for standard fish and invertebrate species)

It should be noted here that K_{ow} plays a dual role is assessing risk. On its own, this parameter indicates relative mobility, ie the risk of leaching from the soil and contaminating the water column. In this case, a high K_{ow} indicates high mobility and therefore high risk. However, in conjunction with a measure of erosion risk (from Modules A and B), K_{ow} indicates the risk of contamination by sediment-bound pesticides. In this case, a low K_{ow} indicates a high propensity for sorption to soil particles and therefore high risk.

Both indices would operate by combining information for each chemical into hazard ratings, then summing individual chemical ratings to produce overall hazard index values for each grid cell. Information on pesticide application rates would be obtained from the FARMSTAT database and combined with information on crop types from the MAFF Census to yield information on pesticide usage. Information on the properties of individual chemicals would be collated from a variety of sources.

Module D - Receiving water quality

Information on Water Quality Objectives and current water quality (chemical and/or biological) would be valuable for comparing the likelihood of contamination with the vulnerability of the watercourse. The risk tool could be equipped with a facility to classify the river network according to given class designations, be they SWQOs or existing water quality. Display of SWQOs would not be possible in the short term since they have not yet been designated. Spatial representation of the river network according to river quality class is, however, currently possible. The classified river reach network would need to be available in digital form in order to represent class designations with the system.

A2.5 Assessment of existing overall risk

A2.5.1 Sediment

Two risk assessments are envisaged, differing in terms of the degree of detail used on existing land use.

1) Empirical combination of: a) land vulnerability to sediment loss (Module A); and b) erosion hazard from existing cultivated land (Module B). This is a relatively stable pattern of risk with respect to time, which does not consider crop type.

2) Empirical combination of: a) land vulnerability for sediment (Module A); and b) erosion hazard from existing crop distribution (Module B). This pattern of risk will change considerably from year-to-year where crop rotations are used.

A2.5.2 Nutrients

Nitrogen

Nitrogen in the dissolved and particulate phases would be considered separately, although it is recognised that the former phase is likely to be the most important transport mechanism.

1) Empirical combination of: a) land vulnerability for soluble nitrogen export (Module A); nitrate leaching hazard from existing crop distribution (Module B); and c) nitrogen loading (Module C).

2) Empirical combination of: a) land vulnerability for sediment loss (Module A); and b) nitrogen loading (Module C).

Phosphorus

Phosphorus in the dissolved and particulate phases would be dealt with separately, although it is recognised that the latter phase is likely to be the most important transport mechanism.

1) Empirical combination of: a) land vulnerability for soluble phosphorus export (Module A); and b) phosphorus loading (Module C).

2) Empirical combination of: a) land vulnerability for sediment loss (Module A); and b) phosphorus loading (Module C).

A2.5.3 Organic material

Risk would be derived from the combination of: a) Land vulnerability to organic material export (Module A); and b) livestock waste loading (Module C).

A2.5.4 Pesticides

Pesticides in the dissolved and particulate phases would be dealt with separately. However, the importance of sediment-bound pesticides to drinking water hazard is considered negligable for the purposes of this risk assessment.

1) Empirical combination of: a) land vulnerability to soluble pesticide export; and b) drinking water hazard index.

2) Empirical combination of: a) land vulnerability to soluble pesticide export (Module A); and b) ecological hazard index (Module C).

3) Empirical combination of: a) land vulnerability to sediment loss; and b) ecological hazard index (Module C).

A2.5.5 Consideration of receiving water vulnerability

The distributions of risk produced for each contaminant type would be compared with receiving water vulnerability (Module D) by spatially overlaying datasets. Visual or computer-aided inspection could then be made of coincidences of high pollution risk and high receiving water vulnerability.

A2.6 Data sets required

The spatial data sets that would be required for the national/regional scale GIS risk assessment tool are given in Table A2.1.

A2.7 Interactive use

Apart from the standard outputs described in Sections A2.4 and A2.5, the system could be used as a basic information source on land management for active interrogation. Areas conforming to specific criteria could be located by the application of logical expressions to the system. In this way, the basic modules could be 'tuned' by the user to respond to predicted or 'what-if?' scenarios. Tools for logical query would be included to enable such expressions to be built up by the user from any combination of database elements.

One specific application of this facility would be the identification of potentially suitable areas for buffer zone establishment across England and Wales. This would be based upon the distribution of pollution risk (for different contaminants) and factors affecting retention efficiency within buffer zones (hydrology, slope, soil type, temperature, etc.). Such an investigation would, however, be constrained by current knowledge of buffer zone function and the spatial resolution of the data sets. Regarding the latter point, the distribution of land-drainage systems (an important constraint on buffer zones) would not be assessable at this scale, and the topographical data set would be too coarse to properly account for the effect of landslope on buffer zone function. Such factors could, however, be better quantified at the catchment scale (see Section A3.4).

Table A2.1 Spatial data sets required for national/regional risk assessment.

Spatial datasets required	Source
Time-independent hydraulic export vulnerability framework	
Elevation, slope, aspect)	Derived from 1:250,000
River network)	Bartholomews digital
Catchment boundaries)	contour data
Average Annual Rainfall	Met. Office
Rainfall energy	Met. Office
Soils: Average water content	SSLRC
Standard Percentage Runoff (SPR)	SSLRC and IoH
Base Flow Index (BFI)	SSLRC and IoH
Time-dependent hydraulic export vulnerability framework	
Land use	MAFF Agric Census
Contaminant modules	
a) Organics	
Livestock numbers by age/size	MAFF Agric Census
Potentially available land for spreading	MAFF Agric Census
b) Pesticides	
Crop types	MAFF Agric Census
Contemporary pesticide usage	Farmstat
Soil chemistry (carbon content)	SSLRC
Soil surface depth	SSLRC
Soil bulk density	SSLRC
Average soil water content	SSLRC
c) Nutrients	
Crop type	MAFF Agric Census
Contemporary fertiliser usage	Farmstat
Livestock numbers by age/size	MAFF Agric Census
d) Soil solids	
Soil erodability classes	SSLRC
Land use	MAFF Agric Census
Receiving water	
Digitised network of river reaches	Availability unknown
Biological and chemical river quality	NRA
SWQO designations for classified reaches	Not available now but could be added later

A3. CATCHMENT-SCALE RISK ASSESSMENT

A3.1 Objective

The 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 NRA and MAFF, and local discussions with either local ADAS staff or farmers.

The system would enable field-level analysis of a single farm, catchment or group of catchments in isolation. As specific areas are examined, the database would expand to form a seamless regional database which would allow subsequaent analysis of the whole or any sub-area.

A3.2 Options

Two options have been identified, from which a selection needs to be made. Selection will largely depend upon the objectives of the NRA in relation to local land management. Options are as follows:

1) A steady-state tool, providing a relative risk assessment of land cells but with no quantification of contaminant loads to receiving waters.

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. Optimisation of detailed agricultural practices (e.g. tillage practices, crop selection, pesticide application methods), to balance environmental benefits against farm income, may be possible.

A3.2.1 Option 1 - Steady-state tool

This tool would be GIS-based as per the national/regional scale tool, and would consist of the same modules, but would operate on higher resolution data (see Table A3.1), using a grid size of 30-100 m, and incorporate the following additional features:

- Land use information would be interpreted from satellite imagery obtained three times a year, in order to improve the accuracy of annual updates. A more detailed classification would be used and this would be customised for the catchment to reflect the local range of land uses. Livestock numbers from the agricultural census would be distributed evenly over appropriate land classes to assess contaminants loads.

- Distance to receiving water along overland flowpaths generated from an elevation grid and slope shape/aspect would be introduced as a factor in Module A (time-independent land vulnerability to contaminant export).

The tool would not deal with information on detailed agricultural practice (e.g. tillage, time of sowing) and would not seek to compare management options. It would simply highlight areas (at the field level of detail) where attention on management practices needs to be focused, based upon the characteristics of the land, the crops being grown and the loads being applied. The benefits of altering management practices (if required) would not be predictable using this type of approach; post-implementation water quality monitoring would have to be undertaken to detect improvements. Within identified high risk areas, the applicability of specific low-risk practices could be assessed using separate agricultural management tools, incorporating economic considerations.

As for the national system, structure query tools for active interrogation of the database would be provided.

Table A3.1 Additional spatial data sets required for the catchment-scale tool (both options).

Spatial datasets required	Source
Transport framework	
Elevation, slope, aspect)	Derived from 1:50,000
River network)	OS digital contour
Catchment framework)	data to 50m grid
Landcover	Landsat 30m
Soils: Water content	SSLRC 100m
Standard Percentage Runoff (SPR)	SSLRC and IoH 100m
Base Flow Index (BFI)	SSLRC and IoH 100m
Time-dependent hydraulic export vulnerability framework	
Land use	Landsat 30m
Contaminant modules	
a) Organics	
Potentially available land for spreading	Landsat 30m
b) Pesticides	
Crop types	Landsat 30m
Soil chemistry (carbon content)	SSLRC 100m
Soil surface depth	SSLRC 100m
Soil bulk density	SSLRC 100m
Soil water content	SSLRC 100m
c) Nutrients	
Crop types	Landsat 30m
d) Soil solids	
Landcover	Landsat 30m

A3.2.2 Option 2 - Dynamic modelling

This option would probably consist of a suite of suitable models (see Table A3.2 for options) operating under a front-end pre-processor. Candidate models would have to be properly tested before a decision could be made concerning the final choice. Each model comprising the suite would consider only one of the four different contaminant types. The models may need to be interlinked so that the output of one model can feed into the input of another. The tool would use essentially the same data sets as Option 1 (some would be of a higher temporal resolution), and would quantify contaminant transport processes to estimate loads to receiving waters. The loading estimates could then be used as input to existing hydrological models that can predict receiving water quality. The models used would not be complex and may even be screening models in some cases. The main reason for choosing a reduced level of complexity is consideration of the available data which would be required.

The suite of models could also contain an economic module that would allow land management options to be optimised on the basis of agricultural cost and economic benefit of improved water quality. Land management as detailed as tillage options might be considered, at least for transport of sediment and sediment-bound contaminants. A number of research projects are currently under way in the UK to establish the relationships between income loss through reduced crop yields and economic benefit of reduced water contamination. However, owing to the wide range of management options available and the high degree of dependence of run-off quality on the options chosen, a comprehensive economic module is likely to be complex and data intensive. Optimal management solutions could be discussed with MAFF, ADAS or individual farmers in relation to existing agricultural practice.

Table A3.2 Candidate models for catchment-scale option 2 (dynamic modelling).

Model subject	Candidate models
Runoff	HYRROM ; AGNPS ; CREAMS ; HSPF
Organics	FARMS
Nitrogen	NO3 ; BEAVERSOFT ; AGNPS ; CREAMS ; HSPF
Phosphorus	MINDER ; AGNPS ; CREAMS ; HSPF
Pesticides	Jury/Focht/Farmer ; CREAMS ; RUSTIC ; HSPF
Sediment	USLE ; AGNPS ; CREAMS ; HSPF

A3.3 Discussion of catchment-scale options

Option 1 is a basic screening tool for risk, directing management attention at specific areas on the farm where attention to existing management practices should be focused as a priority. It also provides basic information to guide management decisions. Unlike Option 2, there would be no consideration of how specific agricultural practices (e.g. tillage, application methods, etc.) affect risk, apart from crop selection. Decisions on which practices to adopt in high risk areas will therefore be judgemental or based upon separate farm management (including economic) tools; such tools could, however, feed off the spatial datasets within the GIS system envisaged.

Option 1 would enable field-level analysis over an extensive area whilst option 2 would be restricted to smaller areas (e.g. large farms or sub-catchments) due to the additional cost of assembling time-series data. This option could also be used as a basic information source on land management for active interrogation. Areas conforming to specific criteria could be located by the application of logical expressions to the system, as with the national/regional analysis, and would provide information of sufficient accuracy for farm-level management options to be assessed.

Option 2 allows the effects of possible detailed practices to be inferred from changes in predicted contaminant transport. The benefits of using a low-risk practice can therefore be demonstrated more objectively, although accurate prediction of effects is constrained by current knowledge of contaminant behaviour, In addition, management scenarios can be objectively tested in terms of cost-benefit, considering agricultural economics and environmental effects.

One specific area in which interactive use of the steady-state GIS option (Option 1) could be applied is the identification of areas within a targeted catchment that are most suitable for the establishment of buffer zones, in terms of both pollution risk and the major factors affecting their retention efficiency. This could be accomplished using the distribution of risk for different contaminants as described previously. Additional factors that affect buffer zone efficacy (slope, hydrology, soil type, etc.) could also be included. The distribution of land-drainage, a key factor affecting buffer zone efficacy, could potentially be mapped at the catchment/farm scale through the use of aerial photography. However, this is likely to be expensive compared to other datasets mentioned, requiring manual interpretation of available photographs.

A4. OUTLINE COSTS OF RECOMMENDED RISK ASSESSMENT TOOLS

A4.1 Summary of costs (£)

	National	Catchment	
		Option 1	Option 2
Staff	78,013	102,475	105,840
Datasets (year 1 only)*	9,550	9,275	9,275
Computing	7,000	7,000	7,000
Travel and subsistence	1,500	1,500	1,500
Report production	1,500	1,500	1,500
TOTAL	**97,563**	**121,750**	**125,115+**

* Excludes cost of FARMSTAT data on pesticide and fertiliser usage, which will need to be negotiated separately.

+ If an economic module needs to be incorporated, the cost of bought-in services will need to be added. This will cost in the region of **£40,000**.

D4.2 Breakdown of data costs

a) National assessment

(These costs are based on a geographic coverage of England and Wales)

Dataset	Supplier	Year 1 cost	Annual maintenance
Contours (1:250k)	Bartholomews	1,500	500
Rivers (1:250k)	Bartholomews	600	200
Annual rainfall	Met Office	800	0
Annual rainfall energy	Met Office	800	0
Soils (5km grid)	SSLRC	600	200
HOST key, per soil dataset	SSLRC	250	0
Land Use (2km census data)	Edinburgh Univ	5,000	5,000
Fertiliser & pesticide usage	FARMSTAT	TBN	TBN
TOTAL		**9,550**	**5,900**

TBN To be negotiated

b) Catchment level (both options)

(These costs are based on the average cost for a square 50x50km area)

Dataset	**Supplier**	**Year 1 cost**	**Annual maintenance**
Contour data (1:50k)	Ordnance Survey	600	100
Annual rainfall	Met Office	200	0
Annual rainfall Energy	Met Office	200	0
Landsat imagery (3 dates/yr)	EOSAT	5,625	5,625
Soils 100m grid	SSLRC	2,400	800
HOST per soil dataset	SSLRC	250	0
Fertiliser & pesticide usage	FARMSTAT	TBN	TBN
TOTAL		**9,275**	**6,525**

TBN To be negotiated

A4.3 <u>Notes on costs</u>

a) Hardware/software

Costs are based on the use of workstation ARC/INFO for the data pre-processing, and the customisation of an appropriate package for the final product. The cost of hardware and software that would be required by the NRA to run the system are not included.

b) Data supply and pre-processing

All data for the national-scale tool would be supplied pre-loaded into the system. Data covering a test area of 100x50km would be provided with the catchment-scale tool. Catchment-scale data for areas targeted for further attention by the national assessment tool would have to be supplied as and when required.

All data pre-processing would be undertaken prior to delivery of the system, the full costs of which are included.

c) Data update

Data maintenance costs are based on an annual update of those datasets where new information is available on this timescale, i.e. MAFF agricultural census data and satellite image land use classification. The costs of data maintenance could be reduced considerably if land use data sets were updated less frequently than this. However, the timescale for detecting changes in risk would inevitably be increased.

Long-term update of other datasets would be carried out as they become available from the suppliers. The annual update costs for data and data pre-processing include an element for the long term update of other datasets.

d) Staff costs

These include data pre-processing, programming, system testing, user testing and acceptance, and documentation. They do not include implementation training and software maintenance.