Interim Report R&D Project 001

SOURCES OF FARM POLLUTION AND IMPACT ON RIVER QUALITY

WRc plc

August 1991

R&D 001/2/W

SOURCES OF FARM POLLUTION AND IMPACT ON RIVER QUALITY

C P Mainstone, G Rutt, T Pickering, D Woodrow, A D Bascombe and C Turner*

* University of Wales

Research Contractor:
WRc plc
Henley Rd Medmenham
PO Box 16 Marlow
SL7 2HD

National Rivers Authority
Rivers House Waterside Drive
Almondsbury Bristol BS12 2UD

NRA Interim Report 001/2/W

Publisher
National Rivers Authority
Rivers House Waterside Drive
Almondsbury Bristol BS12 2UD

Tel: 0454 624400
Fax: 0454 624409

First Published 1991

Dissemination status

Internal: Released to regions
External: Restricted

Research contractor

This document was produced under R&D Contract 001 by:

WRc plc
Henley Road Medmenham
PO Box 16 Marlow
SL7 2HD

Tel: 0491 571531
Fax: 0491 579094

NRA Project Leader

The NRA's Project Leader for R&D Contract 001:

F Jones - Welsh Region

Additional copies

Further copies of this document may be obtained from Regional R&D Co-ordinators or the R&D Section of NRA Head Office.

CONTENTS

CONTENTS continued

CONTENTS continued

CONTENTS continued

CONTENTS continued

CONTENTS continued

SUMMARY

The impact of livestock farming on river quality is an increasing cause of concern in the UK and elsewhere. There is an urgent need for simple field appraisal techniques that allow the rapid application of control measures. On strategic and political levels, the distribution of farm pollution problems needs to be defined in order that attention can be focused on the worst affected areas. This report details work undertaken in the period April 1990 to March 1991 under NRA project references A3.001/A3.012. The work is of direct benefit to the NRA for the strategic planning of farm pollution control at both the national and local level.

A simple farm pollution indicator key, based on the presence/absence of invertebrates and sewage fungus, has been produced which is being tested on a large scale monitoring programme in West Wales. The feasibility of its use by non-specialists is being investigated, and it is envisaged that pollution control staff could apply it to the rapid identification of problem areas/farms. A protocol for developing indicator keys for areas other than Wales is being produced.

The national assessment exercise has used a Geographical Information System to identify hotspots of livestock farming activity. The distribution maps produced provide a means of focussing attention on the farm pollution problem and also of identifying areas where the application of the indicator key approach might be most appropriate.

The literature review has highlighted the lack of centralised governmental involvement (catchment legislation, waste management, levies and incentives) in farm pollution issues compared to other European countries and elsewhere.

KEY WORDS

Farm, livestock, pollution, water quality, invertebrates, pollution risk, national assessment, pollution control.

NRA Interim Report 001/2/W

LIST OF TABLES

LIST OF TABLES

LIST OF FIGURES

LIST OF FIGURES continued

1. INTRODUCTION

The WRc farm pollution research programme was initiated in 1987 in response to widespread concern over the increasing number of reported farm pollution incidents nationwide. In collaboration with the water authorities, a catchment study was set up in tributaries of the Eastern Cleddau, West Wales, to investigate the impact of intensive dairy farming activities on the chemical and biological quality of rivers. Findings of this study have been reported in WRc progress reports PRS 2016-M and PRS 2347-M.

The funding of farm pollution research was taken over in 1989 by the National Rivers Authority (NRA), who have extended the scope of the work to provide nationally applicable tools for farm pollution assessment and control. The research is primarily targeted at the problems arising from organic farm wastes originating from livestock farming.

This document outlines the programme of work agreed between the NRA and WRc, and reports fully on the work undertaken between 1 April 1990 and 31 March 1991. This includes work previously reported in the first interim report, NR 2603.

2. OBJECTIVES

The overall objective of the agreed work was:

To develop biological methods for the detection of organic pollution from farms and for assessing the effectiveness of remedial measures. Such techniques could be used to quickly assess the pollution status of streams over a wide area in order to target pollution control efforts.

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

(i) To identify through biological assessment the principal sources of organic pollution from farms and quantify their impact on water/biological quality and fishery status of receiving streams.

(ii) To identify farming practices causing pollution and assess the effectiveness of remedial measures using biological techniques.

(iii) To develop within the NRA a strategy, using biological techniques, for the future monitoring and control of the farm pollution problem.

3. WORK PROGRAMME

A number of areas of work were agreed to fulfil the objectives listed above.

3.1 Literature review

Information on the assessment and control of farm pollution would be collated and reviewed, taking into consideration international approaches to control.

3.2 National assessment of farm pollution

The nature, extent and distribution of farm pollution problems nationally would be assessed, considering the distribution of livestock farming activity, farm management practices and reported farm pollution problems. Regional pollution control practices would also be reviewed in order to provide information for the development of future strategies.

Information from the national assessment exercise would be computerised and analysed using a Geographical Information System (GIS) in order to identify catchments within the UK at greatest risk from farm pollution. This analysis would indicate areas within which the biological methods developed during this study could be used. Further, it would act as a general aid to the targeting of both resources and attention at farm pollution problems.

3.3 Development of sampling strategies

Field investigations would initially be undertaken in West Wales in order to develop a protocol for the development of simple biological indicator keys for the rapid assessment of farm pollution. Such keys would permit use by a wide variety of staff with a minimum of training, so that a large number of sites could be visited with relatively little invested effort. The applicability of the approach to other regions would then be tested by undertaking additional work in another NRA region. The principles established would then be applied elsewhere in the UK according to the results of the national assessment exercise.

3.4 Detailed investigations

From initial surveys using a provisional indicator key, impacted sites would be identified in order to investigate the specific farming practices causing pollution and the nature of the impact. Continuous water quality monitors linked to a telemetry system (METEORBURST) would be used at selected sites to enable comprehensive monitoring of pollution events, in addition to biological monitoring techniques.

3.5 Implementation of remedial measures

In conjunction with NRA pollution control staff, remedial measures would be implemented at the sites identified in Section 3.4, and monitoring would be continued to assess the effectiveness of these measures.

3.6 Salmonid recolonisation studies

A study of the recolonisation by fish populations of river stretches impacted by gross episodic farm pollution was initiated during the Eastern Cleddau catchment study, when there was a major fish kill in the Deepford Brook following a discharge of slurry. This work would be continued under the new work programme, since further monitoring was necessary. Such studies are important since they allow a more complete picture of the timescale of impact on aquatic communities caused by such catastrophic one-off problems.

3.7 Slurry transport studies

This work was also initiated during the Eastern Cleddau catchment study, and further work was considered necessary to obtain suitable baseline data on the transport and fate of pollutants following slurry spreading. These data would be utilised in models being developed to simulate run-off quality and assess the risk of slurry application to land.

3.8 Biological recovery of streams

A complementary study to Section 3.6, investigating the impact of episodic farm pollution on benthic invertebrate communities and the timescale of subsequent recolonisation, would be undertaken under sub-contract by the University of Wales.

4. LITERATURE REVIEW OF THE IMPACT AND CONTROL OF FARM POLLUTION

4.1 Introduction

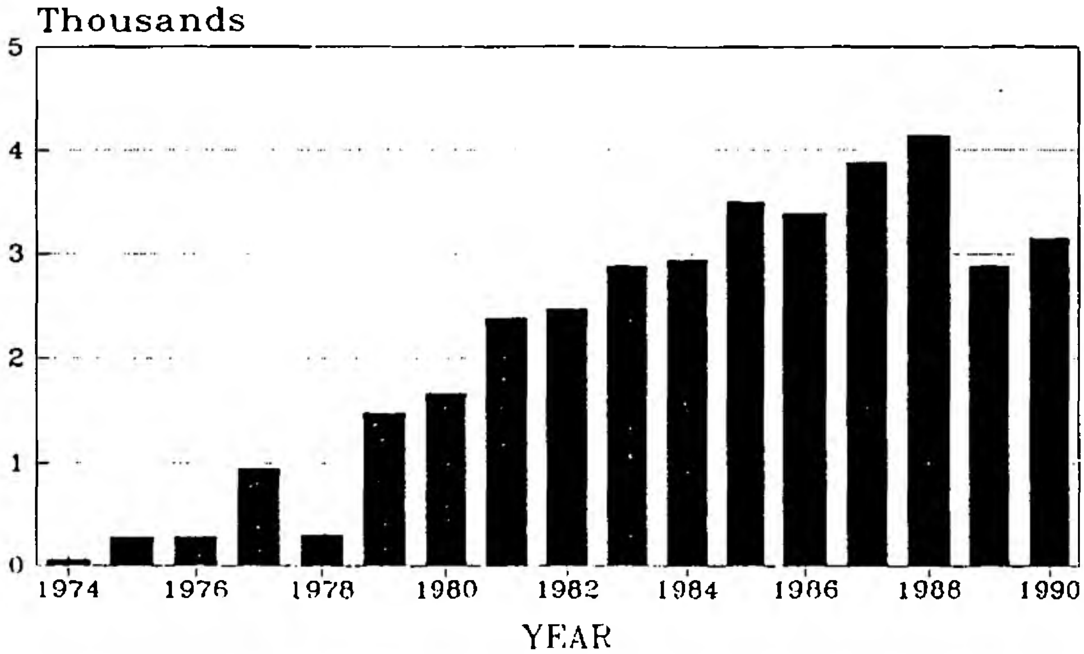
A broad assessment of the adverse effects of farm wastes on water quality has been previously presented to the NRA as WRc Report Nº PRS 2475-M. This subsequent report follows directly from these earlier findings, concentrating on the adverse effects of farm wastes from animal husbandry operations.

Agricultural non-point source pollution has been identified as a major cause of the failure to achieve water quality objectives (Sherwood 1986), and pollution from farm waste has been considered to exhibit one of the largest and most unwanted expansions (Freeman 1986). The number of farm pollution incidents has steadily increased over the last ten years, as illustrated in Figure 4.1 (Payne 1989). However, the last two years (1989 and 1990) have produced markedly lower numbers of incidents; since this has coincided with exceptionally dry weather it is uncertain whether this is due to improved farm waste management or climate.

With the increasing intensity of many agricultural activities, greater concern is being expressed over the impacts of these practices on water quality (Porter 1975). The effects of nitrate-based fertilisers, pesticides (eg Egboka *et al* 1989), silage (eg Beck 1989a) and animal waste disposal practices (eg Humenik *et al* 1987, Ritter 1988), are now being addressed as pollution problems. The contribution of agriculture to groundwater contamination is also receiving increasing attention (eg Bjerke 1989, Kovacs 1977).

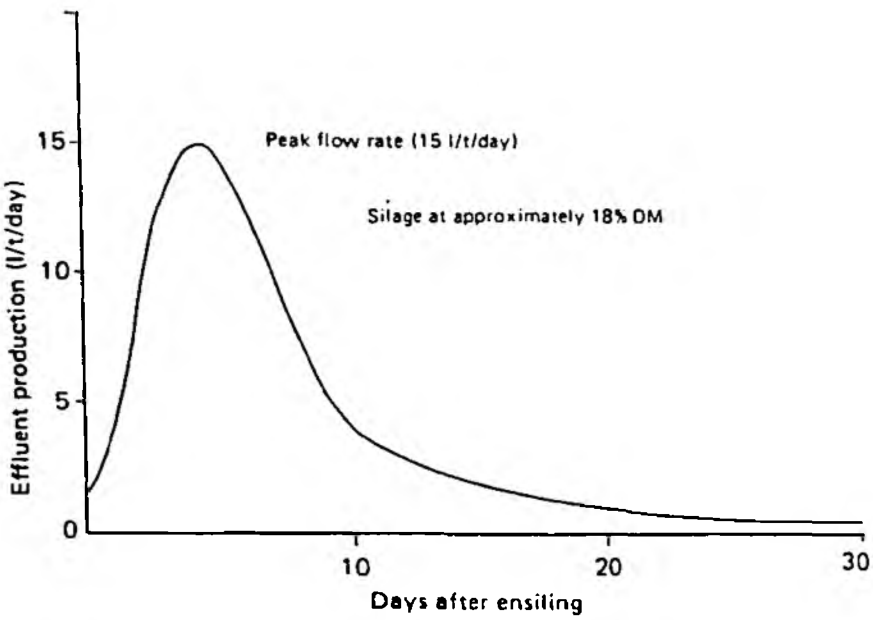
The intensity of agricultural activities in England and Wales has already been described on a region-by-region basis in WRc Report PRS 2475-M. Overall trends of note are a general decline in cattle stocks, with dairy farming concentrated in the west and south west of the country. Pig farming predominates in the Anglian and Yorkshire regions, and the steady increase (23%) of this activity in the latter region since 1980 is also of note. There is an overall increase in numbers of sheep throughout all regions, which has resulted in a nationwide increase of 31% since 1980. A steady rise is also evident since 1984 in the

Figure 4.1 Total numbers of pollution incidents caused by farm wastes in England & Wales, 1974-90.



Data from Payne (1989) and annual farm waste reports (eg NRA/MAFF 1990)

Figure 4.2 Typical production of liquor from a silage clamp (from MAFF 1984b).



number of agricultural holdings, although total area of agricultural land has increased less rapidly over this same period. Despite these overall changes, indicating a greater extensification of farming activity (through an increase in agricultural area), more concentrated stock densities within specific regions (for example, pigs in Yorkshire) have led to a greater intensification on a much more localised scale.

Variations between regions in the importance of different types of livestock farming have meant that farm waste pollution problems receive different levels of priority. Water quality issues associated with farm waste production in different regions are considered in Section 5.

4.2 Nature of farm wastes

4.2.1 General

Farm wastes are of a variety of types dependent upon their source. Each type of waste poses a number of problems to the aquatic environment through different chemico-physical, biological and bacteriological impacts. The major issues concerned have been generally addressed for the benefit of the farmer by MAFF (1985b), and pollution of surface waters is broadly considered. The general toxicity of pesticides and herbicides is addressed, whilst the impact of organic wastes is considered with reference only to their BOD levels. Different types of agricultural wastes are frequently described in this context (eg MAFF 1986b).

The major causes of pollution resulting from livestock wastes which are considered to pose a risk to surface waters are summarised below:

(i) BOD, which reduces dissolved oxygen levels in receiving waters, thereby killing aquatic life.

(ii) suspended solids, which can smother the riverbed and reduce light penetration.

(iii) nutrients, which may stimulate excessive plant growth (particularly phosphate, since this is normally growth-limiting in freshwaters).

(iv) ammonia, which is directly toxic to aquatic life (especially in the un-ionised form).

(v) metals, notably copper and zinc, which are toxic to aquatic life.

(vi) organic compounds (pesticides and oil-derived hydrocarbons), which are highly toxic to aquatic organisms.

The major sources of these contaminants are as follows:

(i) slurry;

(ii) parlour, yard washings and dirty water generally;

(iii) silage;

(iv) pesticides (including spent sheep dip residues);

(v) oil.

These sources are considered in greater detail below.

4.2.2 Slurry

Slurries and manures can provide a valuable resource to the farmer for the fertilisation of agricultural land, despite the tendency to perceive them more as waste materials, with ever greater quantities being produced (Neeteson 1989). This value mainly stems from the high quantities of nitrogen and phosphorus which are present within the slurry and which become available to plants after application to the land. The influence of slurry application on nutrient leaching losses has been investigated by numerous workers (eg Furrer and Stauffer 1986). The lowest nitrate losses occur from slurries applied to permanent grassland. However, it should be emphasised that leaching of nitrogen is dependent upon soil structure, moisture and the cropping system adopted.

The mean chemical content of different cattle slurries is illustrated in Table 4.1 (Suss 1989a). Typical BOD values for slurry are of the order of 10 000-36 000 mg l^{-1} (Mann 1975). This represents a more concentrated waste product than human sewage, but one which is normally disposed of by application to the land without treatment. Often, large quantities of slurry are stored for extended periods prior to disposal.

Table 4.1 - Mean chemical content of cattle slurry (Suss 1989a)

	Dairy	Mean value mixed farms	Bull-farms
Dry matter (%)	7.5	7.7	8.8
Org. matter (%)	74.9	74.9	78.2
NH_4-N	2.4	2.9	2.6
Total N	4.3	5.1	4.6
P_2O_5	2.0	2.1	2.1
K_2O	6.3	6.4	5.3
CaO	2.4	2.1	2.0
MgO	1.1	1.1	1.3

Slurries are also typically rich in ammonia, which is present at concentrations posing a significant toxicity threat to aquatic life. The solids content of slurries varies greatly according to the amount of dilution it receives, but solids inputs to rivers can cause blanketing of the stream bed and loss of microhabitat (Beck 1989a).

Slurry derived from intensive pig farming operations can pose a greater risk to water resources owing to the intensive nature of modern pig farming (producing large quantities in localised areas) and the high organic content of the slurry produced. Frequently, pig slurry has a lower solids content than cattle slurry owing to the foodstuffs used. It has also been shown to be rich in heavy metals as a result of their addition to foodstuffs as a bacterial regulator. Poultry slurries can be of an even more liquid consistency and are likely to require drying before application to the land owing to the large volumes produced by intensive operations.

4.2.3 Yard and parlour washings

Large quantities of water are used in processing and cleaning on farms, and this is particularly so in the case of the dairy industry. These activities inevitably result in large quantities of waste water being produced which can have a high organic content. This problem is further compounded by the increasing tendency towards ever more intensive agricultural operations. An increased economy of water use has often been cited as an immediate measure to reduce risk to waters, as well as the implementation of biological treatment measures where risks remain high.

In addition to dirty water arising from farming activities, rainfall gives rise to run-off from farm yard areas; this can pose a particular problem since it is unplanned. The separation of "clean" waters from roof runoff and "dirty" waters from contaminated yard and parlour areas is therefore an essential step in the design of any farm management strategy.

4.2.4 Silage

Silage liquor is an acidic organic liquid waste with typical BOD values of the order of 30 000-80 000 mg l^{-1} (MAFF 1987). The highly concentrated nature of this waste poses a severe threat to the aquatic environment as only a small trickle entering a watercourse can result in severe pollution. The adverse effects of silage effluent upon receiving waters are of major concern and farmers have been made aware of the associated risks through numerous guidelines and recommendations (eg MAFF 1984b).

The production of silage effluent from a typical silage clamp is illustrated in Figure 4.2. Peak flows of around 15 litres per tonne silage day^{-1} occur 3-5 days after ensiling. However, the magnitude of liquor production varies with the moisture content of the grass at the time of ensiling. Wilting, which results in a drier silage, therefore reduces liquor production and consequently pollution risk, but the prevailing weather conditions in the UK and the need for several early silage cuts means that cut silage will never be completely dry and a liquor will always be produced. Wilting to 25% dry matter has therefore been recommended (MAFF 1985b). Protection from rain-water must also be an important consideration, as additional dilution after ensiling will directly increase the quantity of liquor that can be produced, and therefore increase the degree of pollution risk. Clear definitions are required for the controlled disposal of silage liquor. The discharge of silage effluent can only be undertaken with the written consent of the NRA, and the usual requirement is for BOD to be less than 20 mg l^{-1}. Whilst discharge requirements cannot be relaxed to prevent the storage of large quantities of silage, the quantity of liquor produced can be reduced by minimising the dry matter content of cut silage by cutting during suitable weather, and ensuring its isolation from rain-water during storage (Nielson 1990).

The introduction of milk quotas and MAFF advisory leaflet advice have encouraged a recent increase in silage production to reduce costs. Whilst it is known that efficient wilting can reduce (and virtually eliminate) silage liquor, and is often a practice favoured by farmers, this is not always possible due to unfavourable weather conditions. Silage pollution is most commonly caused by the inadequate design and failure of storage facilities. Allcock (1989) suggests the adoption of additional external peripheral drains for silage clamps. Prevention of silo floor leakage by the use of hot-rolled asphalt rather than concrete has also been suggested as an improvement (Beck 1989b).

Schua (1970) has considered the effects of discharges from fermentation silos and the threat posed to water quality from increasing volumes of silage liquor, outlining the danger to receiving waters and sewers. These problems were considered to be most serious during peak production periods in summer.

Littlejohn and Melvin (1987) have considered the pollution threat of phenols originating from silage on surface water quality. These effects are more often encountered from sheep dip sources but are also associated with grass fermentation processes.

4.2.5 Pesticides

Pesticides are directly toxic to organisms, and therefore pose a significant threat to aquatic organisms by their entry into surface waters through spillage, surface runoff or unsafe disposal. The general impact of pesticides on water quality is being addressed in a separate WRc study (Project ref A10(90)2), while the specific impacts associated with the use of sheep dipping materials are being considered in a continuing WRc study (A19.53).

A major problem encountered when investigating the adverse impacts of pesticides on water quality is that effects can often occur while the pesticides themselves are present at concentrations lower than the accepted level of detection (Walker and Porter 1990). Furthermore, information on the toxicity and environmental hazard in surface waters of pesticides is often incomplete, owing to the large number of compounds widely used, and the rapid rate of development of new compounds by the industry.

4.2.6 Heavy metals

Heavy metals pose significant risks to water quality when present in high concentrations. Sources of heavy metals include slurries, notably those of intensive pig and poultry operations where metals (especially copper and zinc) are incorporated into animal food supplies as bactericides (MAFF 1986a). Van Erp and Smilde (1989) have considered the risk of contamination of waters from excessive application of slurries containing copper, zinc and cadmium, and concentrations are presented in Table 4.2. Fleming (1989) has discussed the problems associated with the application of pig slurry to grassland. At regular rates of application, copper and zinc in particular were found to accumulate at the soil surface. This has been considered in some areas to pose a secondary danger to grazing sheep (eg MAFF 1985b) as well as a potential problem for humans where application is to arable crops or where waters within the catchment are abstracted (Joseph and Clark 1982). McGrath *et al* (1983) have considered seasonal variations in the metal content of sheep livers, concluding that where slurry is spread there is a risk of contamination to grazing animals.

Table 4.2 - Copper, zinc and cadmium levels in slurry (from Van Erp and Smilde 1989)

	Cd	Zn (g/100 kg manure)	Cu
Cattle slurry	0.03	5	3
Pig slurry	0.07	38	22
Chicken slurry	0.11	64	18
Chicken manure	0.35	205	57
Broiler manure	0.41	218	68

4.2.7 Hydrocarbons

Hydrocarbons can cause serious problems in surface waters by preventing the exchange of oxygen across the water surface. Such effects can cause catastrophic local impact upon aquatic communities, and necessitate expensive remedial operations if large quantities enter a watercourse. Fuels and oils are often stored in large quantities on farms, and pose a particularly high pollution risk where storage facilities are unbunded, or where spillage or leakage occurs during filling operations.

4.3 Sources of water pollution

General risks to surface water quality posed by farming activities can arise from a wide range of sources. Poor quality farm building work, and the inadequate supervision of farm workers have been considered to be factors of importance in increasing the potential for water pollution. These risks are often exacerbated by the occurrence of unexpected weather conditions, for which inadequate planning has been made.

Agricultural activities involving wastes which pose a risk of water pollution can be broadly divided into three phases: storage, treatment and disposal. These three phases are discussed separately below.

4.3.1 Storage

Major risks posed through the storage of agricultural wastes arise as a result of the following factors:

(i) lack of separation of clean and dirty waters in mixed drainage systems, leading to the production of larger volumes of liquid wastes;

(ii) inadequate storage capacity;

(iii) deliberate breaching of the embankments of full slurry lagoons in an attempt to allow the supernatant to escape;

(iv) building overflow pipes on effluent tanks;

(v) the sudden collapse of lagoon embankments, manure storage walls or silage clamp walls;

(vi) cracks in silage clamp floors;

(vii) clamps with rubble floors sited over land drains.

(viii) silage stored outside of silage clamps or bales.

With increasing agricultural intensity, there is an increasing trend to provide capacity on the farm to store ever greater quantities of silage and agricultural wastes. In the case of silage, the increase in pollution risk due to larger quantities is being partly offset by the trend towards big-bale storage. However, in general the standard of construction and maintenance required of storage facilities will be more important in the future if larger quantities of farm wastes are to be contained. The new regulations on the storage of slurry, silage and fuel oil (DoE 1991) set minimum standards for storage facilities and are a useful development.

Ensuring an adequate period between silage cuts enables the percentage dry matter to be maintained within silage, and should be encouraged as a lower volume of liquor is produced. The selection of a suitable site for storage, and the efficient design, maintenance and management of clamps and silos are vital for the prevention of accidental spillage. The use of enzyme additives to encourage fermentation of ensiled matter has also been considered (Neilson 1990). The practice of bankside storage should be actively discouraged, as the proximity to waters considerably increases the likelihood of accidental spillage.

With the increasing quantities of materials stored in the UK, there is clearly a greater need for tightened control over the prevention of spillage. A greater emphasis should be placed on the prevention, rather than the amelioration after the event, of the adverse effects of stored wastes on water quality.

4.3.2 Treatment

The treatment of farm wastes is not a widespread practice in the UK farming industry. Treatment to produce a less hazardous end-product may allow a greater initial quantity of a waste to be handled at the farm, provide a smaller quantity of a less hazardous waste for disposal to the land, or produce an end product which can be profitable in itself (eg composting). In certain cases, such as for agrochemical wastes, treatment may be a necessary measure before safe disposal is permissible.

While the use of treatment facilities seems a potentially valuable method to manage the large amounts of waste produced by intensive livestock farming, in practice such treatment options are not only expensive to install and run, but are frequently overloaded, and in most cases poorly understood and maintained by the farmer. These problems mean that treatment plants, rather than providing a solution to farm waste management, can result in further pollution problems, particularly if the effluent is to be discharged to a watercourse. Treatment plants are also subject to failure, and if large volumes of wastes are being handled the pollution risk is high.

4.3.3 Disposal

In the majority of cases, the most frequently chosen disposal method for agricultural wastes is application to land. A range of equipment can be employed: travelling and static irrigators, conventional tanker systems or soil injection methods for the disposal of slurries and dirty water, and muck spreaders for manures. Animal wastes are a valuable source of nutrients, but there are a number of risks attached to land disposal practices and care is required to prevent water quality impacts.

The principal causes of water pollution from land disposal are as follows:

(i) over-application of slurry to the land, causing saturation and/or surface runoff;

(ii) the application of slurry to frozen soils;

(iii) application to steeply sloping land, to soils of low permeability, or to land adjacent to water courses;

(iv) application during periods of rainfall, especially when the land is at field capacity;

(v) disposal guns left unattended for extended periods;

(vi) irrigation pipes with leaks;

(vii) reliance on a neighbour's land for slurry disposal;

(viii) the deliberate emptying of slurry tankers into ditches.

Current guidelines tend to give rather vague recommendations for the minimising of the pollution threat posed by disposal methods, for example, the recommendation not to dispose 'close to' a stream (MAFF 1984b). The new draft Code of Good Agricultural Practice (MAFF 1991) gives slightly improved guidance, but there is a need for more precise advice and the development of waste management plans on individual farms, approved by the regulatory authorities.

The disposal of slurry to public sewer has been considered as a safe, although potentially expensive, alternative to land disposal (eg STW 1986). Guidelines produced for disposal to sewer included the enforcement of control by issuing a 'consent' to discharge upon receipt of a 'trade effluent notice' from the discharger, giving details including the premises, the operation producing the effluent, composition of the effluent and the volumes and times of discharge. However, discussion between the then National Water Council and NFU concluded that the application of farm wastes to land was preferable wherever this was possible and that the minimising of discharges to public sewers was to be favoured. It was considered important that silage liquor, sheep dip wastes, pesticides, herbicides, and petroleum and oil products should not be discharged to sewers.

Lenat (1984) has studied the effect of agricultural runoff on water quality and the effectiveness of recommended agricultural management techniques. Well managed and poorly managed catchments were compared with control sites in various geographic regions. Physico-chemical measurements showed that agricultural activity had an adverse effect on water quality but these influences could be minimised by good management practice. Differences found in the species richness of benthic macroinvertebrate communities indicated that erosion control could also mitigate the impacts of agricultural runoff. Poorly managed sites had the least stable benthic communities. Ephemeroptera, Plecoptera, Trichoptera and Coleoptera were considered to be the most intolerant taxa. Collector-gatherers, scrapers and filter feeders were considered to be most tolerant of agricultural runoff, suggesting that the addition of particulate organic matter augmented food supplies. Agricultural runoff was demonstrated to cause water quality changes which affected the stream biota, but this effect could be reduced by using recommended erosion control techniques.

The disposal to land of 'dirty water', ie effluent consisting of water contaminated with manure, urine, cleaning materials, crop seepage and other waste products (MAFF 1989f), has been described with reference to its polluting nature (MAFF 1989f,g,h). Probably the most important single preventative measure that can be taken by the farmer to prevent water pollution is the separation of clean and dirty water at source. The dilution of wastes from yard areas by rain water serves to increase the quantity of waste waters profoundly, causing increased problems of ensuring safe disposal. Remedial action is simple, often only requiring the installation of guttering to farm buildings and the isolation of this water from yard areas. This can clearly be implemented at minimal cost to the farmer, but is a measure which is not eligible for financial aid under the Farm and Conservation Grant Scheme, since it is deemed not to pertain directly to the prevention of pollution (as it relates to the handling of clean water rather than effluent).

The safe transport and handling of slurry prior to disposal to land are described for the benefit of the farmer in advisory booklet 2126 (MAFF 1985a). Considerable information is provided on the effective handling of these wastes, but the consequences of not following the advice given, however, the adverse effects of over-application and accidental spillage are considered separately in booklet 2200 (MAFF 1985b).

Soil injection of slurry offers an alternative which has a number of advantages over surface application. Hall (1986) has considered the status of soil injection research in the UK. An extensive research programme on soil injection has been carried out at WRc in order to find better spreading methods to prevent possible air and water pollution problems arising from surface spreading. Soil injection has been considered to be a means for meeting environmental quality objectives, as injection offers reduced disposal costs, better pasture hygiene, nutrient management and soil loosening. To an extent the quantity that can be injected is governed by land slope and soil moisture condition at the time of application:

Slope: The control of surface runoff demands safe injection on slopes without run-out from the cavity (made by injection) at the base of the slope. To facilitate this a maximum gradient of 13 degrees has been chosen, this being largely defined by steeper slopes not allowing the safe negotiation of tractor and tanker. Run-off can be controlled by the percentage of dry solids (ie the mobility) within the slurry applied.

Soil moisture: This factor is very much influenced by soil type. Most success has been established by injection in the spring on structured soils when they are in their most plastic condition. The moist surface soil layers and lower evapotranspiration rates of the crop allow satisfactory results for autumn injections.

The combination of slurry with animal litter provides a greater dry matter content, and therefore constitutes a lower pollution risk to receiving waters as pollutant mobility is reduced. Although in the UK there has been a tendency not to use litter in most animal housing, this is not the case throughout Europe, and the use of alternative litter types for dairy cattle has been considered (eg Peltola 1986).

4.3.4 General

MAFF advice concerning the storage and handling of slurry is considered to be inadequate for farms situated close to waters, on steep slopes, or within high rainfall areas. The absence of appropriate advice for farms in these conditions leads to the poor siting, construction and maintenance of such facilities. Overflowing and swamping of inadequate handling systems is frequently cited as a cause of pollution, resulting in the adoption by farmers of environmentally dangerous practices such as the deliberate breeching of lagoon walls to allow slurry seepage, and large-scale spreading operations being carried out in winter despite contrary MAFF advice. Inadequate knowledge therefore leads to insufficient care being taken and results in increased pollution risk.

4.4 Impacts of wastes on surface water quality

4.4.1 Physico-chemical effects

Middlebrooks (1972) has provided an account of the effects of agricultural practices on water quality, detailing increases in total solids concentrations, nutrients enhancement (notably phosphorus and nitrogen), temperature increases, and the effects of insecticides and herbicides.

Wallace (1971) has considered the inter-related variables determining the effects of land run-off on water quality in receiving streams and designed a computer model to estimate the effects of agricultural run-off on dissolved oxygen (DO) concentration in rivers. The relative significance of this type of pollution compared to discharges of municipal and trade waste waters was also considered. Results showed that existing waste water discharges have negligible effects on the DO concentration, but storm runoff was responsible for serious oxygen depletion. In the Iowa River it was found that concentrations of DO lower than 5 mg l^{-1} could extend for up to 75 miles along the river length, often lasting for periods of over 24 hours and recurring several times each summer.

Placido and Soldatini (1988) have investigated the Cornia river, Tuscany, Italy, a catchment characterised by non-intensive agriculture and an absence of industrial discharges. After studying its hydrology, sampling stations were set up above and below each confluence, and water quality parameters were determined. The results indicated that while dissolved oxygen was generally maintained at around saturation level, intermittent impacts associated with agricultural waste sources could result in a dissolved oxygen concentration as low as 23 per cent.

A number of farm pollution studies in the literature deal with livestock farming as a cause, either singly or in combination with other sources, of lake or reservoir eutrophication. Examples are the studies on a number of Irish loughs (John *et al* 1981), the **Canonsville Reservoir** in New York State (Brown *et al* 1989) and **Lake Okeechobee** in Florida (Flaig and Ritter 1989).

4.4.2 Bacteriological effects

Several investigations have considered the bacteriological effects of farm wastes on water quality. In such studies, the most useful microbiological parameters are considered to be faecal indicator bacteria. The bacteriological content of farm slurries has already been reviewed (WRc Report PRS 2484). Excreta from livestock has been highlighted as the most probable source of cryptosporidium in cases of suspected drinking water contamination (DoE/DoH 1990).

The microbiological monitoring of rivers and estuaries has not been encouraged within the UK, and management decisions about water quality have only infrequently required the results of bacteriological analysis (White and Godfree 1985).

4.4.3 Biological effects

Little information is available in the scientific literature on the effects of farm pollution on river biota. The WRc study on the Eastern Cleddau catchment provided valuable information on biological impact (Schofield and Bascombe 1990), and this has been continued during the present study (this report, Sections 6, 7, 8 and 10).

In Ireland, phosphorus enrichment of **Loughs Ennell** and **Sheelin** from inadequately treated sewage and pig slurry has caused inhibition of charophyte (stoneworts) growth and stimulation of other algae and macrophytes, leading to a contraction in the extent of important charophyte beds. Champ (1990) reports that nutrient levels in Lough Sheelin and the frequency of pollution incidents around the catchment increased through the 1970s due to a rapid increase in pig numbers (from 9000 to 50 000 fattening places). This led to the incidence of algal scums and enhanced growth of filamentous algae. By 1982, algal blooms were causing deoxygenation on a scale that restricted trout to the top 5 metres of the water column, whilst dead trout were observed on the lough bed. Low oxygen levels in cold hypolimnion water have been suggested as the cause of the disappearance of arctic char (Champ 1977).

Studies of the invertebrate fauna of Lough Sheelin (Blackwell and Convery 1983) indicated a virtual disappearance of the previously abundant mayfly *Ephemera danica*, and drastic reductions in the numbers of caddis-flies (*Phryganea* spp, *Mystacides* spp, *Leptocerus* spp, *Cloeon simile* and *Centroptilum luteolum*). By 1979, the main diet of 'rising' trout was emerging chironomids. An integrated catchment management plan for farm waste, instigated in the early 1980s (Section 4.6.7), is now allowing a recovery of the biological community, although signs of improvement were only recently observed.

Some of the most serious pollution incidents occurring in England and Wales are briefly described each year in the annual farm waste report (NRA/MAFF 1990), giving the total number of fish killed. The most serious incident occurring in 1989 was a rupture of an earthen-banked pig slurry store in NRA Anglian Region, where 3 million gallons of slurry killed 10 500 fish and produced measurable effects over a distance of 60 km. This is an extreme case, but numerous incidents occur each year where hundreds of fish are killed due to farm wastes entering watercourses and causing pulses of intense pollution.

It should be noted that incident statistics are summarised in the annual farm waste report into categories of 'serious' or 'minor', depending on whether an incident affects one or more of a variety of water uses; this means that it is not possible to extract information from the farm waste report on the scale of biological impact nationally (ie how pollution incidents generally relate to biological effect), since effects on the biota are combined with effects on other water uses. This is a serious drawback to the current format of reporting farm pollution incident statistics. Moreover, the farm waste report does not deal with chronic farm pollution, where biological communities may be continually impoverished without readily observable catastrophic effects.

An example of a targeted biological study is that on the **Wyre** (NRA North West Region internal report 1989) in NRA North West Region, where biotic indices (Biological Monitoring Working Party score, Average Score Per Taxon) indicated highly impoverished invertebrate communities at a number of sites (BMWP scores between 15 and 30, ASPT scores between 3 and 5) between 1987 and 1989. Active discharges from farms were found upstream of a number of impoverished sites; other sites with poor biological communities were likely to be recovering from episodic farm pollution events, which are unlikely to be discovered by pollution control staff.

The NCC has recently (NCC 1991) reported that in a selection of regions in England and Wales, 71 Sites of Special Scientific Interest (SSSIs) are known to have been affected by pollution from livestock wastes between 1986 and 1990. Of these, 19 sites were streams or rivers, 8 were ditches, 31 were lakes and 13 were mires. Seventy percent of sites suffered from slurry pollution, often from land run-off. In addition to these sites, another 16 SSSIs have eutrophication problems where livestock farm pollution is suspected. It should be noted that the true number of sites of high ecological interest affected by farm pollution is likely to be much higher than this for a number of reasons: firstly, owing to the difficulties of adequately protecting riverine SSSIs, the NCC has until recently restricted designation to only a few sites; secondly, the NCC report does not consider the whole of England and Wales; lastly, even within the regions considered, monitoring effort is not sufficient to cover all sites of concern.

4.5 Preventative strategies and remedial measures

There is a need for the development of appropriate preventative strategies and remedial measures for the control of agricultural non-point source pollution. Models which incorporate the determination of dissolved pollutant concentrations in run-off and estimation of pollutant delivery to surface waters are considered to be useful screening devices prior to the design of catchment management plans.

The choice of preventative strategy that can be applied is largely dependent on the risk posed by the waste concerned. Such strategies have therefore also been grouped according to the three waste management phases of storage, treatment and disposal.

The responsibility for the implementation of preventative measures originates with the farmer, who must be provided with both the necessary advice (through consultation and development of the code of practice), and the incentive (both in terms of awareness of the problem through education, and financial aid) to tackle the problem at source. Such measures need not be costly to be effective; for example, the covering of slurry storage tanks to prevent the ingress of rain-water (Mannebruck 1986), which can also reduce odour problems, should be encouraged.

4.5.1 Storage

The cost-effectiveness of a range of farm waste handling facilities has been addressed in a separate report (Brewer 1990). Recommendations for the design and location of farm waste storage facilities are detailed in a number of ADAS publications (MAFF 1987, 1989a,b,c,d,e). In these booklets it is stressed that careful consideration should be given by the farmer to avoiding pollution from manures and slurries, and a reminder of the pertinent legislation is found at the rear of each leaflet. The choice of facility depends upon the livestock type and nature of the slurry produced (MAFF 1989a). While the advisory guidelines are detailed within the code of practice, the farmer has until recently only been liable in the event of spillage, with no legal obligation to obtain approval for the adequacy of his storage facilities. The recent introduction of regulations to control pollution from farm storage facilities will largely redress this problem, although some of the required specifications now imposed fall short of the standards imposed on the continent (Sections 4.6 and 4.7).

4.5.2 Treatment

As stated in Section 4.3.2, the use of treatment facilities provides a potentially useful tool to the farmer for the disposal of excess farm waste material, given increasingly intensive operations and ever greater quantities of wastes being produced.

A wide range of systems has been developed for slurry treatment. Most trials, however, have proved disappointing and it is considered that as yet there is no system which is able to provide a final effluent which is suitable for safe direct discharge into a river. Two processes have been widely applied:

(i) **Anaerobic digestion** - This method produces a gas which has the potential of being a fuel source to the farmer given the appropriate facilities. Nevertheless, the cost of installation and operation of facilities able to make use of this fuel as yet outweigh the potential benefits and are not encouraging to farmers. Experimental units have proved to be both expensive and problematic (Hobson 1984). A high degree of supervision is required. Anaerobic digestion of slurries has not been widely employed and only about ten installations exist in the UK at present. However, when assessed as a pre-treatment for very dilute poultry wastes (Harper *et al* 1990), anaerobic treatment has proved effective. In contrast, anaerobic digestion is practised widely on the continent, in both small scale (individual farms) and large scale (communal) plants (Section 4.6).

(ii) **Aerobic systems** - These have been extensively researched in the UK, but WRc studies in 1975 yielded no encouraging conclusions (Beck 1989a). Barrier ditches have been used on a number of farms in the UK, but have not proved to be effective (Willets and Weller 1977). Aerobic systems have also been considered to be particularly problematic for the handling of poultry wastes (Riley 1988).

The use of reed bed systems for the treatment of concentrated agricultural wastes has been considered. Gray *et al* (1990) have assessed experimental horizontal-flow reed beds, considering the quality of agricultural wastes before and after their movement through the bed. It was concluded that the use of artificial reed beds would provide a potentially low-cost means of treating organic agricultural wastes with BOD levels up to 3000 mg l^{-1}, the resulting effluent being suitable for disposal to land but not to watercourses. The use of reed beds for the treatment of poultry manure wastes has also been shown to be promising, with up to 80% BOD removal efficiency (Vymazal 1990).

Aerobic treatment has been considered to be a viable option for the control of waste from intensive pig farming operations (ASAE 1966). Primary treatment of piggery wastes by lagooning may make such treatment more effective.

Poultry manure is problematical since water content can be high (depending upon waste management design). The dewatering of chicken manure by vacuum filtration, and the removal of moisture from poultry waste by electro-osmosis have therefore received attention (ASAE 1966).

Harrod (1989) has recommended that on-farm treatment be adopted for the control of farm wastes. This has the cost advantage of no initial transport requirements, although does little in itself to reduce non-point discharges. Integrated on-site treatment plants for piggery wastes are commercially available (Brown and Gibbs 1986). Guiver (1989), however, has indicated that farmers are not likely to employ on-site treatment unless methods are both foolproof and cheap, with few maintenance requirements.

An alternative to on-farm treatment is the establishment of treatment plants which serve a number of farms. Although not in use at present in this country, government-subsidised communal treatment plants are in operation in Europe (Section 4.6).

For the treatment of pesticide wastes, biological treatment methods are currently under investigation by at least one company but nothing has yet been published. Chemical treatment systems which can be transported by trailer are more advanced. The processes used include chemical flocculation, carbon adsorption and sludge settling. However, the cost of the treatment chemicals alone is reported to be equivalent to that of the pesticides used, and this is further enhanced by the additional cost of sludge disposal. For sheepdip waste, the mobile Sentinel plant is undergoing trials: blockage by solids in the waste is proving problematical, but may be overcome by initial screening. Chemical treatment of waste pesticides has been assessed by Johnson and Harris (1989). Since many pesticides are only partly soluble, flocculation of suspended matter followed by the use of activated carbon, for the removal of the relatively small amount of dissolved pollutants remaining, was recommended. Potential costs are nonetheless high, although this process is considered cost-effective for dealing with 'very difficult' toxic pesticides. Such treatment provides an effluent which may be disposed to public sewer. Only small amounts of solid waste are produced, so the cost of disposal to the waste contractor is low.

Waste materials otherwise disposed of are potentially useful as a fuel and therefore power, and power generation systems are commercially available (eg SCS Biotechnology 1989). The formation of integrated 'rural energy centres' which combine treatment and power generation has been considered by Locke *et al* (1985), with the responsibilty for the establishment of such centres obviously resting with agricultural organisations. Such projects represent potentially profitable business investments and are therefore areas worthy of further consideration by the farming community and NFU. Methanogenic fermentation (Klinger and Marchiam 1986) has been recommended as a solution for ecological problems involved with the accumulation of animal wastes, as well as providing a profitable end-product. Biofiltration (Noren 1986) has also been suggested, which has the advantage of reducing odours and ammonia volatilisation.

Harrod (1989) has considered the problems associated with straw based wastes due to their bulk when handling. There are advantages associated with the use of straw-based wastes in terms of pollution prevention, since the high proportion of dry matter makes them much less mobile and therefore less likely to gain access to watercourses. Composting represents an opportunity for farmers to obtain a profitable end-product from excess slurry production. While composting may represent too costly an investment for an individual farmer, it nevertheless may be attractive to a consortium of interested individuals. This approach has already proved to be successful in the Netherlands (Fane 1989, see Section 4.6). Kroodsma (1986) has illustrated a process for the composting of poultry manure. These products are normally treated like liquid manures, but when air dried and heated, were found to produce a dry, odourless manure of at least 55% dry matter, suitable for application to most soils. Gonzalez *et al* (1989) has further described options available for composting procedures. The introduction of these schemes, while potentially beneficial to the protection of waters, should, like 'rural energy centres', be the responsibility of the farming community and NFU.

Incineration of farm wastes is likely to become more feasible as technological improvements are made, but it is very unlikely that this will prove to be an economical or practical proposition in the foreseeable future.

4.5.3 Disposal

Disposal options are constrained by three factors:

(i) the persistence of the waste applied;

(ii) the mobility of pollutant constituents upon and within the soil;

(iii) the direct toxicity of those pollutants and the toxic effects of their degradation products.

Recommendations for the reduction of pollution risk during the disposal phase must therefore address each of these factors. With the exception of pesticides, the persistence of wastes does not pose a major problem, since most are highly biodegradable. However, most wastes are highly mobile and are therefore prone to direct run-off following their application to land. The main exception to this is manure, which has a much higher dry matter content.

The majority of farm wastes are highly toxic as has been already established in Section 4.2. The toxicity of pesticides is complicated by the occurrence of toxic breakdown products, which may present a greater hazard than the parent substance (both toxicity and persistence may be higher). Disposal options for the waste types of most concern are dealt with separately below.

Slurry

The efficient use of slurry (Suss 1989a) in land application requires care to be taken during both storage and handling. It is important that the farmer should maximise the fertiliser value of slurry, whilst minimising pollution risk. Nitrogen losses should therefore be kept to a minimum, and it may be necessary to treat the slurry before its application.

Farmers have a vested interest in ensuring a high soil retention of nitrogen from slurries when fields are dressed. Retention will be influenced by the methods of collection and preparation of the slurry, nature of the soil, land topography, slurry composition, application method, and the weather conditions during and after spreading. Besson *et al* (1986) have compared nitrogen losses from different slurry types when applied to the land. For cattle slurries losses were found to be greatest for methane digested slurries, with a better nitrogen retention from stored and aerated slurry.

The adverse effects of incorrect slurry application have been reviewed by Vetter and Steffens (1989). It was noted that their application was rarely optimal, often owing to the vast quantities that are produced from intensive agricultural production. The problems associated with incorrect application are numerous, and have been summarised in Table 4.3 (Hojovec 1989).

Table 4.3 - Problems of incorrect applications of slurry (Hojovec 1989)

Soil	Nutrient enrichment (phosphorus, zinc, copper, nitrogen and potassium). pH too high after the long-term use of large poultry slurry dressings. Salt accumulation in dry areas. Excessive loosening of soil after large applications. Compaction during wet conditions or by heavy slurry tankers. Anaerobiosis after incorporation to wet soils.
Crops	Yield decrease by over-fertilisation (eg lodging of cereals). Negative effects on plant quality (eg decrease in settled yield of sugar beet; decrease in starch content and keeping quality of potatoes, magnesium deficiency in green fodder and therefore diet of grazers after excessive potassium dressings). Increased weed competition. Negative effects on grassland sward composition. Scorching due to surface dressing, especially in hot conditions. Smothering of plants, especially after slurry dressings with high dry matter content. Risk of direct contamination (decrease in fodder intake by grazers and poor silage quality). Risk of spreading animal and plant pathogens.
Water	Groundwater pollution, especially nitrate. Nitrate, ammonium, phosphate, copper and organic enrichment from runoff; also enrichment following erosion of phosphorus and copper from soils, especially on steep slopes and bare compacted soils.
Atmosphere	Odour. Ammonia volatilisation, and other emissions.

The timing of application is also important in order to maximise nitrogen uptake by plants. The proportion of nitrogen lost due to leaching from slurry applied to grassland in different seasons has been calculated (Table 4.4, Archer pers comm). High losses sustained during the autumn and winter suggest that spring is the best slurry application time (Demuynck 1984); since plant growth is maximal at this time; however, it should be remembered that land is likely to be at field capacity during spring, so the risk of surface run-off is still high.

Table 4.4 - Percentage nitrogen lost to leaching from slurry applied to crops and grassland (Archer pers comm)

			Nitrogen leached expressed as % of total manure N applied	
			Arable	Grass
Farmyard manure	-	autumn	15	10
	-	winter	10	5
	-	spring	10	5
Cow/pig slurry	-	autumn	30	10
	-	winter	15	10
	-	spring	5	5

The timing of slurry production, as well as the timing of its disposal, is an important consideration; the practice of overwintering dairy cattle in animal housing, for example, will concentrate slurry production within small areas at this time, and should be considered when assessing disposal options.

It is often difficult to apply at rates lower than 15 m^3 ha^{-1}, although even this rate may be too high for the application of highly organically concentrated slurries such as poultry and pig manure (Vetter and Steffens 1989). It is therefore likely to be necessary to encourage the development of equipment which is capable of applying slurry at lower rates.

The timing of application is also important for dressing arable land in order to maximise the incorporation of nutrients within the soil, so that losses are minimised; for this reason, incorporation should be carried out directly following spreading. It has been recommended that spread slurry should be incorporated within the soil within 2-3 hours after application. Such incorporation should not involve the deep-ploughing of slurry, but benefits to the soil should be maximised by tilling the top 5-10 cm, thus making nutrients available to the roots of young crops. Gaseous losses are very low after such shallow incorporation. Soil compaction should be avoided through, for example, the use of low ground pressure tyres and umbilical supply equipment (Hann 1989) as this can cause plant damage through application rates being too high, dressing when crops are at a susceptible growth stage, when slurry is applied to frozen ground, or where application is followed by dry or hot weather or deep frost.

The relative merits to the farmer of different land spreading options have been described in detail (MAFF 1985b). Climatic and soil conditions, land use types and the sensitivity of the environment to rates of application must be considered within any proposed guidelines. MAFF recommend that a maximum slurry spreading limit of 50 m^3 ha^{-1} is adhered to where any risk to surface waters is identified, and that there should be 3 week intervals between applications; however, the basis of this application rate is not clear.

In contrast, Vetter and Steffens (1989) recommend that single dressings per growth period, using undiluted slurry of 10% dry matter not exceed the following values:

cutting areas: 15-20 m^3 ha^{-1} cattle slurry, or 10-15 m3 ha^{-1} pig slurry;

grazing areas: 5-10 m3 ha^{-1} cattle slurry (up to 15 m3 ha^{-1} in autumn).

The timing of land disposal of slurry in the UK is often restricted by current farming practices (though not by law). Two to four silage cuts are made each year, and it is considered undesirable to spread slurry until after the last cut, since the farmer fears that grass yield may be reduced. If the last cut is late in the year, as is usual, rainfall and low or non-existent soil moisture deficits further restrict spreading. However, if slurry is applied little and often through the growing season, it is likely that the effect on grass yield will be negligible (Section 4.7). Alternatively, soil injection of slurry provides a method of supplying nutrients to grassland during the growing season without risking any loss in grass yield through smothering and scorching.

Waterlogged and frozen land is unsuitable for spreading as slurry cannot be efficiently incorporated within the soil. Waterlogging can also occur due to excessive application, therefore preventing the incorporation of surplus slurry. Problems can also be encountered in excessively dry weather, when cracks may open up in clay soils due to shrinkage; these may provide rapid access to watercourses via under-drainage systems. Avoiding such situations when applying slurry is an essential part of any preventative strategy.

In order to minimise pollution risk from the land disposal of slurry, it is necessary to develop a clearly defined programme of spreading which ensures: a uniform rate of application over the entire available land area (not just the most accessible fields); and application to specific fields at a time when those fields are best suited to the acceptance of slurry, considering factors such as soil type, slope, rainfall and trafficability.

Silage liquor

Current recommendations for the minimisation of pollution risk from silage liquor are:

(i) to prevent effluent production by wilting (Bastiman 1976);

(ii) be prepared to store large volumes and have necessary disposal facilities (Beck 1989a).

Of these options, the widespread trend is to increase storage capacity, since if silage is left to wilt for short periods only it is possible to harvest more frequently and enable greater quantities to be produced. The feeding of silage liquor to cows directly is currently receiving attention as a potential disposal option (Beck 1989a). Current practice is to dilute and spread thinly to land.

Pesticides

The traditional practice of disposal of waste sheepdip to soakaway is now discouraged (except on low permeability soils well away from aquifers). Farmers are now advised by the NRA to spread thinly to land following dilution of waste residues with slurry. This supposedly renders organophosphorus insecticides harmless in a matter of weeks through a combination of photochemical and bacteriological degradation, coupled with immobilisation. Care should nevertheless be taken to prevent rapid runoff to water sources; spreading on heavily drained land, compacted or frozen soils, or on steeply sloping land should be avoided.

Advice on pesticide disposal in the MAFF code of practice (MAFF 1990) essentially parallels that given by the NRA and emphasises the need to gain approval from the NRA for disposal to land or soakaway.

4.5.4 Catchment management

The effectiveness of riparian environments in the control of non-point source pollution through the amelioration of run-off quality has been investigated using a retention-time model (Phillips 1989). Specific combinations of soil, topography and vegetation characteristics were compared in their ability to filter nitrates from agricultural runoff. Although all typical riparian forests protected water quality, a wide variation was found in their effectiveness and a need for flexibility in determining buffer zone width was emphasised.

Howells (1971) has described pollution from runoff from agricultural and urban areas with respect to the control options available. These have included the use of appropriate conservation practices (for example, a well-vegetated strip alongside all streams would reduce phosphorus, pesticide, and suspended solid loadings to streams), treatment of run-off, and control of land use to make it compatible with water-use classification schemes.

Riparian buffer zones have been widely reported to produce reductions in pollutant load (suspended solids, nitrogen, phosphorus, BOD) from land run-off. Smith (1989) reports suspended solids, particulate phosphorus and nitrogen, dissolved phosphorus and nitrate concentrations in run-off to be <87%, <80%, <85%, <55% and <67% respectively lower from retired riparian pasture than from grazed riparian pasture. In the US and elsewhere, grant-aided programmes have been implemented for the widespread development of riparian buffer zones (see Section 4.7). In the UK, no such programmes exist, except for the Set-Aside scheme which is EC-funded and only relates to land under intensive arable production; even with this scheme, the setting aside of riparian land is only offered as a suggestion rather than actively encouraged by extra funds or provisos in grant award. Research into the effectiveness of buffer zones is currently being part-funded by WRc at Oxford Polytechnic.

Hillman and Whyman (1984) used data collected on the high-flow response of a small river in southern England, chemograph responses and rainfall-runoff relationships to establish a predictive catchment water quality model. Such a model can be reasonably accurate and it can be augmented to include a number of water quality parameters with only marginal increases in the requirement for data collection. More complex models using data on land management, farming practices, topography, geology and pedology are considered possible and some of these factors are included in the evaluation of runoff response. Agricultural management plans can be incorporated within a comprehensive catchment water quality management plan. Such plans, generated by a conflict of resource development and resource conservation, have been applied to effect an optimal solution to environmental, domestic, industrial, commercial and agricultural needs through the use of pollution studies, supported by computerised data storage and retrieval systems and ecological models (eg Lee and Adan 1983).

Moore *et al* (1988) have applied the Hydrological Simulation Programme FORTRAN (HSPF) for predicting water quality changes caused by agricultural operations. This model was evaluated using experimental data obtained from a catchment planted with corn, to which nitrogen, phosphorus and potassium fertilisers and the herbicide atrazine were applied. All surface runoff was directed to a discharge structure equipped with a flume, continuous flow recorder and automatic sampler. Analytical data for water and soil quality was obtained for a 19-month period to provide a preliminary calibration of the model which produced good simulations of runoff and sediment behaviour, and reasonable simulations of atrazine and soluble nitrogen levels within the receiving waters.

Braden *et al* (1989) have attempted to quantify the important link between farm management practices and implications for aquatic communities in receiving waters. They have produced a theoretical optimisation model which incorporates farm management practices, pollutant transport to watercourses and likely effects on fish habitat suitability (using the US Fish and Wildlife Service Habitat Suitability Index approach). The model deals with the effect of sediment and pesticide inputs, but the principle could be applied to organic pollution from livestock. The output from the model is a trade-off solution between crop yield and habitat suitability, and a management plan can be constructed from the optimal solution for each land unit.

Water management programmes depend on both the naturally occurring environmental conditions and the water-related needs of the population as determined by prevailing socio-economic conditions (Sadler and Cox 1987). There is an overriding management need to make water quality improvements by the treatment of point discharges and the control and identification of the impacts of non-point discharges.

A comprehensive management plan was developed for improving the water quality of the Siuntionjoki watercourse, Finland (Tamminen *et al* 1990). Inventories of pollution loads and wildlife species inhabiting the river and of the natural vegetation were compiled, and the effects of competing interests and activities on water quality and pollution abatement were assessed. The investigation involved consultation and collaboration with all interested parties, local authorities and nature conservationists, and the development of an agreed procedure for the evaluation of future developments from the standpoint of water quality protection was devised.

Osteen *et al* (1981) advocate the merits of water-based land management (WBLM) (ie relating the choice of land management practices to water use and water quality goals) as an important method of controlling agricultural non-point

4.6 Legislation and incentive schemes

4.6.1 Legislation

Section 111 of the 1989 Water Act provided for the establishment of Water Protection Zones (WPZs) where specified activities may be forbidden; these powers have not yet been used. Nitrate Sensitive Areas (NSAs) are special cases of such protection zones, and 10 pilot NSAs have been set up within which agricultural practices (including the timing and rate of livestock waste application to land) are restricted. However, NSAs differ from normal WPZs in that restrictions are purely voluntary, with financial incentives for compliance. Further designation of NSAs is planned, but this type of protection zone only deals with areas with vulnerable potable supplies. Ecological protection has not been a consideration, and the NCC have recently urged WPZ designation to protect ecologically sensitive catchments, such as lake and mire SSSIs (NCC 1991).

As already mentioned, the Government has recently released new regulations on the storage of slurry, silage and fuel oil (DoE 1991). The NRA are empowered with the enforcement of these regulations, and can serve notice for improvements on farmers with installations that do not comply with the specifications laid down. These regulations will be a useful tool in pollution prevention since they allow prosecution on the basis of risk (as defined by the regulations), but their usefulness has been restricted by the leniency of some of the required specifications. Moreover, farmers have the right of appeal against improvement notices, which is likely to introduce a considerable delay into the implementation of remedial measures. These regulations are are discussed further in Section 4.8.

In 1986, 128 prosecutions arising from farm incidents were recorded in England and Wales, with an average fine of £276. In 1987 the Lord Chancellor encouraged the imposition of higher fines, suggesting a starting point of £2000 (the maximum fine) which would be reduced according to mitigating factors. However, in 1987, 225 prosecutions, with average fines of £205 were recorded. Subsequent increases were noted in 1988 but the NRA was not satisfied with the low penalties enforced. In 1989, 163 prosecutions were recorded and the average fine rose to £500. However, there were marked regional variations, with average fines ranging from £105 in NRA Yorkshire Region to £904 in NRA Severn Trent Region.

Under the Environmental Protection Act (1990), the maximum penalty in the magistrates court for pollution offences has been increased from £2000 to £20 000, but it remains to be seen whether this change will be used effectively.

4.6.2 Incentive schemes

The **Farm and Conservation Grant Scheme (FCGS)**, which succeeded the Agricultural Improvement Scheme (AIS) in 1989, pays for 50% of the cost of pollution prevention measures approved by the NRA. However, there are several deficiencies in the current format of grant allocation, including the non-eligibility of clean water separation systems (which are crucial to pollution prevention). The AIS offered 60% of costs in less favoured areas and 30% in favoured areas, in contrast to the current allocation of 50% in all areas. Less favoured areas are generally more at risk from farm pollution, with land typically having heavy soils, high rainfall and high landslopes; grant aid has effectively been reduced by 10% in these areas since 1989. Less favoured areas also usually produce oligotrophic waters, particularly sensitive to pollution from farm wastes (NCC 1991).

There is therefore justification in having a graded system of grant allocation, with higher incentives paid in high risk areas. The payment of 50% of costs has been criticised generally by the NCC as being too low to provide a significant incentive to farmers, given the current economic climate; they suggest that 75% would be more appropriate. Such a change could be assimilated within the existing grant aid budget if allocation were graded.

Other relevant incentive schemes are more catchment-based than the FCGS (which focuses on waste collection and storage), comprising the designation of **Nitrate Sensitive Areas** (NSAs) (MAFF 1990) and **Environmentally Sensitive Areas** (ESAs) (MAFF 1989). Both of these schemes aim to extensify agricultural practices within designated 'sensitive' zones. The former is government-funded and is primarily designed to reduce nitrate levels in drinking water supplies. The latter is EC-funded and is primarily concerned with landscape and conservation. Both schemes may stipulate restrictions on livestock numbers depending upon the nature of the designated zone, farmers are not obliged to enter either scheme. So far, 10 pilot NSAs and 10 ESAs have been designated. The **Set-Aside** scheme, another EC-funded venture, only applies to intensive arable farming.

4.7 International approaches to farm pollution control

4.7.1 Introduction

In order to make comparisons between farm pollution control activities in the UK and abroad, a review of international approaches was conducted. This was largely undertaken through telephone discussions and correspondence with relevant governmental bodies in Europe and elsewhere, which yielded most of the literature cited.

4.7.2 European combined initiatives

Control of pollution from livestock farming in Europe, as a whole mainly stems from the need to protect soil quality and prevent nutrient contamination of surface and groundwaters. At present control measures are left to individual member states; however, there is a proposed EC Directive on the control of nitrate from diffuse sources (CEC 1989). This directive would require Member States to designate vulnerable zones, and within these to apply certain catchment management restrictions. Regarding livestock, there would be requirements to:

- restrict the number of livestock according to the land available for manure/slurry spreading (see Table 4.5);

- introduce rules for manure spreading and for the storage of manure/slurry during prohibited periods.

The proposed directive has the objectives of avoiding: nitrate levels in freshwaters which would conflict with legitimate water uses; and eutrophication of surface, estuarial, coastal and marine waters. The system of Nitrate Sensitive Areas in the UK has similar aims to the proposed directive, ie the extensification of agriculture within designated zones, but the UK system involves voluntary grant aid rather than statutory compliance. The ultimate effects on UK agriculture of this directive, if approved, could be widespread and obligatory.

Table 4.5 - Maximum livestock numbers per hectare of land available for slurry spreading, as proposed by EC Directive COM(88)708.

Livestock type	Maximum no of livestock ha^{-1}
Dairy cows	2
Young stock or beef cattle	4
Fattening pigs	16
Sows with piglets	5
Turkeys, ducks	100
Laying hens	133
Young hens, 0-16 weeks	285

NB Numbers are not cumulative

In addition to this, the Ministerial Declaration at the 1987 London Conference on the North Sea agreed to take effective national steps in order to reduce nutrient inputs into areas of high pollution risk in the North Sea (Paris Commission 1989). The aim of the declaration is to reduce inputs by c 50% between 1985 and 1995. The Paris Commission felt that it was not possible to realise this aim without very stringent measures in the agricultural sector.

4.7.3 The Netherlands

a) Legislation

i) Waste production and land application

Control of livestock farm pollution in Holland is mainly provided by the Soil Protection Act (1987) and the Act on Manure and Fertilisers (1986), which control slurry/manure production and disposal. The objective of the Dutch strategy is to reduce animal waste production so that the amount applied to the soil does not exceed the nutrient requirements of the crop. This should ensure that there is no nutrient/mineral accumulation in the soils and little potential for contamination of ground- and surface waters.

Every livestock farmer has a non-negotiable waste production quota, set in terms of phosphate load since nutrient enrichment of their waters is the primary concern. If part of a production quota is transferred from one farmer to another, that part of the quota is reduced by 30%. The quota indirectly sets an upper limit to the number of livestock that a farmer can keep on his land. Quotas for individual farms will be reduced in phases up to the year 2000. This is intended to force farmers to adopt practices that produce manure with a low phosphorus content, rather than to force reductions in livestock numbers. However, a limit on livestock density (which is likely to be as little as 3 dairy cows ha^{-1} or its equivalent) is to be set for land-dependent livestock farming (ie non-intensive) in order to strengthen the dependency on the land for grazing cattle (Dutch Ministry of Agriculture (DMA) 1990).

In addition, maximum application rates for land-spreading are specified, which become progressively more restrictive until the year 2000 (see Table 4.6). At present, the application rates are much higher than the calculated requirements of the soil (van Boheemian 1987) and the phased increase in spreading restrictions is to allow a transition period towards environmentally sound application rates. The values in Table 4.6 can be roughly converted to slurry volume using a phosphate content of 2 kg m^{-3} for undiluted cattle slurry, and 4 kg m^{-3} for undiluted pig slurry (both assuming 10% dry matter) (ADAS 1985). In addition to these restrictions, application of dirty water is restricted to

50 m^3 ha^{-1} yr^{-1} on grassland and 25 m^3 ha^{-1} yr^{-1} on arable land (van Boheemian 1987).

In 1991/92 areas of conservation interest sensitive to eutrophication will be designated, and allowable phosphate loadings will be much lower.

Land application is prohibited at different times of the year according to soil type, as indicated in Table 4.7.

Table 4.6 - Maximum application rates of slurry/manure to land in the Netherlands (Dutch Commodity Board for Feeding Stuffs (DCBFS) 1989)

PERIOD	GRASSLAND	SILAGE MAIZE FIELDS	ARABLE LAND
up to 1:1:91	250	350	125
1:1:91 to 1:1:95	200	250	125
from 1:1:95	175	175	125
by 2000	final standard	final standard	final standard

Values are in kg P2O5 ha^{-1} yr^{-1}.

Table 4.7 - Prohibitions on land application of slurry/manure in the Netherlands (Basset *et al* 1990).

SOIL TYPE/LAND USE	PROHIBITION PERIOD
Grassland	1 October to 30 November (and 1 January to 15 February on snow-covered ground).
Sandy soil	
a) silage maize/arable	Harvest (c 1 July) to 31 October.
b) silage maize/arable followed by after-crop (ie winter crop)	1 October to 31 October
Clay soil	Under discussion

These restrictions will become more severe in phases similar to those governing maximum application rates, and by 1995 the spreading ban will run from September to February (Dutch Ministry of Agriculture 1990). At present, slurry spread to arable land must be ploughed in within 48 hours; however, from 1991 it must be ploughed in directly after application, and from 1995 all slurry spread to grassland must be injected. These latter stipulations are largely designed to reduce atmospheric emissions of ammonia (it is intended to reduce emissions by 70% compared to 1980 levels) and odour, although they are also likely to be effective in reducing the risk of direct run-off; it should be noted, however, that the risk of direct run-off is low anyway due to the low-lying nature of the land in the Netherlands.

New legislation is being developed which will set a maximum allowable nitrogen concentration in the top metre of soil, which will further restrict land application (of both organic and inorganic fertilisers) (pers comm Dutch Ministry of Transport and Public Works). This is an approach used in some areas of Germany, and will be introduced in the Netherlands in phases starting in the early 1990s.

The above controls give rise to large manure surpluses in central and south-eastern areas of the country (van Boheemian 1987). In 1988, total manure/slurry production was estimated at 96 million tonnes, with the theoretical surplus totalling 14 million tonnes. (Dutch Ministry of the Environment 1990). In 1985, approximately 55% of the theoretical surplus was transported to other farms for land-spreading (Voorburg 1988). It is expected that total production will be 82 m tonnes in 1991, with a surplus of 15 m tonnes, and 81 m tonnes in 1995, with a surplus of 16 m tonnes.

Under the legislation, livestock farmers with a waste production of greater than 125 kg $P2O5$ ha^{-1} are required to keep records of slurry/manure produced and where it is to be disposed, thus indicating whether a surplus exists and how large it is. Farms producing more waste than this are prohibited from expanding; this restriction will affect most those types of farming not tied to the land (mainly pig and poultry farming). Farmers pay a 'surplus levy' of up to 0.5 guilders kg^{-1} of phosphate over the reference production of 125 kg ha^{-1}; this tax is reduced if a bilateral waste disposal contract is signed with an arable farmer, if the waste is transported off the farm by government-approved means, or if a low-phosphate feeding system is used. The income from this tax is used to develop manure surplus disposal strategies in the form of the Manure Action Programme (MAP, which is additionally funded directly by the government).

Many bilateral agreements have now been made between farmers. There is even a private company that organises the long distance transportation and disposal to arable land of chicken manure. This is economically viable because of the highly concentrated nature of chicken manure, but long distance transfers are not really feasible for cattle or pig slurry in their original consistency.

The effectiveness of phase 1 restrictions is currently being evaluated, and phase 2 restrictions will be amended accordingly.

ii) Slurry storage

From 1990 there will be measures requiring minimum slurry storage capacities under the Soil Protection Act. This is in addition to other legislation stipulating design criteria, ammonia emissions, and a minimum slurry storage capacity of 6 months (rising to 9 months in certain areas depending upon local circumstance). As part of the National Environmental Policy Plan, slurry/manure stores built after 1987 will have to be covered by 1991 in order to reduce ammonia emissions; this will also have the effect of reducing dilution by rainfall.

b) Monitoring and enforcement

The monitoring of compliance with waste storage requirements is undertaken by local authorities. Enforcement of the relevant legislation within the Soil Protection Act is the joint responsibility of the Ministry of Agriculture and the Ministry of the Environment. Two main methods of enforcement are adopted:

- Book-keeping - the records of surpluses kept by farmers are checked against receipts given by arable farmers or processing plants upon delivery of manure. This ensures that all surplus manure is disposed of outside of the farm. A 'minerals accounting system' was introduced in 1990, which looks at the net flux of minerals (N, P, K) at the farm level with the aim of controlling losses. The possibility of using this system in a regulatory way, which would link up with manure/slurry accounting, is currently being investigated (DMA 1990).

- Farm visits - AID, the relevant monitoring authority within the Ministry of Agriculture, undertakes site visits to ensure compliance. This includes audits of the number of livestock kept on the farm; if the number is too high for the waste production quota set for the farm (estimated by using average outputs per unit of livestock) the farmer will be instructed to reduce his herd size. AID do not assess pollution risk on farms, but merely enforce the appropriate legislation.

In addition to the above enforcement methods, the civil police enforce the prohibition periods on the application of manure to land.

Water pollution control authorities comprise 40 - 50 regional water authorities, responsible for small rivers and tributaries, and a National Water Authority responsible for major rivers such as the Rhine. They are not involved in the enforcement of any of the legislation mentioned above and only become involved with farms once a water quality problem has been identified. However, the Water Pollution Control Act (1970) makes provision for the setting up of buffer zones, for which the water authorities would be responsible.

c) Waste control

The Manure Action Programme is directing effort into three main areas: the improvement of feed quality; the improvement of manure/slurry quality and facilitating acceptable manure storage and disposal (for which the Foundation National Manure Bank is responsible); and centralised manure treatment and processing.

Regarding feed quality, research is focusing on improvements in: digestibility; the elimination of anti-nutritional factors (anfs) which block protein digestion; reduction in phosphorus content (especially through the addition of phytases which improve phosphorus digestibility); and reductions in heavy metal content (DCBFS 1990). Nutrient balances have shown that inputs of nitrogen, phosphorus and potassium to Dutch dairy farms greatly outweigh outputs, such that there is a net accumulation in the soil which can leach into ground- and surface waters. There is concern, however, that reducing waste phosphorus outputs will allow compliance with current regulations without necessarily reducing nitrogen (or indeed whole slurry) outputs.

Regarding manure storage, subsidy schemes worth 50 m guilders have been implemented for the enhancement of storage capacity. Such subsidies will help to alleviate the problem of storage for increasingly long periods over the autumn/winter period. The development of a manure application (to land) plan for each farm will be encouraged by the DMA.

The transportation of surplus slurry/manure to areas with a deficit is handled by the Manure Boards, which received a legal status in 1987 (van Boheemian 1987). The boards are obliged to remove surpluses from farms upon payment of a standard tariff. They subsidise the transport costs if the waste is taken from an area with a surplus to one with a deficit, and if it involves a distance of over 75 km for poultry waste and 50 km for other wastes.

A research programme was initiated in 1985 aimed at the development of large scale animal waste processing techniques. Field testing of these techniques commenced in 1988, aided by a subsidy scheme worth 51.5M guilders from the MAP, and the Dutch government has since been working to relieve the bottlenecks impeding large scale processing. It is intended that by 1994 there will be an industrial manure processing capacity of 6 million tonnes, with the responsibility for this resting with the Dutch agricultural sector. If this target is not met further legislative restrictions will be imposed.

At present, it seems unlikely that the manure processing industry will be able to handle even 1 million tonnes per annum by 1994. Voorburg (1988) concludes that 'slurry purifying', in which a final effluent is produced for discharge into receiving waters, is not practical since the effluent is too nutrient-rich. The Netherlands government now prefers evaporation of the liquid fraction to form a dry pelletised fertiliser, which can then be easily distributed over long distances to areas in which it can be safely utilised.

4.7.4 Denmark

a) Legislation

Statutory regulations concerning the control of pollution from livestock farming were introduced in Denmark in 1988 (Danish Ministry of the Environment 1989). These impose very tight and detailed restrictions on waste management and are enforced by the 275 local councils throughout the country.

i) Slurry and manure storage

The regulations include construction requirements concerning impermeability, strength and general design of storage facilities such as drainage to reception tanks. For farms holding more than 31 livestock units (LU - 1 LU is equivalent to one large dairy cow) a storage capacity of at least nine months of slurry production is required, although there may be smaller stipulations for farms with between 31 and 120 LU or in special cases on larger farms. Similarly, larger storage requirements may be stipulated. Surface water from adjacent areas and roofs should not run into solid manure yards. Field stacks of cattle and pig manure are forbidden.

There is a requirement for regular emptying of storage facilities (including silage and waste water tanks) to prevent overflow, and regular maintenance against wear and corrosion. Moreover, containers should be tested for effectiveness at intervals of at most 10 years.

ii) Stock restrictions and waste application to land

Stocking density in Denmark is limited to 2 LU per hectare (Anderson *et al* 1990). In addition, the following maximum waste application rates must be adhered to:

Cattle slurry	2.3 LU ha^{-1} yr^{-1}
Pig slurry	1.7 LU ha^{-1} yr^{-1}
Other animals	2.0 LU ha^{-1} yr^{-1}

Slurry spread to tilled soil must be ploughed in within 12 hours of application. Also, slurry, silage liquor and waste water should not be applied where there is a risk of surface water contamination, although the regulations do not specify what type of land area constitutes a hazard. Application of slurry or silage effluent is not allowed between harvest and 1 November unless the area supports an established crop or is to carry a winter-sown crop. No application to bare frozen soil is allowed unless it can be ploughed in within 12 hours.

If more slurry is produced by a farm than can be disposed of on the available land, written agreements are required for the safe disposal of the surplus, to be approved by the local council. Disposal may be to other farms or to biogas plants, of which there are approximately 10 in Denmark. Biogas plants are considered to be a success in Denmark, taking not only animal waste but other waste materials including sewage sludge (after disinfection) (pers comm Danish Ministry of the Environment).

b) Monitoring and enforcement

There are c 80 000 farms in Denmark, 50 000 of which hold livestock. All of these farms were visited in 1987/88 by the local councils to assess the state of waste management practices in relation to the new regulations. Farmers were informed of remedial measures required and the deadlines for compliance. The deadline for compliance with storage capacity stipulations is the end of 1992, and 70% of farms are already complying. The penalties for non-compliance range from fines to imprisonment for up to one year.

It should be noted that only a small proportion of farms in Denmark have insufficient land to dispose of their own waste. Generally, animal waste does not need to be transported more than 3-4 km before it can be applied to the soil. The restrictions imposed, therefore, do not affect the farming community as much as they would in more intensively farmed countries, such as Holland.

Compliance with application rate restrictions is assessed by estimating total waste output (based on livestock holding and estimates of output per animal) and the extent of available land for disposal. If waste output is greater than the local disposal capacity of the holding, a known surplus will be produced. The farmer has to provide evidence that this surplus was produced and disposed of outwith his holding via council-approved routes.

Twelve regional councils control the local councils and are responsible for the quality of surface and groundwaters. Regional councils are not directly involved with the monitoring of farm waste management practices, and only become involved when an environmental impact is observed. Compliance with the regulations should ensure that pollution risk is low, but where an immediate risk of leakage or overflow from a waste container is identified by a local council immediate remedial action or a cessation of use can be ordered. A farmer can be convicted for causing a **risk** of environmental damage, which gives the regulatory authorities much more power to order remedial measures than is the case in the UK.

4.7.5 Switzerland

a) Introduction

In 1988, Switzerland produced 35 million m^3 of animal slurry, to be disposed of on 1 million ha of agricultural land along with an annual production of 200 000 tonnes of sewage sludge.

b) Legislation

Legislation on pollution control from livestock farming is contained within a draft chapter on agriculture (Swiss Government 1990) to be included in the Water Protection Act. In addition, the Law of Agriculture restricts livestock numbers, with the aim of maintaining farms as, or restoring them to, small traditional enterprises with sufficient land for their own waste disposal. With this objective in mind, it is the aim of the government to phase out intensive piggeries, which have no land for waste disposal. New constructions of intensive piggeries are banned.

i) Livestock restrictions

Table 4.8 gives the maximum numbers of livestock allowable on a single farm. Each figure shown is the maximum allowable number of that specific livestock type assuming that no other livestock types are present. Table 4.8 also gives the minimum amount of land legally required to dispose of the waste produced. Farms that do not comply with these requirements by the end of 1991 will, from the beginning of 1992, pay the taxes (per head of excess livestock) shown in the same table. There are lower exemption limits where all types of livestock can be kept on one farm without incurring extra taxation, thereby encouraging traditionally diverse farming practices.

ii) Storage

A minimum storage capacity of 3 month's production will be required, which the local authorities (cantons) can increase in mountainous areas or where climatic conditions are unfavourable. The requirement can also be lessened where livestock housing is only occupied seasonally. The local authorities are to fix dates for compliance with these requirements, but all farms should comply within 15 years.

Table 4.8 - Maximum numbers of livestock allowed on a single farm in Switzerland (Swiss Government 1987, Strauch 1989)

Livestock type	Maximum number of head	Taxation on surplus (Swiss Fr per head)	Exemption limits (No of head)
Cattle	250	500	10
Fattening calves	200	200	10
Sows	150	500	10
Gilts	150	500	5
Weaner pigs for breeding	1000	100	10
Weaner pigs for fattening	1000	20	30
Fattening pigs	1000	100	60
Laying hens	12000	20	500

NB Numbers are not cumulative

iii) Land spreading

Under the new draft regulations, each farmer will require a contract with the local authorities to apply his waste to land. Such contracts will define an 'area of exploitation' within which a farmer should be able to dispose of all of his slurry according to good agricultural practice. The farmer has to prove that the land surface within this area is suitable for the maximum allowable slurry/manure application rate of 3 cattle units ha^{-1} (1 unit = the annual production from one 600 kg cow). This maximum rate equates to c 54 m^3 ha^{-1} yr^{-1} of cattle slurry, using estimates of waste output in ADAS Booklet 2081 (1986). When this limit is reached, no more slurry or inorganic fertiliser may be applied. The maximum application rate can be reduced by the local authorities according to altitude, topography and soil type. Table 4.9 shows the guidelines used by the Cantons when assessing land suitability for slurry application, but these will have to be reviewed in the light of the new restrictions.

The land within the area of exploitation may be owned by or leased to the farmer, or confirmed as land where he has a contract to simply dispose of his slurry. If a farmer transports slurry out of this area he must have proof that he either owns or has the lease to at least 50% of the land used for slurry application, ie only up to 50% of the land used should be available through simple 'slurry application contracts'. This regulation is designed to prevent intensive piggery farmers from continuing their current practices without either leasing or buying a large proportion of the land required for disposal of their slurry.

The local authorities are to fix dates for compliance with these requirements, but all farms should comply within 5 years. It is envisaged that contracts to ensure sufficient land for slurry application will gradually disappear as intensive practices are phased out.

The draft legislation states that land spreading must be undertaken according to the most recent techniques and in a way which does not harm soil or water. It also allows for, in the interests of water protection, a complete cessation of land application where necessary, to be implemented over a transitional period of 5 years.

Table 4.9 - Guidelines on land characteristics for the disposal of slurry in Switzerland (Swiss Office Federal de L'Agriculture 1979).

Physical factor concerned		Implications for slurry application
1. Intensity of rainfall and slurry spreading	a) High loading of very dilute slurry/ dirty water	Spray evenly
	b) Heavy rainfall	Do not spray slurry
2. Infiltration characteristics	a) Non-cultivated soil	
	- uncovered, muddy or frozen surfaces	Do not spray slurry
	- loose soil	Spraying possible
	b) Cultivated soil	
	- frozen or snow-covered	Do not spray slurry
1. Intensity of rainfall and slurry spreading	a) High loading of very	
	- Limited infiltration	Spray evenly Reduced load only
	- High infiltration	Standard loads
3. Topographic characteristics	a) Slope 10-25%	
	- thick vegetation	Standard loads
	- little or no vegetation	Reduced load only
	b) Slope 26-45%	
	- thick vegetation	Reduced load only
	- uncultivated	V reduced or no load
	c) Slope >45%	V reduced or no load

Standard load: isolated doses up to 60 m^3 ha^{-1}
Reduced load: isolated doses up to 40 m^3 ha^{-1}
V reduced load: isolated doses up to 25 m^3 ha^{-1}
The total annual quantity should be administered over 2 or 3 applications.

iv) Waste treatment

The farmer will have a legal requirement to maintain and repair water treatment plants, which the local authorities will periodically inspect. Generally, the types of waste treatment being developed elsewhere in Europe are felt to be too sophisticated, costly and energy-consuming to be run on the small farms typical of Switzerland.

4.7.6 Western Germany

a) Introduction

It is estimated that 211 million tonnes of animal waste is produced annually in West Germany, 80% of which comes from cattle (FAO/EC 1990). Slurry accounts for *c* 40% of this total, but regionally it can account for up to 70% (in the northern states).

b) Legislation

Each state develops a proportion of its legislation internally, and for this reason those states with the greatest farm pollution problems have produced specific ordinances controlling livestock waste disposal. The greatest concerns are nitrate levels in drinking water and eutrophication, rather than run-off of whole slurry.

i) Land application

Table 4.10 summarises the restrictions on slurry application in 4 German states. The 'Dung Unit' is widely used in West Germany as a means of expressing nutrient load. The exact definition of the dung unit varies, and Table 4.10 shows the variation between the 4 states considered. As Table 4.10 shows, Nieder-Sachsen imposes a maximum slurry application rate of 2.5 Dung Units ha^{-1} yr^{-1} (3 DU until 31/12/92), and this rate can be reduced by the authorities if there is a pollution risk to surface or groundwaters. In

Table 4.10 - Restrictions on the land application of slurry in 4 German states (pers comm D Strauch, Universitat Hohenheim)

State	Nieder-Sachsen	Schleswig-Holstein	Nordrhein-Westfalen	Bremen
Date of ordinance	1:2:90	1:8:89	1:6:84	1:5:89
Definition of Dung Unit (DU)	80 kg total N yr^{-1}	80 kg total N yr^{-1} or 60 kg total P205	80 kg total N yr^{-1} or 70 kg total P205	80 kg total N yr^{-1}
Maximum allowable application	2.5 DU (3.0 DU until 31:12:92)	2.0 DU	3.0 DU	2.0 DU
Periods of prohibition	16 Oct - 31 Jan for pasture harvest - 31 Jan for arable land	16 Oct - 31 Jan for pasture and covered soil 1 Oct - 28 Feb for arable land	1 Nov - 31 Jan for pasture and arable land with soil-covering winter crops 16 Oct - 14 Feb on uncult. arable land	16 Oct - 31 Jan 16 Oct - 14 Feb on marshy land 16 Sept - 26 Feb on uncovered soils*

* Except when winter crops are cultivated

Schleswig-Holstein, the maximum application rate is 2 DU ha^{-1} yr^{-1}, and the farmer has to prove to the authorities that he is not exceeding this rate. Application in this state is prohibited on certain types of ground, such as fallow land, frozen soil and protected biotopes. In Bremen, the maximum is again 2 DU ha^{-1} yr^{-1}, and this has to be split into several applications through the year with no one application exceeding 1 DU ha^{-1}.

Slurry application during the winter months is prohibited in all 4 states, the only exceptions arising (in 2 of the states) when winter crops are grown. In such cases very reduced applications are allowable. In Bremen, the regulations state that even during the months when slurry application is allowed, there should be no application if the weather creates a risk of run-off to surface waters.

A number of states suffer from increasing levels of nitrate in drinking water, and water protection zones have been set up in states such as Baden-Wurttemberg to control nutrient applications (similar systems are in operation in other European countries such as the Netherlands). Three zones are identified, and slurry application is not permitted at any time in the inner and middle zones, whilst spreading is allowed between 1 October and 15 February in the outer zone (Strauch 1989). Compensation for loss of yield is paid to the farmer, and soils analyses are conducted after harvest to ensure that the recommended fertiliser applications have been followed. Control sites have been set up on different soil types to ensure a fair comparison with which to test compliance.

ii) Storage capacity

The required minimum waste storage capacity across the country is 6 months of waste production, but farmers are now being requested to have sufficient capacity for 9 months production (van den Weghe 1990). Many farmers do not at present comply with the minimum required capacity.

c) Waste control

As in the Netherlands, greater nutrient utilisation in livestock feed is seen as an important step in the control of nutrient output. It is estimated that optimisation of feed composition and nutrition will allow a reduction in feed nutrient content of 25-30% (van den Weghe 1990). Research effort will also be invested in methods of drawing up nitrogen balance sheets in order to ensure that slurry application rates are compatible with soil requirements.

It is envisaged that stationary or mobile treatment facilities will be developed in areas of large slurry surpluses that can dry slurry into a reusable pellet form. 'Manure banks', and contracts for slurry disposal between farmers, already exist and the management structure for such activities is being developed further.

Anaerobic digestion and subsequent biogas production is a well-tested form of treatment for animal wastes in West Germany, but is only operated at a farm level. In 1986, 130 biogas systems were in operation, the majority of which handle under 150 dung units per year (equivalent to the production from 150 large cows), with 6 handling between 150 and 300 DU yr^{-1}, 4 handling 300-600 DU yr^{-1} and 2 handling over 600 DU yr^{-1} (Loll 1987). The plants can process slurry in its normal consistency. Biogas production in Germany is not profitable at present if viewed purely in economic terms (ie setting the revenue from energy production directly against capital and running costs), and it would appear that greater governmental subsidies are required for further expansion of the industry. The very important use of anaerobic digestion in odour control (emissions can be reduced by up to 90% - Voermans 1986) may help to win further subsidies for this method of waste control in Germany and other countries.

Proponents of biogas plants in Germany are pushing for communal systems handling far larger quantities of animal waste. This would serve to reduce overheads whilst greatly increasing energy output.

4.7.7 Other countries

a) Belgium

The Manure Decree (1985) prohibits slurry storage and spreading on land within protection zones and water supply zones. In other land areas, the maximum allowable land application rate is 4 animal units ha^{-1}, with a prohibition on land-spreading from September to the end of January. In the future, spreading will be prohibited on non-agricultural soils. A taxing scheme for manure surpluses similar to that operating in the Netherland is envisaged.

New constructions are required to have the capacity for 6 month's waste production. Centralised manure banks will be available in the future.

Centralised manure banks will be a major route for the treatment and destruction of manure surpluses. Advice is given to farmers on an individual basis on how to use animal waste efficiently and how to farm in non-polluting ways.

b) Sweden

Land-spreading is banned between 1 December and 28 February as from 1989 (Paris Commission 1989), and from 1995 will be further prohibited from 1 August to 30 November on land which does not hold a growing crop. Slurry/manure must be incorporated within the same day. Maximum stocking densities will be implemented shortly in order to restrict the amount of waste that requires disposal to land.

For all new installations, a minimum storage capacity of 8-10 months is required in the south of Sweden and coastal zones as far north as Stockholm from 1 January 1991. Existing installations must comply by 1995. In some areas there is a subsidy of 20% for increasing storage capacity.

Free advice is available for developing slurry/manure disposal plans on each farm. There are also plans to operate an approval system for waste spreading equipment.

The use of buffer zones is receiving research attention, and a plan for stream restoration incorporating improvements in agricultural run-off quality has been proposed by Petersen (in Press). This involves the setting aside of 10 metre-wide buffer strips and planting fast-growing woody shrubs (possibly for harvest) to intercept run-off. The discharge outlets of tile drains are dug back away from the river bank to a distance of 8 metres, and the intervening land is made into a wetland area (a so-called 'riparian wetland horseshoe') for the reception of under-drainage run-off.

Petersen gives no experimental data on the removal efficiency of these horseshoe wetlands, although he does quote a number of references indicating efficient removal of nitrogen and phosphorus by wetlands in general. However, the role of wetlands in reducing phosphorus levels in run-off has recently been questioned (Gehrels and Mulamoottil 1989). It is clear that the effectiveness of wetlands in improving run-off quality will ultimately depend upon site specific factors such as nutrient loading rate, residence time, vegetation type and management practices, and that generalised statements are therefore unhelpful. Whatever their role in nutrient removal, a wetland with sufficient capacity to avoid overland flow is very likely to reduce BOD loadings (by physical filtration and biodegradation) on receiving waters, and will therefore serve to maintain ambient oxygen levels: for instance, Knight *et al* (1987) report high BOD removal rates across a wide range of loading rates on a natural wetland).

c) Norway

The maximum land application rate stipulated in Norway is 2.5 animal units ha^{-1} yr^{-1}. Spreading is banned on frozen or snow-covered fields. Slurry/manure must be ploughed in immediately after spreading on tilled soils, except in the growing season. Plans to limit spreading to the growing season in sensitive areas are being considered.

Waste storage capacity must exceed that required for the longest period for which spreading is restricted. Silage effluents must be collected for use as fodder or fertiliser.

The development of individual waste management plans is offered to all farms. Subsidies are available for the establishment of buffer zones along vulnerable watercourses. For pollution prevention developments on the farm, farmers can get 35% of the outlay in grants, 10% in interest-free loans and 30% in low-interest loans.

d) USA

Farm pollution control programmes have been undertaken in 7 catchments throughout the USA under the Model Implementation Programme (MIP) (Brown *et al* 1989), initiated by the Department of Agriculture and the Environmental Protection Agency. The west branch of the Delaware river (New York State) was one of the catchments chosen, where phosphorus loads (particularly from livestock) into the eutrophic Canonsville Reservoir were causing problems. A survey of the 275 farms in the catchment was undertaken, targeting those farms with livestock buildings within 100 metres of a watercourse. The remedial measures applied involved the reduction of yard run-off volumes, particularly through clean water separation. Although phosphorus loads from yard drainage were reduced considerably, the limited monitoring performed and model simulations suggested that dissolved phosphorus losses from the catchment as a whole were only reduced by less than 5%.

Nutrient modelling showed that run-off from manure-spread fields contributed greatly to phosphorus loadings to the reservoir. Manure spreading schedules were subsequently developed, which stipulated when individual fields should be used according to their physical and soil characteristics, accessibility and the likelihood of rain. These schedules encouraged a more even spreading of waste over the whole farm, rather than the use of a few fields adjacent to the farmyard. Model predictions for one section of the catchment suggested that total phosphorus losses could be reduced by up to 35%. It is not clear how these results relate to the run-off of whole slurry and the likelihood of acute impacts on aquatic life, but the development of such manure spreading schedules is also likely to reduce BOD loads and consequently have an ameliorative effect on this type of impact.

Lake Okeechobee in Florida is another catchment suffering from eutrophication problems largely due to livestock farming. Three years ago the Florida Department of Environmental Regulation imposed certain requirements (Best Management Practices, BMP) upon livestock operations to combat this, with the main stipulation being the collection and spray irrigation of yard washings (Flaig and Ritter 1989). The South Florida Water Management District (SFWMD) is also sponsoring a buy-out programme for those farms that choose not to make the required changes to their operations. Several dairies have chosen to sell their holdings, and several more are giving this consideration.

A separate study was undertaken on a sub-catchment of Lake Okeechobee, the Kissimmee River, to assess the efficiency of wetlands buffering as a BMP for improving run-off quality from livestock areas (Goldstein 1986). Two wetlands were monitored, and it was found that they were both in near steady-state equilibrium with respect to total nitrogen, whilst removal of total phosphorus was better but decreasing as adsorptive capacity was gradually spent. No measurements were made of inputs to and outputs from the wetlands of ammonia and BOD.

In an experimental agricultural non-point source pollution control programme in the USA (Young and Shortle 1989), the major problem of nutrient runoff in spring, resulting primarily from the winter-spreading of manure, was eliminated in 60 of 62 participating farms by installing manure storage systems. New legislation (The Rural Clean Water Programme) allowed 75% cost-sharing of eligible costs, and representative farm models indicated significant economic benefits from installing both earthern pit storage systems or more expensive above ground systems. The ability to store manure led to a change from daily to seasonal manure application times, which reduced annual costs by around 22% for labour and 30% for commercial fertiliser, meaning that earthern-pit systems would probably be profitable without cost-sharing. The benefits of this scheme were noted in the improved quality of receiving waters.

Research is currently being conducted into the use of constructed wetlands for the treatment of agricultural wastes, including slurry (Hammer 1989). Slurry from a 500-pig holding is being fed, after primary settlement, into an experimental wetland system to determine optimum design criteria.

The use of riparian buffer zones (Vegetative Filter Strips or VFSs) is expected to become much more popular in the US following their approval under the Conservation Reserve Programme (CRP) by the Department of Agriculture (Dillaha *et al* 1989). This programme has the objectives of reducing soil erosion, improving water quality and enhancing wildlife habitat. Soil erosion is a major concern in the US and is probably the main motivation for the incorporation of VFSs into the CRP.

Farmers receive between \$75 and \$200 ha^{-1} yr^{-1} over the 10 year contract period, and the VFSs they construct must meet certain requirements (concerning width and planting of vegetation, for example). Funding for VFSs is also available from 'State non-point source pollution control programmes' such as the Chesapeake Bay Programme in Virginia. Farmers receive \$0.33 $metre^{-1}$ of VFS, but must refund this if the strip is not properly maintained. Construction specifications similar to those laid down by the federal programme must be observed. Both programmes specify that the strip must be designed to filter sheet flow. A survey was undertaken by Dillaha *et al* (1989) to assess the effectiveness of VFSs installed so far in Virginia, and many were found to be breached by concentrated overland flows of run-off which were not filtered at all. These breaches were often associated with large fields where run-off could gather into significant flows with high momentum. Such problems can only be remedied by better design and regular maintenance.

e) Ireland

As discussed in Section 4.4.3, Lough Sheelin has suffered from nutrient enrichment largely due to intensive pig farming. A manure management plan was instigated in 1975 (Dodd and Champ 1983), the main actions being to:

(i) increase manure storage capacity to 6 month's production;
(ii) spread manure only through the growing season;
(iii) check soil nutrient status regularly;
(iv) base application rates on the nutrient requirements of the soil.

Following continual poor waste management practice, brought about largely by the sheer volume of slurry requiring disposal, a slurry transport scheme was initiated in 1980. Through the winter of 1980/81, 6.9 million gallons of slurry were exported from the catchment area, costing £2.23 (1980 prices) per 100 gallons in subsidy to defray haulage charges. In the first two years of operation, the scheme exported 29 million gallons of slurry at a cost in subsidies of £84 000, plus the labour cost of providing a full-time coordinator.

In 1982, 16 pig producers were participating in the scheme, with a combined nominal slurry production of 23 million gallons yr^{-1}; about 15 million gallons of this was exported. Slurry was transported using up to 10 large (25 m^3) tankers, hauling over distances of up to 40 miles. Some of these tankers were owned by the large pig producers, whilst independent hauliers also became established.

Despite the large reductions in phosphorus level in feeder streams, static subsidy for the transport scheme was curtailed in 1984 (Champ 1990). Since then, efforts have centred on the development of slurry management plans, which are now in place for nearly all piggeries. These plans include a complete ban on spreading over the winter months. Restrictions have been extended to cover cattle farming operations in the catchment. In the longer term, it is hoped that anaerobic digestion will relieve the dependency on landspreading, and state funds were made available in 1989 to construct a trial digester.

4.8 Discussion

It is clear from the international initiatives outlined in Section 4.7 that the control of farm pollution abroad involves a far higher degree of central planning than in the UK. This takes the form of: strict legislation governing high risk farming practices; tax penalties on undesirable activities; and the necessary infrastructure and funds to help and encourage farmers to comply with legislation.

b) Waste storage

The new UK regulations on the storage of slurry, silage and fuel oil (DoE 1990) give stronger powers to pollution control authorities, in that they provide a more objective platform for the risk assessment of storage facilities and permit prosecution for non-compliance irrespective of whether pollution has occurred. This is important, since it provides a legislative means of **preventing** pollution, rather than punishing polluters after the damage has been done. However, the level of risk which is deemed acceptable in the regulations, as defined by the required storage specifications, is higher than that in other European countries. For instance, the new minimum acceptable storage capacity in the UK is 4 months' of waste production, as opposed to 6 months in **Germany** (9 months is recommended), 6 months in **The Netherlands** (rising to 9 months in certain areas), 9 months in **Denmark** and 8-10 months in Southern **Sweden**. Small storage capacities lead to a higher risk of overflow, especially in areas of high rainfall or on farms where there is no clean water separation (see Section 5.3.2).

Danish legislation permits prosecution on the basis of pollution risk irrespective of whether the storage specification requirements have been breached. This allows the regulatory authorities more scope in assessing what actually constitutes a risk, which is a difficult phenomenon to quantify in legislative terms.

c) Waste control

Control of livestock waste by means other than legislation is practised abroad in the form of financial penalties for continuing undesirable practices, financial incentives for switching to desirable practices, and a high degree of centralised planning of waste management. In extreme cases, land buy-outs may be considered (eg **US**). In the UK, financial incentive is the only option that is used, in the form of the Farm and Conservation Grant Scheme. Set-aside may be used as an incentive to set up riparian buffer zones, but this is not particularly encouraged by the UK government and the funds are derived from the European Commission in any case.

Examples of financial penalties imposed in Europe include the levy placed on manure surpluses in **The Netherlands**, which also acts as an 'inverted incentive' since the levy can be reduced if certain desirable practices are followed. Money raised from this initiative provides a proportion of the funds for the centralised infrastructure that deals with the country's manure surplus. **Belgium** is also developing a taxation system for manure surpluses. Another example of financial penalty is the **Swiss** system of livestock restriction, whereby a sizeable levy is due for each head of livestock on a farm above set limits.

Examples of financial incentives used in Europe include a number of grant aid schemes similar to the UK Farm and Conservation Grant Scheme, subsidised slurry transport (**The Netherlands**), and schemes to develop riparian buffer strips to ameliorate run-off quality (**US, Norway**).

Centralised planning of waste management takes many forms. A number of European countries have set up 'manure banks' (**The Netherlands, Germany, Belgium**), from where the utilisation or processing of surplus livestock waste is determined. Large scale processing plants have been constructed to handle surplus waste (**The Netherlands, Denmark**), often involving the production of biogas. **Germany** and **The Netherlands** are seeking to provide treatment systems (mobile ones in the case of Germany) which dry slurry to a readily storable and transportable pellet-form. Where centralised waste management is not offered, some European countries provide a free service that formulates farm waste management plans for individual farms (**Sweden, Norway**). In contrast, ADAS now charge for consultations concerning pollution prevention (although the first meeting is free).

In the UK, there is no such centralised involvement in farm waste management as that described above. An example of where such involvement would be of benefit, apart from in the types of initiative mentioned above, is in assisting in the distribution of straw from areas with a surplus to those with a deficit, in order to make a return to straw-based waste management systems more feasible. Solid manure, the end-product of straw-based systems, carries a low pollution risk compared to slurry, due to the high mobility of the latter.

d) Monitoring and enforcement

It is clear from the description of practices abroad that the level of effort invested in the monitoring and enforcement of farm pollution controls is much higher in other European countries than in the UK. This is largely due to the fact that there are few UK controls against which to test compliance. What is also evident is the major role played by local councils in the enforcement of catchment-based legislation (waste storage, land application). In **The Netherlands**, a duty also falls on the civil police, to enforce prohibition periods on the land application of slurry. In the UK, local authorities have no such role to play, and responsibility for any such enforcement (at present the only relevant legislation is the new regulations on the storage of slurry, silage and fuel oil) lies with the water pollution control authorities. This creates an extra resource burden which is not covered by current budget allocations.

The regulatory authorities in a number of European countries (**The Netherlands, Denmark, Switzerland**) base enforcement on the estimation of waste production on individual farms, and relate this to the amount of land available on each farm for disposal. This gives an indication of the waste surplus to be expected, which can then be checked against the amount of waste transported off the farm. In the UK, there is at present no formal monitoring of the capacity of a farm to dispose of its own waste. In **The Netherlands** and **Germany**, this process is being taken one step further; the development of nutrient budgets on individual farms will help to maximise nutrient recycling and minimise losses to surface and groundwaters.

All of the European countries looked at in detail place an onus on the farmer to demonstrate safe disposal of his livestock waste. This takes the form of: legally binding contracts between farmers for slurry transfers (**The Netherlands, Denmark, Switzerland, Germany**); disposal via safe routes (eg biogas plants, 'manure banks') approved by the regulatory authorities (**The Netherlands, Denmark**) or receipt systems for slurry transfers (**The Netherlands, Denmark**). There may also be soil monitoring to check that allowable slurry application rates have not been exceeded (**The Netherlands, Germany**). There are no such systems of accountability organised in the UK, where in effect pollution has to occur before improper disposal can be verified.

5. NATIONAL ASSESSMENT OF FARM POLLUTION

5.1 Introduction

The only national assessment of farm pollution available at present is the annual farm waste report, produced jointly by NRA and MAFF (eg NRA/MAFF 1989). This will be superseded by the new NRA annual pollution report, which will incorporate pollution incidents from all sources. A similar annual report is produced in Scotland by the Scottish Farm Waste Liaison Group (eg SFWLG 1989). Such annual reports are useful, but they have only a coarse geographical resolution (based on regional differences). There is a need for a national assessment with a finer resolution of farm pollution problems, down to the catchment level. Such an assessment needs to incorporate pollution **risk** in addition to details of observed impact, so that the results can be used proactively for preventative planning. Furthermore, the farm waste report deals only with intermittent problems in the form of pollution incidents, and does not consider the chronic effects of farm pollution.

Operationally, there is also a need for an investigation of regional approaches to farm pollution control, in order to provide information for the development of future strategy.

5.2 Methods

5.2.1 Consultation

A questionnaire was constructed and sent to regional NRA pollution control managers prior to discussions. The questionnaire (see Appendix A) dealt with a number of issues, including regional risk assessment practices and monitoring and archiving procedures, but the main objective was to extract any information available within each region on the distribution of livestock farming and, more particularly, pollution problems arising from it. The questionnaire was intended to act as a guide to discussion, but the interviewees were also requested to gather any quantitative information available prior to the meeting. The questionnaire was also sent to River Purification Boards (RPBs) in Scotland and to the DoE (N Ireland) for written responses.

5.2.2 Identification of high risk areas

i) Data collation

In order to gain an indication of the distribution of pollution risk arising from livestock farming activities, data on a number of factors contributing to risk were collected on a national scale. The factors considered, listed below, were felt to be the most important contributors to farm pollution risk (see Section 5.3.2) that were amenable to a national assessment of this nature.

- Livestock numbers - Computerised data on livestock numbers in England and Wales for 1988, together with information on agricultural land areas, were obtained from ESRC Regional Research Laboratory for Scotland. These data were derived from parish-level MAFF Agricultural Census data, which were reduced onto a 1 km^2 national grid using a 3-way land classification. This effectively allowed urban areas to be located, and livestock numbers were subsequently divided up between the two remaining land classifications (moorland and 'other' agricultural land). Sheep numbers were divided up equally between these latter two land classes, whilst other livestock types were assigned to 'other' agricultural land only. In order to keep the database to manageable size, data from this source were initially aggregated into 2 km^2 gridsquares. Livestock numbers in Scotland were obtained at the parish level directly from the DAFS 1988 Agricultural Census, whilst 1988 district level data were obtained for N Ireland from the Department of Agriculture (N Ireland).

- Landslope - a national distribution of landslope was formulated on an ARCINFO Geographical Information System using an irregular elevation matrix digitised from 1:500 000 scale topographic maps. Landslope values were generated from a Triangulated Irregular Network (TIN) created from the elevation matrix.

- o Winter Rainfall Acceptance Potential (WRAP, an indicator of soil permeability) - the national distribution of WRAP was digitised onto ARCINFO from a 1:500 000 map.

- o Rainfall - the contour distribution of average annual rainfall over the period 1941-1970 was digitised from 1:500 000 scale maps. A TIN was generated from points sampled along the contours, and a point-value grid was created from this with 1000 m^2 cells.

Data was stored in an ARCINFO Geographical Information System for subsequent analysis.

A catchment map of the UK was constructed (see Map 1, Map Annex), using maps supplied by NRA regional staff, quinquennial River Quality maps and Ordnance Survey maps, to act as a basis for the development of all distribution maps produced in this study. This was digitised into an ARCINFO coverage.

Data on farm pollution incidents from 1988 (a relatively wet year) and 1989 (a dry year) were sought from all NRA regions to gain a semi-objective picture of the distribution of intermittent pollution problems. The national grid reference, incident type and incident severity of all farm pollution incidents occurring in the calendar years 1988 and 1989 were requested. The incident types stipulated were essentially the categories used in the annual farm waste report, whilst the incident severities stipulated were either those used in the farm waste report or the new NRA national incident categories (see Appendix B for further details).

The pollution incident data gathered were used to modify the level of detail of the national catchment map to ensure that the map was consistent with the level of spatial heterogeneity exhibited by pollution incidents. The data were subsequently used to compare the distribution of known intermittent farm pollution problems with the formulated pollution risk maps.

Data were also sought from NRA regions on recent NWC downgradings known or suspected to be caused (at least in part) by farm pollution. This was meant to give an impression of the distribution of chronic farm pollution problems, which could then be compared with the distribution of pollution risk in the same way as the pollution incident data.

River biota provide an integrated picture of prevailing water quality (Section 6), and for this reason biological data would be a useful inclusion in a national assessment of farm pollution. However, biological data are not as readily available on a national scale as data on pollution incidents and NWC downgradings, with the consequence that any coverage of information would be very patchy. With the incorporation of biological assessment into the 1990 River Quality Survey, the inclusion of biological information in this type of assessment becomes a possibility for the future.

ii) Data analysis

Using the ARCINFO database, values for each factor considered were assigned to each catchment.

Livestock

The total numbers of dairy cattle, beef cattle, pigs, poultry and sheep were calculated for each catchment in the national catchment map by aggregating values in individual 2 km^2 grid squares within each catchment). In order to allow comparison between catchments these numbers were converted into livestock density, in terms of **total** catchment area. Whilst this indicates the national distribution of livestock farming activity, much of the pollution risk posed is related to the amount of organic waste produced, especially in relation to the amount of land available for its disposal.

Estimates of organic waste production from each livestock type (except sheep) were made for each catchment, based upon information on waste output in ADAS advisory booklets (ADAS 1985 and 1986 - see Appendix C). These estimates took into account the dependency of volumetric output on bodysize. Volumetric output was converted into a waste loading by dividing by the land area that was potentially available within each catchment for disposal (by land application). Available land was taken as the combined area of crops, fallow and pasture. The output from each livestock type was then combined to give a total volumetric waste loading.

Although total volumetric waste loading gives an indication of the relative likelihood of run-off occurring due to over-application, it gives no indication of the polluting strength of the waste. Polluting strength varies with livestock type (see Section 4.2), and it is important to take this into account when combining livestock waste outputs to give an indication of pollution risk. Estimates of Biological Oxygen Demand (BOD), nitrogen and phosphorus output were calculated from estimated volumetric waste output, assuming typical waste compositions for each livestock type (see Appendix C).

It should be noted here that the estimates of waste volume and polluting strength made above take no account of farming practice or subsequent waste management, which will critically modify the pollution risk posed. The amount and nature of waste that is stored and ultimately requires land disposal will depend upon factors such as: the intensity of farming; the length of over-wintering period (if applicable); methods of waste management (particularly the production of manure or slurry); the age of the waste and the amount of ammonia volatilisation. Since the above factors could not readily be accounted for in this analysis, it was decided to express waste output in terms of the daily production of undiluted fresh slurry (excreta and faeces).

The organic waste loading figures so produced give an assessment of pollution risk in each catchment due to the presence of livestock alone, which can then be refined by taking the risk due to landslope, soil permeability and rainfall into account.

Other important pollution risks due to livestock farming arise from silage production and sheepdipping. The distribution of risk associated with silage has not been dealt with specifically in this analysis (although it will roughly follow the distribution of cattle), but an attempt has been made to indicate the distribution of risk of sheepdip pollution. For this, the assumptions (relevant to this analysis) made by Littlejohn and Melvin (1989) were followed. These were that:

- 300 sheep are dipped in one day in one dipper;
- the dip volume is 2700 litres;

- propetamphos is the active ingredient, at a working concentration of 320 mg l^{-1};
- a topping up of the dipper with fresh sheepdip is required through the day;
- a completely fresh volume of sheepdip is made up each day.

Using these assumptions, spent sheepdip production, in terms of both volume and 'propetamphos equivalents' can be estimated for each catchment (see Appendix C). Dividing this production by total catchment area gives a coarse relative indication of waste loading. The use of propetamphos also gives rise to large quantities of waste phenolic compounds, which can be simply estimated from the amount of propetamphos used (see Appendix C).

Looking at the distribution of waste sheepdip production in terms of only one pesticide (albeit a common one, accounting for perhaps up to 70% of UK sheepdip usage) is useful since it gives an indication of the scale of waste sheepdip production in terms of one of the main active ingredients; however, there are a wide range of sheepdips on the market with varying ecotoxicities (these are currently being reviewed by WRc - NRA reference A19.53). Similar estimations could be performed for other sheepdip pesticides using the volumetric estimations of sheepdip usage and the active concentration of the pesticide concerned. If the relative usage of different formulations were known in a catchment the scale of waste production of each pesticide could be estimated in the same way. A more detailed study of sheepdip usage which may provide such information is currently being undertaken by WRc (NRA Reference A07.2(208)).

Physical factors

For the national distribution of rainfall and landslope, which had been resolved into point-value grids, points falling within a catchment were averaged to give a mean rainfall and landslope. For the WRAP distribution, which was zonated, a mean value was assigned to each catchment by giving areal weightings to each area of WRAP class falling within a catchment.

Overall risk

The relative importance of each of these factors is difficult to determine, and so a pragmatic approach to assigning weighting factors has to be taken in order to produce a combined index of risk.

Appendix C gives the list of weighting factors used and, as can be seen, a high weighting has been given to livestock activity compared to the physical factors considered. The combination of all 3 physical factors constitutes 20% of the value of the index. BOD has been used as the parameter which describes total livestock activity (for the above reasons), and two different BOD factors have been used to produce the livestock contribution to the index: 1) BOD production in relation to available land area; and 2) BOD production in relation to catchment area. Both of these measures are important, since the former gives an indication of intensity of risk, and the latter indicates the scale of risk throughout the catchment. Thus, one small dairy farm may present an acute risk in an otherwise non-agricultural catchment (ie waste loading is high), but the scale of risk over the entire catchment is not important (ie catchment waste production is low).

Based on the application of similar weighting factors to those used in estimating organic pollution risk, it has been possible to produce a map of pollution risk due to waste sheepdip.

iii) Limitations of the approach

The number of factors contributing to farm pollution risk that can be accounted for in a national analysis such as this are limited. Whilst the factors used in this study are very important to overall pollution risk, factors such as form and quality of management, chance events, proximity to watercourse, the presence of land drains (ie factors acting at the level of detail of individual farms or even fields) are equally important and cannot be incorporated into the analysis. It is therefore clear that this approach can only hope to direct attention to those catchments that have the most potential, on the basis of known factors, to give rise to farm pollution problems.

Mention should also be made of the level of accuracy of the digital data used in the analysis. From an error analysis, it has been estimated that 90% of grid cell values of average rainfall lie within 150 mm of the true average. The estimated accuracy of the digitised WRAP map is 500 metres, whilst 90% of point-values of height (from which landslope was derived) are estimated to lie within 50 metres of their true location. Concerning the base catchment map, the scope of the study allowed no more than a relatively crude estimation of watershed position, usually from small regional catchment maps copied freehand onto 1:250 000 River Quality maps. Nevertheless, 90% of representative sample points on these boundaries are estimated to lie within 500 metres of the true watershed - the exception to this would be NRA Southern Region, for which no catchment map was available and where low drainage densities make estimation of watershed position from River Quality maps highly dubious.

For the above reasons it is evident that this analysis can only provide a general description of each catchment in terms of slope, soil permeability and rainfall. Although data on livestock are held at a finer resolution than catchment level (2 km^2 grid-squares), the catchment is treated as the smallest discriminable unit. It is not possible to accurately locate agricultural land within a catchment, although the total area of catchment occupied by agriculture is known. For this reason, and because of the limits to the accuracy of the physical data described above, it is not possible to link agricultural land to its physical characteristics. It may well be, therefore, that within a catchment most livestock farming is practised in relatively low risk areas (flat land, permeable soils), whilst potentially high risk areas are devoid of livestock; such a catchment could be designated as high risk in this analysis. This has to be accepted as one of the limitations of a wide-ranging assessment such as this.

Agricultural census data have their own limitations, since livestock are assigned to the parish in which the owner is registered, and this may not be the same parish in which they are held. This can lead to catchments appearing to be of high pollution risk when there are in reality very few livestock present.

Lastly, the limitations of the data on observed farm pollution used in this study should be noted. These limitations are particularly important since the validity of the pollution risk maps produced has largely been judged on these data.

Pollution incident information is largely based on chance observation, usually by members of the public, and as such depends upon a clearly visible effect, public vigilance and public presence. This dependency means that it is inevitable that large numbers of incidents are never observed or reported, and that the efficiency of reporting is likely to decline with increasing remoteness from population centres. It also means that less visible forms of pollution, such as that from sheepdip, hardly feature in pollution statistics. Furthermore, incidents have to be verified by pollution control staff, and the inevitable time delay between reporting and attendance often means that real incidents are missed and cannot therefore be reported as such. All of these considerations lead to an underestimate of uncertain magnitude in the frequency of intermittent farm pollution problems and, more importantly to the identification of high risk areas, the likelihood of spurious geographical distributions of pollution incidents.

The usefulness of information on chronic farm pollution problems is limited in that the NWC classification system is not applied in headwater streams, where a high proportion of problems are to be found. Moreover, classification of a river stretch is based on a limited number of discrete samples through the year, which may not adequately reflect the prevailing water quality. Both of these factors lead to a likelihood of gross underestimation of chronic farm pollution.

For the above reasons, it is important not to place too much emphasis on agreement between the distribution of farm pollution risk, as produced in this analysis, and existing data on observed pollution problems. However, such a comparison is useful as a general guide, and it can highlight areas where water quality problems are likely to occur but where little monitoring has been undertaken.

5.3 Results and discussion

All maps referred to below can be found in the separate map annex to this report.

5.3.1 Distribution of livestock farming activity

Map 1 shows the national catchment map used as the basis for all subsequent distribution maps in the map annex. Table 1 in the map annex is a list of catchments, by region, which cross-refers to the catchment codes in Map 1.

Unfortunately, owing to problems in obtaining appropriate district boundaries it has not been possible to show livestock densities for Northern Ireland, although livestock data have been obtained for this area. The following discussion is therefore necessarily restricted to England, Wales and Scotland. Northern Ireland would be included in any subsequent analysis if further funding were available.

a) Dairy cattle

Map 2a shows the UK distribution of dairy cattle by river catchment. Hotspots of activity are apparent in south west Wales, south west and north west England, and around the Cheshire Plain. Very little activity is evident in Eastern England or Scotland, although there are significant numbers of dairy cattle to the south of Glasgow. Areas of lower but significant activity generally border the above hotspots.

At a more detailed level, the highest densities of dairy cattle in the south west of Wales are located in the **Taf, Cynin** and **Cywyn** valleys (0.9-1.2 head ha^{-1} catchment area), with the **Eastern** and **Western Cleddau,** the middle and lower reaches of the **Teifi,** the **Gwili,** lower **Tywi, Nyfer, Gwaun** and surrounding coastal areas having slightly lower densities (0.6-0.9 head ha^{-1}).

Some of the catchments around the Cheshire Plain have the highest dairy cattle densities in the UK (>1.2 head ha^{-1}), these being the upper **Weaver, Gowy,** and **Northerbury Brook** (Dee catchment). Adjacent catchments with slightly lower densities (0.9-1.2 head ha^{-1}) include the **Dane, Wheelock** and **Wincham Brook** (all in the main Weaver catchment), the middle reaches of the **Dee,** the **Sow, Churnet** and middle and lower reaches of the **Dove.** Slightly lower densities again (0.6-0.9 head ha^{-1}) are found in the upper tributaries of the **Severn** (including the **Morde, Perry, Roden** and **Rea Brook**).

In the south west of England (encompassing NRA South West and Wessex Regions), intermediate to high densities are widespread, with the greatest densities (0.9-1.2 head ha^{-1}) in the **Axe** catchment (near the Exe), upper **Tamar** (main river), the middle reaches of the **Stour** and its tributaries (**Cale, Lydden**), the **Mells** (Bristol Avon), **Hartlake** and **Sheppey** (Brue). Intermediate densities (0.6-0.9 head ha^{-1}) are found throughout the **Torridge** and **Exe** catchments, the tributaries of the upper **Tamar** (**Thrushel, Carey** and **Ottery**), the **Erme, Yeo, Isle, Axe** (Weston-Super-Mare), the upper **Bristol Avon** and upper and middle reaches of the **Frome.** There are hardly any catchments in the South West area which fall into the lowest density class (<0.3 head ha^{-1}), indicating significant dairy activity throughout.

In the north west of England, high densities (>1.2 head ha^{-1}) are found in the **Brock** catchment and middle reaches of the **Wyre,** with slightly lower densities (0.9-1.2 head ha^{-1}) on the lower **Wyre** and lower **Ribble,** the **Conder,** and also on the **Wampool** and **Waver** in the northern Lake District. The lower **Eden** (including the **Caldew** and **Petterill**), **Ellen,** middle reaches of the **Ribble,** upper **Aire, Darwen** and **Bela** all have intermediate densities (0.6-0.9 head ha^{-1}). Low but significant densities (0.3-0.6 head ha^{-1}) are found throughout the **Eden** catchment and the middle reaches of a number of catchments running eastwards across the Pennines to the east coast (**Aire, Nidd, Washburn, Wharfe, Ure, Swale, Wiske** and **Leven**).

In the South West of Scotland, intermediate densities (0.6-0.9 head ha^{-1}) are found on the **Irvine,** with lower densities on the **Ayr,** middle reaches of the **Clyde, Avon Water, Urr Water** and lower **Nith.**

Finally, low density clusters of dairy activity are evident in Gwent and the southern Welsh border area (eg lower **Usk** and **Wye**), and also in south east England along the South Downs and adjacent catchments (eg middle reaches of the **Arun, Kurd, Adur West,** upper **Mole** and **Eden)**.

b) Beef cattle

It is evident from Map 2b that beef farming activity is generally not as concentrated into specific areas as dairy farming, but areas of higher activity are still apparent. The distribution is again skewed towards the western side of the UK as with dairy farming activity, with the most notable concentration of activity in the south west of England, and other important concentrations in northern England (along the Scottish border), the border area between Wales and England, south west Wales, and (in Scotland) the Solway area and north eastern Perthshire.

In south west England, beef farming is concentrated in the NRA South West Region, in contrast to dairy farming which is also very important in NRA Wessex Region. The highest beef cattle densities (>0.6 head ha^{-1}) are found in areas of the **Tamar** catchment (the **Ottery, Inny** and lower reaches of the **Tamar**), with slightly lower densities (0.45-0.6 head ha^{-1}) in other areas of the catchment (the **Lynher, Thrushel, Lydd, Tiddy** and lower and middle reaches of the main river), and also in the **Camel** catchment, the **Fowey,** the middle reaches of the **Exe** (including the **Batherm**), **Tresillion** and **Allen, Carnon** and **Kennal Vale.** Virtually the whole of the remainder of NRA South West Region has intermediate densities of beef cattle (0.3-0.45 head ha^{-1}), including the **Torridge** catchment, the rest of the **Exe** catchment and the **Taw.**

Along the Welsh border, the highest densities (0.45-0.6 head ha^{-1}) are found in areas of the upper **Severn** (including the upper **Teme**), Intermediate densities are found throughout the **Wye** catchment (including the **Monnow, Lugg, Frome** and **Ithon),** the upper **Severn** (including the **Clun,** middle reaches of the **Teme, Onny, Corve, Rea, Camlad, Rea Brook** and **Tanat)** and lower **Usk**.

Catchments holding significant densities of beef cattle (0.15-0.3 head ha^{-1}) in south west Wales are essentially the same as those holding high densities of dairy cattle (Section 5.3.1 (a)). Other noticeable concentrations in Wales are found on Anglesey (including the **Cefni** and **Braint)** and the **Leyn Peninsula,** on the south coast between Swansea and Cardiff **(Ogmore, Ely, Kenson** and **Cadoxton**), and in the **Clwyd** catchment to the north.

In northern England, the catchments of the northern Lake District hold the highest densities of beef cattle, with the **Wampool** having >0.6 head ha^{-1}, and the **Waver, Ellen** and lower **Eden** having between 0.45 and 0.6 head ha^{-1}. Intermediate densities (0.3-0.45 head ha^{-1}) are found in adjacent catchments (upper and middle reaches of the **Eden, Petterill, Caldew,** lower **Derwent, Cocker, Irthing, White Lyne** and **Black Lyne**) and other catchments stretching east across to the Northumbrian coast (lower reaches of the **North** and **South Tynes, East** and **West Allen,** upper reaches of the **Wansbeck** and **Blyth,** lower **Aln** and lower **Coquet**). There are also a number of catchments with intermediate densities (0.3-0.45 head ha^{-1}) running from the south of NRA Northumbrian Region down into the Vale of York (the **Browney, Gaunless,** middle reaches of the **Tees,** middle and lower reaches of the **Swale, Wiske,** lower **Ure** and the upper **Ouse**).

A few small catchments around the western Peak District area hold intermediate densities of beef cattle (**Sow, Blithe,** lower **Dove, Hilton Brook, Wye** (tributary of the Derwent) and **Amber**), and there are also similar densities in a cluster of catchments to the south of Birmingham (**Avon** headwaters, upper **Soar, Sence, Eye** and upper **Welland**).

In Scotland, the Solway area holds a concentration of beef cattle, with a high density (0.45-0.6 head ha^{-1}) in the **Urr** Water catchment and intermediate densities (0.3-0.45 head ha^{-1}) in catchments such as the lower **Nith** and **Cairn Water,** the **Water of Fleet** and the **Dee,** the **Bladnoch** and the **Water of Luce.** Further north in Perthshire, there are high densities in the **Ythan** and **Ugie** catchments and intermediate densities in the **Cowle Water** catchment, upper **Don,** lower **Dee, Urie** and **Deveron.**

c) Pigs

Map 2c shows the UK distribution of pigs by river catchment. From this, it is clear that pig rearing is concentrated in two main areas along the east coast, Yorkshire (Vale of York and eastwards to Humberside coast) and East Anglia, with minor but significant concentrations in the north west of England, the Midlands, Thames Valley, Somerset, Dorset, and a small pocket of activity in Perthshire. Very little activity is evident along the west coast of the UK.

In the Yorkshire hotspot (all in NRA Yorkshire Region), highest densities (class 5, >3 ha^{-1}) are found in the upper **Ouse** catchment, the **Foulness** and **Mires Beck, Stream Dyke** and around **Spurn Head**. Slightly lower densities (2-3 ha^{-1}) are found in the lower **Calder,** lower **Ure, Foss,** lower **Derwent,** the **Beck** and the **Hull**. Catchments holding intermediate densities (1-2 ha^{-1}) are the **Wiske,** the middle and lower reaches of the **Swale** and **Nidd,** middle reaches of the **Ure, Gypsey Race,** middle **Ouse** and lower **Aire**. A number of adjacent catchments have low but still significant densities (class 2, 0.5-1 ha^{-1}).

In the East Anglian area of activity (all within NRA Anglian Region), densities of >3 ha^{-1} are found in the **Dove** and **Chickering Beck** and parts of the **Deben** and lower **Wissey** catchments, whilst slightly lower densities (2-3 ha^{-1}) are located in the middle reaches of the **Waveney,** the upper **Alde** and **Ore, Deben, Gipping, Tas** and upper reaches of the **Little Ouse**. Catchments with intermediate densities (1-2 ha^{-1}) are the upper **Waveney,** the **Thet,** upper **Yare** and **Tiffey,** upper **Wissey, Tud,** upper **Bure, Blyth** and **Walpole,** and tidal reaches of **Deben** and **Orwell**. As in Yorkshire, a number of catchments bordering this hotspot of activity have low but significant densities (class 2, 0.5-1 ha^{-1}).

In the small area of activity in the north west of England (within NRA North West Region), the middle reaches of the **Wyre** hold densities of 2-3 ha^{-1} (class 4), whilst the lower **Wyre,** tidal **Ribble** and lower **Douglas** have intermediate densities (1-2 ha^{-1}). To the south of this area, a number of catchments hold low but significant pig densities.

In the Thames Valley, the **Lambourne, Pang** and **Sulham, Ock,** and some of the upper and middle reaches of the Thames itself hold intermediate densities

(1-2 ha^{-1}), with the predominantly agricultural catchments to the north and west holding low but significant densities (0.5-1 ha^{-1}).

Further west in NRA Wessex Region, intermediate densities are found in the **Semington Brook** catchment, **Cam Brook, Mells, Cary** and **King's Sedgemoor Drain, Cerne** and **Frome**. High densities are found in some small catchments to the south of this area (upper **Frome** and **Piddle,** and the **Simene**).

To the west in NRA South West Region, the **Otter** has intermediate densities (1-2 ha^{-1}) and a number of adjacent catchments have slightly lower densities (0.5-1 ha^{-1}), but there is generally very little activity.

In the Midlands, a few isolated catchments hold densities of 1-2 head ha^{-1} (upper **Soar** and **Witham** and some reaches of the **Trent**), and a number of catchments (particularly to the south of the Yorkshire hotspot and in the Cheshire Plain area) hold slightly lower but significant densities.

d) Poultry

It is evident from map 2d that poultry farming activity has a much more scattered distribution than other livestock types, with isolated catchments of high density (>40 ha^{-1}) in north Wales (**Braint**), the Midlands (**Hilton Brook, Rothley Brook**, upper reaches of the **Great Ouse**), and north east England (**Castle Eden Burn, Leven**). However, small clusters of catchments with significant activity are evident in East Anglia, Lancashire, Lincolnshire/Nottinghamshire and around the Forth Estuary, and there are belts of catchments with lower densities running north-to-south along the Welsh border country, and also east to west in south west England. A number of catchments in south east England also have significant densities.

Catchments with the highest density (>40 head ha^{-1}) in the East Anglian area of activity are the middle reaches of the **Waveney,** the **Dove** and **Chickering Beck,** the upper **Ant** and the **Tas,** whilst the upper reaches of the **Little Ouse** have slightly lower densities (30-40 ha^{-1}). Intermediate densities (20-30 ha^{-1}) are found in the upper **Waveney,** the **Thet** and the **Gipping,** and a number of adjacent catchments have lower but still significant densities (10-20 ha^{-1}).

In Lancashire, the lower **Douglas** and the middle reaches of the **Wyre** have high densities (class 5 - >40 head ha^{-1}), and slightly lower densities (30-40 ha^{-1}) are found in the **Darwen** and **Lostock**. Intermediate densities (20-30 ha^{-1}) are found in the **Crossens** and **Yarrow** catchments.

In the Lincolnshire/ Nottinghamshire area, the lower **Maun** has a high density (class 5 - >40 ha^{-1}), whilst class 4 (30-40 ha^{-1}) densities are found in the lower reaches of the **Trent,** and the lower **Ancholme.** The upper **Maun** , **Slea** and **Hobhole** drainage area have intermediate densities (20-30 ha^{-1}), and a number of adjacent catchments have densities of 10-20 ha^{-1}.

It should be noted that due to the lack of large scale clustering of poultry farming activity in specific areas, it is likely that large poultry farms will occur in catchments in isolation, such that when poultry numbers are averaged out over the catchment low densities are indicated even though localised pollution risk may be high. This is unfortunate but unavoidable in an assessment on this scale.

e) Sheep

Map 2e shows high sheep densities over most parts of Wales, stretching into the border country; indeed, only the cattle farming area in south west Wales has low densities. In comparison, the rest of the UK has relatively low concentrations of sheep. The next most important area is the Pennines, with lower but significant densities in the adjacent areas of the Lake District and Yorkshire Dales. Southern Scotland also has low but significant densities, but further north all catchments are placed in the lowest category, even though sheep farming is an important activity in these areas. The south west of England has a concentration of sheep in the Exmoor area and a smaller concentration in the Dartmoor area; in addition, much of the rest of the south west has low but significant sheep densities. Smaller concentrations occur in Kent (around Romney Marsh), the Peak District, the Yorkshire Wolds and the northern Cotswolds.

In Wales, the upper reaches of the Wye (including the **Irfon** and **Ithon**) have the highest sheep densities in the UK (>4 ha-1), along with tributaries of the upper Severn (upper **Teme,** the **Sence** and middle reaches of the **Soar**) and the **Elwy** (a tributary of the Clwyd). Adjacent catchments have slightly lower sheep densities of 3-4 ha^{-1} (middle reaches of the **Tywi,** upper **Usk, Monnow,** upper **Teifi, Ystwith, Wye headwaters**, upper **Dovey, Severn headwaters** and several upper Severn tributaries (**Banwy,** lower **Vyrnwy** and **Tanat**), **Dysynni,** upper reaches of the **Dee** including the **Alwen** and **Ceiriog,** upper **Clwyd,** lower **Conwy, Gwyrfai** and **Seiont**) but still higher than nearly all other catchments in the UK. Similar densities are found on Anglesey (including the **Alaw**), and the **Llyn Peninsula.** Catchments between the Welsh uplands and lowland areas tend to have intermediate sheep densities (2-3 ha^{-1}).

In the Pennines, a number of catchments have intermediate densities of 2-3 ha^{-1}: the **Eamont, Lowther, Kent, Rawthey,** upper **Eden, Greta,** middle reaches of the **Lune, Wenning,** upper and middle reaches of the **Ribble,** upper **Hodder,** upper **Aire** and middle reaches of the **Wharfe.** Adjacent catchments in the Yorkshire Dales (including the upper **Swale,** and the upper and middle reaches of the **Ure** and **Nidd),** the Lake District (including the upper and middle reaches of the **Eden,** the **Petterill, Caldew,** upper **Derwent** and upper **Leven**) and up into the Cheviots (including the upper and middle reaches of the **Tees,** the **North** and **South Tynes** and the **Coquet)** all have lower but significant densities (1-2 ha^{-1}).

In southern Scotland, significant densities (1-2 ha^{-1}) are found throughout the **Tweed** catchment (including the **Teviot, Ettrick** and **Yarrow Waters, Blackadder** and **Whiteadder Waters**), in some areas of the Solway region (including **Urr Water,** lower **Nith** and **Cairn Water, Annan**), the upper and middle reaches of the **Clyde,** and the **Esk** (Forth region).

In the south west of England, catchments draining Exmoor with the highest sheep densities (3-4 ha^{-1}) are the **Barle, Yeo** and **Lyn,** with intermediate densities (2-3 ha^{-1}) in the much of the rest of the **Taw** catchment (**Mole, Bray** and tidal **Taw**), the **Batherm** (Exe tributary), and the **Cober** (which drains the adjacent Dartmoor). Lower but significant densities (1-2 ha^{-1}) are found over much of the remainder of NRA South West Region, including throughout the **Torridge, Tamar** and **Camel** catchments.

In Kent, the **Brede,** lower **Rother** and **Welland Marsh** have the highest densities (2-3 ha^{-1}), with the **Beult,** upper **Great Stour, Dour** and the middle and upper reaches of the **Rother** having lower but still significant densities (1-2 ha^{-1}).

Small clusters of catchments with densities of 1-2 sheep ha^{-1} occur in the Peak District (**Wye,** upper **Derwent, Manifold** and upper **Dove, Derwent reservoirs, Goyt, Sett, Etherow, Dean** and **Micker Brook**), northern Cotswolds (**Leam** and **Stowe, Stour,** upper **Cherwell, Tore,** upper **Nene, Wilton Nene, Avon headwaters** and **Sence**) and Yorkshire Wolds (middle reaches of the **Rye, Walmouth Beck, Costa Beck, Seven** and the **Esk**).

5.3.2 Pollution risk and its assessment

Farm visits to assess pollution risk are a vital aspect of farm pollution control. In addition to giving an indication of the likelihood of pollution problems, they fulfil an essential educational role and also serve to remind the farmer that his activities are under scrutiny.

i) Current practices and survey results

The level of effort put into, and degree of formalisation of, farm pollution risk assessment varies considerably between regions, depending to a certain extent upon the perceived importance of farm pollution in each region relative to other sources. Individual farm visits are necessarily labour intensive and there is often little opportunity for pollution control staff to pursue such proactive work in the face of their large reactive workload. Farm and Conservation Grant Scheme assessments and responses to pollution incidents provide *ad hoc* opportunities for general risk assessment; in most RPB regions these are the only opportunities to undertake risk assessments.

It should be noted that the risk assessment is only the initial phase of pollution prevention, and that follow-up work to ensure preventative measures are taken is vital if improvements are to be made. Such follow-up work constitutes a large proportion of the effort used in farm surveys.

NRA South West Region have a regionwide farm campaign and have now visited over 6000 farms since 1984. **Anglian region** also have a rolling programme of farm visits across the region, and **Northumbrian Region** plan to develop a regionwide programme. A number of NRA regions (**Severn-Trent, North West, Yorkshire, Thames and Welsh**) target their proactive effort by selecting catchments/areas where farm pollution problems are most acute. **Welsh Region** survey all potential polluters, rather than concentrating only on farms, in order to show farmers that they are not being singled out. **Wessex** and **Southern regions** perform risk assessments on a more local and *ad hoc* basis, relying upon the knowledge of local pollution control staff rather than directing effort at a regional level.

Risk is assessed subjectively in all regions, based on various contributory factors which are not standardised between or within regions. The only real exception to this is **Forth RPB**, who have recently introduced a standardised farm questionnaire which is now used on all their farm surveys. This asks for a long list of details including: slurry and silage storage capacity, the likely fate of effluents, detailed questions on sheep dippers (construction, method of pesticide disposal, etc), and the current impact on receiving waters.

Although risk assessment is subjective countrywide, it is performed by experienced pollution control staff whose knowledge should not be underestimated. Factors that are considered in most instances are given below:

Presence of discharges
Age, condition and type of storage facilities
Waste storage capacity (in relation to waste production)
Clean water separation
Proximity to watercourses
Topography
Soil type
Rainfall
Quality of management
Scope for containment of leaks/spillages
Presence of land drains
Downstream users

Waste handling facilities
Sheep dipper design

The area of suitable land for waste spreading in relation to waste production is not usually assessed, although general land suitablility (in terms of topography and soil type) may be.

Farms are divided into 3 risk categories in a number of NRA regions **(South West, Yorkshire, Welsh, Thames and Severn-Trent)** and the type and timescale of follow-up action is dictated by these categories. In the other 5 regions, high risk farms are identified and singled out for follow-up action.

The following risk categories are used in **NRA South West Region**:

Red - farms that are polluting and have been reported to pollution control staff for a quick remedial visit.

Green - farms that are discharging but not causing pollution. This category consists of: those farms likely to be discharging but not causing pollution; those likely to cause pollution; and those which cannot be classified as blue.

Blue - farms that are unlikely to pollute.

Results up to the summer of 1990 showed that 465 farms out of the 6000 visited so far in their campaign had a red status, with a further 1333 having a green status.

NRA Severn Trent Region undertook a major farm pollution risk survey in 1988, targeted at the major dairy areas of Shropshire, Staffordshire, Warwickshire and Leicestershire. One thousand and sixty-eight farms were visited, and each was given a series of grades ('satisfactory', 'doubtful' or 'unsatisfactory') on a number of different types of pollution risk (including land disposal, farm housing, drainage etc). It was concluded that 39% of farms surveyed had unsatisfactory or dubious slurry systems, whilst 36% had unsatisfactory or dubious silage systems. Taking all types of pollution risk into account, only one third of farms were considered satisfactory.

NRA North West Region have recently undertaken targeted farm pollution risk surveys on the Weaver (1987), Brock (1987) and Gowy (1988) and Wampool catchments. In the Gowy catchment, pollution risks were divided into 9 categories (eg slurry stores, silage, land run-off, etc) and each farm was classed as 'satisfactory' or unsatisfactory' in each category. Out of 157 farms visited, 84 (54%) are to be sent or have been sent letters requiring remedial action. Visible impacts on water quality in the Gowy catchment are mainly restricted to unclassified headwater streams. A number of tributaries in the Brock catchment vary between NWC class 1B and 4 due to the fluctuating impact of farm discharges. Two hundred and nine working farms were visited in the 1987 survey and were classed according to the NRA/MAFF Farm Waste Report categories for pollution incidents. Forty-two percent (87) of farms were producing some sort of discharge, with 26% having leaking silos, 24% discharging parlour/dairy washings, and 22% having overflowing storage/reception tanks. These 87 farms were sent letters requiring remedial action, and a total of 97 farms required follow-up visits within different timescales.

NRA Yorkshire Region has conducted recent risk surveys on the Wharfe, Wiske, Upper Derwent and Upper Dearne. The Wharfe survey consumed 3 man years of effort (6 staff each occupied for 6 months), and involved visits to 300 farms. It was found that one third of farms posed a serious pollution risk, whilst another third posed an intermediate risk.

NRA Northumbrian Region conducted a small catchment study of sheepdip locations and found high risks of pollution due to the close proximity of dippers to watercourses and the presence of plugged drains with direct access to the river. **NRA Welsh Region** still finds a high number of sheepdips with direct plugged access to adjacent watercourses. The risk of sheepdip pollution varies with the stipulations laid down by MAFF each year. In 1990, only one dipping period was required, meaning a halving of sheepdip usage and in many cases, where spent sheepdip is not emptied until the next dipping period, more pesticide degradation prior to disposal. **Tweed RPB** are currently engaged in a study of sheepdips in their region, and initial indications are that a relatively high proportion (*c* 40%) of dippers could cause pollution. They believe that pollution risk is minimised if the dipper is emptied immediately after use and the spent dip is diluted and spread thinly to land. In reality dippers are invariably not emptied until the next dipping period. Disposal of sheepdip to land is now recommended by the majority of regions, except in aquifer protection zones. In areas where there is no risk to groundwater some regions still allow soakaways.

Standard risk report forms are completed in 4 of the NRA regions (**Southern, South West, Welsh** and **Yorkshire**), and one RPB region (**Forth**), and in one NRA region (Chichester district of **Southern Region**) the information is subsequently entered onto a computer archive. **South West Region** keeps a computerised archive of farm details, including risk category. **Yorkshire Region** also maintains an archive of 6000 farms.

ii) Discussion

Most farm pollution problems in surface waters occur on heavy soils where surface run-off is high; in dry conditions such soils crack and can give wastes easy access to watercourses via land drains. The high risk of contaminated run-off on such soils is compounded by sloping ground and high rainfall. High rainfall also puts greater strain on waste storage facilities if clean water is not separated or storage is not covered (which is often the case). Areas of high rainfall also suffer from fewer suitable opportunities to spread waste to land, meaning that waste has to be stored for longer periods, again leading to high risks of undersized storage facilities.

The above considerations of risk are all related to physical factors that can be quantified relatively easily from mapped information. Pollution problems arising include overflowing slurry stores and reception pits, yard run-off, and land run-off following land application. There are other less predictable risk factors, mentioned in Section 5.2.2, which can only be quantified through farm visits. These include quality of management, farm practices (eg yard washing), design and age of waste management systems, the presence of land drains, and the proximity of farm buildings and storage facilities to watercourse access. Such factors can give rise to the whole spectrum of farm pollution problems.

Land drains can short-circuit the normal and more difficult route of wastes into watercourses, and their presence is often unknown to pollution control staff. Under-drainage is frequently installed on heavy soils prone to waterlogging, where pollution risk is already high. A key consideration in pollution risk from sheepdip is dipper design, and in particular whether there is a drainage area that collects sheepdip dripping off fleeces and returns it to the dipping tank. Contractors using mobile dips are an increasing cause of concern in many areas, since they have the potential to dump spent sheepdip injudiciously and quickly move out of the area.

Certain methods of waste handling give cause for concern and have to be considered high pollution risks. The use of mobile dips above is one example, and third party arrangements for the disposal of pig slurry are a similar concern.

Approaches are being developed for a more objective assessment of farm pollution risk. The Potable Abstraction Risk Index (PARI) is to be further developed within the NRA R&D Programme (Ref A17(90)1) for the assessment of point-source discharges, such as storage failure or sheepdip overflow/discharge. It considers the amount of pollutant likely to enter a river, the likely available dilution and highest acceptable environmental concentration of the pollutant. The index is given by:

$$I = \frac{W}{(A \times Q95 \times C)}$$

where: W is the weight of pollutant in kilograms,

Q95 is the 95 percentile exceedance flow of the river in m^3/s,

C is the highest acceptable environmental concentration,

and A is a factor which varies depending upon the likely duration of pollutant discharge (A = 3600 for a discharge lasting 1 hour).

The index can be modified by assigning weightings to factors affecting risk. These would include installation design, age, visible condition and capacity in relation to the storage volume required (particularly relevant for slurry storage).

For dispersed pollution sources, two methods for assessing the potential polluting load from land spread with animal slurry and sludge are being developed at WRc, so that areas of farmland can be classified as high or low risk with respect to the pollution of receiving waters (NRA Project Ref A17.007). One method uses basic land use characteristics, such as soil type, slope and distance from watercourse, together with a subjective ranking of the importance of each factor, to allow each land unit to be given a risk classification. This approach is ideally suited to an analysis using Geographical Information Systems (GISs), and the method has been applied to some catchments.

The alternative method being developed involves the formulation and solution of flow and pollutant transport equations in a water flow and quality simulation. This yields more objective results in terms of cause and effect than the method previously described, but has a considerable data requirement and would not readily be applied to many catchments. The best way forward would appear to be to combine the two approaches so that the simulation method is used to refine the GIS methodology, which may then be more widely applied. The estimation of the capacity of a farm to accept the slurry it produces is a key consideration in determining the risk of over-application. The combination of these two approaches offers a way of determining this parameter.

5.3.3 Identification of high risk areas

i) Data collation

The collation of a complete national coverage of observed farm pollution problems, with which to compare formulated distributions of risk, was hampered by the difficulty in obtaining data from regional NRA archives.

Regarding pollution incidents, computerised archive systems are at various stages of development and sophistication around the NRA regions. Thames and

North West Regions have highly interactive systems, with the former being menu-driven and the latter requiring some degree of computer literacy. They are both based on river catchments, which is useful for pollution prevention work. **Yorkshire** and **South West Regions** have good systems, but the former is perhaps not particularly interactive and the latter has some difficulty with some types of data extraction due to the historical extract programmes inherited from South West Water Authority. All four of these regions were able to provide full lists of pollution incident data from 1988 and 1989. South West were, however, unable to supply severity grades due to the form in which the data were requested (ie individual incidents by national grid reference).

Welsh Region have recently commissioned a new pollution incident archive, but historical data is not available on the system. However, district pollution control staff managed to extract all of the required incident information from individual files.

Wessex Region have a pollution incident archive, but it was essentially designed for operational management in the water industry and was not useful for this data collection exercise. A new archive is being developed but it will be some time before it is operational. For this reason, the only information that could be gathered without great difficulty from Wessex concerned those incidents where formal samples were taken and a decision was taken centrally as to whether prosecution proceedings should be initiated. This amounted to just over half of the serious incidents recorded in the Wessex region for both 1988 and 1989, and can therefore only be taken as a very crude indication of the true distribution of incidents.

Northumbrian Region have recently set up a computerised archive based on that of Yorkshire Region, but was not operational in time to be of benefit to this study. However, regional staff manually extracted the data required from individual files. **Anglian Region** have also recently set up a regionwide archive, but again it was not operational in time for this study. Eastern Area managed to extract data on a catchment basis from incident files.

Severn-Trent Region have recently set up an incident archive, and **Southern Region** are in the process of doing so, but again these were not available in time for this study. It was deemed to be too time-consuming for staff in either region to extract the required information from individual files, meaning that no incident data have been collected from these regions.

With respect to NWC class downgradings attributable to farm pollution, only 4 regions (**Severn-Trent**, **Yorkshire**, **Welsh** and **Anglian**) provided data, whilst there were no known downgradings in **Northumbrian Region**. The data received are given in Appendix D.

ii) Data analysis

a) Dairy cattle

Map 3a shows the distribution of organic waste production from dairy cattle in relation to the amount of land potentially available for disposal. The pattern is very similar to that in Map 2a, suggesting that the density of dairy cattle in relation to the area of land potentially available for waste disposal is relatively constant between catchments. Farm pollution incident data from 1988 are superimposed for comparison of pollution risk and observed impact.

Catchments with the highest waste loadings have loading rates in the region of 40 litres day^{-1} ha^{-1} of potentially available land. For an overwintering period of 4 months, the loading rate of stored undiluted waste on the available land would be 6.4 m^3 ha^{-1}, assuming that all waste is stored as slurry. If the slurry is diluted on a 1:1 ratio (this is normal practice for ease of handling) the loading rate would amount to 12.8 m^3 ha^{-1}.

Importantly, this loading rate assumes that all agricultural land within a catchment is available for disposal and would not pose a pollution risk. The major obstacles to such an assumption are that: the farmer wishing to dispose of slurry may not own the land that is potentially available for disposal; and that physical factors such as rainfall, soil permeability and landslope will not permit safe application on all potentially available land. Physical catchment characteristics will be considered later in the section.

The pollution incidents indicated on Map 3a are those attributable to cattle generally (ie dairy and beef) rather than dairy cattle as a whole. This means that comparisons with waste loadings derived purely from dairy cattle are not likely to yield good relationships. Also, it should be borne in mind that data for NRA Severn Trent and Anglian Regions are not available, and that regional differences in the way that data is archived means that data is not readily comparable between regions. Notwithstanding these considerations, the distribution of pollution incidents does broadly reflect the distribution of waste loading from dairy cattle.

In the Cheshire Plain area, pollution incidents are concentrated into catchments with high waste loadings. The most notably affected catchments are the upper **Weaver, Northersbury Brook** and the middle reaches of the **Dee,** with the majority of the incidents being caused by leaking slurry stores, silage liquor and farmyard drainage. Pollution from silage liquor is not dealt with in this risk analysis directly, but it can be seen that it follows the same pattern as cattle slurry problems.

The catchments to the south and east of the worst affected catchments have high dairy cattle waste loadings, but no pollution incident data is available for comparison since they fall within NRA Severn Trent Region. However, information on NWC class downgradings is available (Appendix D) for Severn Trent Region. This shows that none of the catchments with very high waste loadings (class 5 - **Blithe, Churnet, Tean** and the middle and lower reaches of the **Dove**) have any recently reported downgradings attributable to farm pollution. Of the catchments in the next highest waste loading category (class 4 - upper **Terne, Sow,** upper **Trent, Roden, Perry,** upper reaches of the **Severn, Manifold,** upper **Dove, Hilton Brook,** and **Ecclesbourne**), the **Roden** is the only catchment with reported downgradings (8.7 km, including Soulton Brook).

Further north, the middle reaches of the **Ribble** has a high number of pollution incidents, along with the lower reaches of the same river and middle reaches of the **Wyre**. The area first mentioned is in a high (class 4) waste loading class, and the other two areas are in the highest class (class 5). Again, those incident types featuring most are slurry store discharges, silage liquor leaks and farmyard drainage. On the Wyre, dairy problems combined with discharges from intensive piggeries have led to a downgrading in NWC class to class 3. Some catchments further away from the main concentration of waste loading in this area also have high pollution incident densities: the upper **Dearne** (class 4 waste loading), the middle and lower reaches of the **Calder** (only class 2 waste loading), the **Colne** (class 3) and the middle reaches of the **Nidd** (class 3) are examples of this. In contrast, some catchments with high waste loadings (class 4 or 5) in the main area of activity have low pollution incident densities: examples are the **Conder,** lower **Lune, Bela** and **Keer.** These catchments tend to be located along the coastal strip and the low number of incidents may be related to some ameliorating physical factor (such as reduced landslope); however, NRA North West Region have identified the **Lune** as a problem catchment, and the absence of recorded pollution incidents here may be due to gaps in the availability of national grid reference data for some incident records.

Further east, the **Wiske** has an intermediate waste loading but has no recorded pollution incidents for 1988; however, this river was downgraded in 1987 from NWC class 2 to class 4 due to dairy farming. It has since recovered after an intensive campaign by NRA Yorkshire Region, but 24.1 km are still downgraded (NWC class 2, Appendix D). In the same area, NRA Northumbrian Region have recorded high ammonia levels in the **Skerne** and **Leven** which may be due to dairy or beef cattle; these catchments both have low but significant waste loadings from dairy cattle (class 2).

In the northern Lake District, the **Wampool** and the **Waver** have the highest waste loadings but have relatively low pollution incident densities compared with the upper and middle reaches of the adjacent **Eden** catchment, which have intermediate to low waste loadings from dairy cattle.

In south west Wales, high pollution incident densities reflect high waste loading more accurately, with the highest number of incidents occurring in the **Taf** (class 5), **Cynin** and **Cywyn** (class 5), and the **Eastern** and **Western Cleddau** (both class 4). The majority of incidents are again due to either slurry stores, silage liquor or farmyard drainage. The Eastern and Western Cleddau also have recent reported NWC downgradings (see Appendix D) due to cattle (either beef or dairy): 14.6 km on the former (mainly on the **Syfynwy**) and 6.1 km on the latter (including the **Anghof**).

In Gwent and southern Welsh border country there are catchments with high numbers of pollution incidents but relatively low waste loadings: these are the lower **Usk** (class 3 waste loading), **Monnow** (class 1), **Frome** (class 2) and lower **Lugg** (class 2). Recent NWC downgradings due either to beef or dairy cattle in the same area have been reported (see Appendix D) in: the lower **Usk** (Olway Brook, 8.0 km), the **Monnow** (Trothy, 12.9 km; Worm Brook, 16.2 km; Jury Brook, 5.8 km), lower **Wye** (Garren Brook, 13.8 km; Rudlace Brook, 4.0 km; How Caple Brook, 5.8 km), **Frome** (Lodon, 18.0 km; Hackley Brook, 5.0 km), lower **Lugg** (Withington Lakes, 5.2 km; Withington Marsh Brook, 6.8 km; Moreton Brook, 8.8 km; Wellington Brook, 4.8 km; Bodenham Brook, 6.1 km), upper **Lugg** (Main Ditch, 13.0 km; Ridgemoor Brook, 5.6) and the middle reaches of the **Wye** (Enig, 6.9 km). This represents a severe impact on minor tributaries in the lower and middle reaches of the main Wye catchment, and cannot readily be explained by the intensity of dairy farming alone.

In the south west of England, catchments in NRA Wessex Region show few incidents due to lack of data availability, as explained above. Those incidents which are shown do not generally fall into the main concentration of waste loading (centred on the Lydden, middle Stour, Cale, Meels, Hartlake and Sheepey), but a number fall into catchments to the north east of this area in catchments with intermediate loadings (eg upper and middle reaches of the **Bristol Avon**). NRA Wessex Region identified catchments such as the **Yeo, Brue, Cary, Somerset Frome** and **Bristol Avon** as having the worst problems, mainly from dairy farming. With the exception of the Bristol Avon, all of these catchments have high waste loadings from dairy cattle (class 4 - 30 to 40 litres day^{-1} ha^{-1}).

Further west in NRA South West Region, incidents are relatively evenly spread over all catchments with intermediate to high waste loadings, with reduced numbers in catchments with low (class 1 or 2) loadings. Numbers of incidents occurring in areas with high loadings (class 4 or 5) does not appear to be any greater than those occurring where loadings are intermediate (class 3). The 3 main causes of incidents throughout the area are again slurry stores, silage liquor and farmyard drainage.

In the south east of England, the **Eden** has a high incident density, with an intermediate loading of dairy cattle waste. Other catchments with intermediate waste loadings in this area fall within NRA Southern Region, for which no pollution incident data are available. Southern Region report that the majority of farm problems are caused by dairy farms on clay, including the **Uck,** and upper **Medway (Eden, Beult** and **Teise)**. The Uck has one of the highest waste loadings in the region (class 3) whilst the upper Medway tributaries fall within class 1 or 2.

b) Beef cattle

As with dairy cattle, the general distribution of waste loading from beef cattle (Map 3b) is similar to the distribution of livestock density. However, the situation with beef cattle in NRA South West Region appears more acute in a number of catchments when viewed in terms of waste loading: the **Bovey, Tavy, Walkham** and **Fal** all have intermediate beef cattle densities (class 3), but are all in the highest waste loading category (class 5). A number of adjacent catchments have changed from class 3 in terms of stocking density to waste loading class 4. Interestingly, this area appears not to suffer greatly from cattle-related pollution incidents, unlike nearly all other areas of NRA South West Region.

The area of activity in the Scottish border region is also more important when viewed in terms of waste loading. Again, although waste loading is high in a number of catchments, few cattle-related pollution incidents have been reported. Catchments in class 4 (20-30 litre day^{-1} ha^{-1}) in this area include the **Wampool, Waver** and **Esk** in NRA North West Region, and the lower reaches of the **North** and **South Tyne** in NRA Northumbrian Region. No cattle-related pollution incidents were reported in 1988 in any Northumbrian catchment with a class 4 designation; high ammonia levels in the **Skerne** and **Leven** are possibly caused by dairy and/or beef cattle, as mentioned previously, but these catchments have only intermediate beef cattle waste loadings.

Generally, the relationship between waste loading and pollution incident distribution is poor, in contrast to the situation with dairy cattle. Beef cattle waste loading around the Cheshire Plain is low (class 2 in most catchments), but there is a high concentration of incidents in this area. Similarly, catchments with a high waste loading (class 4) in the Welsh border area (middle reaches of the **Wye** and **Usk**) have few or no recorded cattle-related incidents (no data is available for adjacent Severn Trent catchments - the **Clun,** upper **Teme, Rhiw** and parts of the upper **Severn**). However, NWC downgradings of minor tributaries are extensive in the southern Welsh border area (see above discussion on dairy cattle), where waste loadings are intermediate or high (lower and middle **Wye, Monnow,** lower **Usk,** lower and upper **Lugg, Frome**).

It would appear from these observations that dairy cattle farming is far more important than beef cattle farming as a cause of pollution incidents. This may be due to a tendency to house beef cattle in deep litter, which presents a far lower pollution risk than slurry.

There are a number of catchments with high waste loadings in the Solway and Perthshire regions of Scotland, generally reflecting high livestock densities rather than a low catchment availability of land for disposal. Pollution incident data are not available from these areas for comparison with the distribution of waste loading.

c) Pigs

Map 3c shows the distribution of waste loading from pigs. Again, the distribution of waste loading is similar to the livestock density distribution, with highest loadings apparent in clusters of catchments in East Anglia, Yorkshire, and to a lesser extent Lancashire and the Thames Valley. It is immediately apparent that waste loadings to land potentially available for disposal are very high in catchments in the main hotspots of activity, up to 75-100 litres day^{-1} ha^{-1}. One catchment in NRA Wessex Region has a loading of more than 100 l day^{-1} ha^{-1} (**upper Frome**).

Such high loadings are particularly problematic since the majority of pigs are intensively reared and thus housed throughout the year. This results in the entire annual production of waste passing through the farm's waste management system of storage and disposal. For catchments with a loading of 100 litres

day^{-1} ha^{-1}, this means that 36.5 m^3 ha^{-1} of fresh undiluted pig waste has to be spread to all agricultural land within the catchment each year. Assuming all waste is produced as a slurry and allowing for a typical 1:1 dilution, this amounts to a waste loading of 73 m^3 ha^{-1} yr^{-1}. Again, this figure assumes that all potentially available land is suitable for spreading, which will certainly not be the case, and is also available to the farmer with slurry to be disposed of. This latter assumption is particularly inappropriate for intensive pig farming, as the amount of land attached to piggeries is invariably small in relation to the livestock holding.

In East Anglia, catchments in waste loading class 4 (75-100 litres day^{-1} ha^{-1}) are the same as those in the highest pig density class from Map 2c (**Dove** and **Chickering Beck,** and parts of the **Deben** and lower **Wissey** catchments). Catchments with class 4 loadings (50-75 litres day^{-1} ha^{-1}) again follow high pig densities: the upper and middle reaches of the **Waveney,** the **Thet, Tas,** upper reaches of the **Little Ouse, Blyth** and **Walpole,** upper **Alde** and **Ore, Deben, Gipping,** and to the north the upper Bure. Mapped pollution incident data are not available for these catchments for visual comparison, but data have been supplied by NRA Anglian Region in terms of the number of incidents occurring in each major catchment (not the catchments used in this study). In 1988, the **Waveney** suffered 8 pig-related incidents (none serious), whilst the **Dove** and **Chickering Beck** suffered 9 (2 serious). The majority of these incidents were due to leaking slurry stores and land-run-off in equal measure. The frequency of incidents in these catchments would appear higher than in any other catchments on Map 3c, although the proportion of serious incidence is higher elsewhere. The Gipping and Deben suffered 3 and 4 pig-related incidents in 1988 respectively (all minor). In terms of recent NWC downgradings, the **Dove** and **Waveney** catchments have a combined total of 13 km downgraded to class 3.

In Yorkshire, the lower **Calder** and **Spurn Head** have the highest waste loadings (class 4, 75-100 litres day ha^{-1}), and again the pattern generally follows that of livestock distribution (Map 2c). Few pig-related pollution incidents are evident within this area of activity, but it should be noted that nearly all of these are classed as serious. The majority of incidents occurred in catchments with either class 3 or 4 waste loadings.

In Lancashire, the middle and lower reaches of the **Wyre** have waste loadings of between 50 and 75 litres day^{-1} ha^{-1} (class 3), as does the adjacent tidal **Ribble**. Only 2 pig-related pollution incidents in the Wyre were reported in 1988 (both serious), but much of the Wyre is downgraded to NWC class 3 due mainly to pollution associated with pig farming. To the south east, high waste loadings (class 4) are also evident in the Medlock.

In the Thames Valley, the **Pang** and **Sulham, Blackwater, Bourne, Chertsey Bourne** and **Crane** have intermediate waste loadings (class 3). If this is compared to livestock distribution (Map 2c), it can be seen that for all of these catchments except the Pang and Sulham these very significant waste loadings are due to a relatively low availability of land for disposal. The majority of pigs in the Thames Valley are kept further upstream (Map 2c), where waste loadings are somewhat lower (generally class 2). It can be seen from Map 3c that in this area no pig-related pollution incidents were reported in 1988. The low frequency of incidents is largely due to the practice of 'free range' rearing, which is predominant in NRA Thames Region.

It should be noted that any catchment in Map 3c falling into any class other than class 1 has a very significant volumetric waste loading on a catchment-wide basis. In volumetric terms, the bottom of pig waste loading class 2 is equivalent to the middle of dairy cattle class 3 or the middle of beef cattle class 4.

d) Poultry

Map 3d shows the distribution of volumetric waste loading due to poultry. It can immediately be seen that the volumes of waste involved are considerably lower, than for cattle or pigs, but it should be remembered that the polluting strength of this waste is considerably greater. The distribution of waste loading again largely reflects livestock distribution (Map 2d), showing a scattered distribution but with clusters of catchments with high waste loadings in East Anglia, Lincolnshire and Lancashire and elsewhere to a lesser extent. Poultry farming does not give rise to many pollution incidents, and this is evident from Map 3d; however, it should be remembered that mapped incident data are not available for some NRA regions containing clusters of catchments with high waste loadings (NRA Severn Trent, Anglian and Southern Regions).

In Lancashire, pollution incident data are available from NRA North West Region, and a number of poultry-related incidents are evident in the main area of activity (waste loading classes 3 - 5). In East Anglia, information supplied on a catchment basis (not shown on Map 3d) indicates that only 2 incidents were reported in 1988 in the main area of activity, one on the Blyth and one on the Deben.

e) Total volumetric waste loading

Map 3e shows the combined volumetric waste loading from dairy and beef cattle, pigs and poultry by river catchment. It is immediately evident that total loading is highly concentrated into relatively small areas. The highest total loadings (>60 litres da^{-1} ha^{-1}) are found in clusters of catchments in the south west of England (Dorset, Somerset and east Devon), the Cheshire Plain and Lancashire. Clusters of catchments with generally intermediate loadings are found in south west Wales, south west England (Cornwall and west Devon) and Yorkshire, whilst catchments with lower but still very significant loadings are evident in East Anglia, south east England and south west Scotland.

Fortunately, the combination of high pig and poultry waste loadings with high dairy and beef waste loadings is rare, and for this reason total waste loadings are not as high as might have been the case. The most significant mixing of cattle farming with pig and poultry farming is in Lancashire, centred on the **Wyre** and lower **Ribble** catchments. As can be seen, the distribution of all farm pollution incidents generally fits the distribution of total waste loading well.

f) Total BOD loading

Map 4a shows the distribution of waste loading to agricultural land in terms of BOD content, and the influence of poultry waste, and to a lesser extent pig waste, is immediately evident (see Maps 3c and 3d). The emphasis has largely moved away from the west of the UK towards the east, especially East Anglia, Lincolnshire and Yorkshire, with south west Wales and much of Devon and Cornwall hardly rising above the lowest loading class. Catchments around the Forth Estuary in Scotland also become very important. However, the cluster of catchments in Lancashire centred on the **Wyre** and lower **Ribble** maintains its high waste loadings.

Since considering waste loading in terms of the land area available for disposal can lead to an over-importance of essentially non-agricultural catchments with a small amount of intensive agriculture, BOD production with respect to the entire catchment area was also considered (Map 4b). Although there are a number of catchments which change class relative to each other, changes are generally restricted to adjacent classes (ie 3 to 4 or 4 to 5) and the general pattern is similar to that in Map 4a.

It is evident that this distribution of waste loading does not fit the pattern of occurrence of pollution incidents as well as when waste loading was expressed in terms of volume (Map 3e). This is largely due to the very low occurrence of poultry-related incidents, which highlights the importance of the potential of a pollutant to gain access to watercourses. Poultry waste is highly concentrated but has a relatively high solids content, making it comparatively immobile; slurry, although not as high in polluting strength, is very mobile and gains access to watercourses very easily.

g) Total nitrogen loading

Map 4c shows the distribution of total nitrogen loading due to cattle, pigs and poultry. Catchments with highest loadings are scattered, but broadly match those catchments with high poultry waste loadings. Highest loadings are in excess of 400 g N day^{-1} ha^{-1}, which over a year equates to 146 kg N ha^{-1} if all waste is disposed of on available agricultural land within the catchment. Some states in Germany impose nitrogen restrictions (Table 4.10), with the range in maximum application rates for the 4 States considered being 160-210 kg total N yr^{-1}. Highest loading rates in the UK are comparable to this range without accounting for the proportion of agricultural land that is not available for waste disposal due to ownership or physical characteristics.

h) Total phosphate loading

Map 4c shows the distribution of phosphate loading from cattle, pigs and poultry to agricultural land. As with nitrogen, this follows the distribution of poultry and pig waste loadings much more closely than loadings due to cattle, due to the concentrated nature of the former. Catchments with the highest (Class 5) loadings, such as the middle **Waveney, Tas, Dove** and **Chickering Beck** in East Anglia and the middle **Wyre, Darwen,** lower **Douglas** and **Lostock** in north west England, take more than 400 g P2O5 day^{-1} ha^{-1}. If it is assumed that all of this is disposed of within the catchment, this amounts to an annual loading of 146 kg P2O5 ha^{-1} - again, the actual loading is likely to be higher since not all agricultural land will be suitable for disposal.

This loading can be compared to standards being adopted by other European countries (see Section 4.7). Of the two German states in Table 4.10 which lay down phosphate restrictions, Schleswig-Holstein is the more stringent with a maximum allowable loading of 120 kg P2O5 ha^{-1} (2 Dung Units), although a greater loading would be acceptable if the total nitrogen loading did not exceed 160 kg N yr^{-1}. The Netherlands, although allowing very high phosphate loadings at present, are working towards maximum loadings of around 125 kg P2O5 ha^{-1}. Denmark allows a maximum loading of 2.3 Livestock Units ha^{-1} $year^{-1}$ for dairy cattle, which equates to roughly 67 kg P2O5 ha^{-1} $year^{-1}$. From these comparisons it would appear that a number of UK catchments exceed the loading rates that would be acceptable in certain areas of the continent, and that a significant number of other catchments are also likely to do so. Although the risk of phosphate enrichment of surface waters and subsequent phytostimulation will depend upon soil mobility and bioavailability of this phosphorus, there is a clear risk of significant river contamination.

i) Sheepdip waste loading

Map 5a shows the estimated volumetric loadings of waste sheepdip by river catchment (in terms of total catchment area), based on assumptions made by Littlejohn and Melvin (1989). It can be seen that catchments in the Welsh uplands suffer loadings of over 48 litres ha^{-1} of catchment from one dipping period alone. If all sheepdip used in these catchments was propetamphos (a very widely used compound), Map 5b shows that these loadings could amount to up to 24 grammes of propetamphos ha^{-1} of catchment. However, without detailed knowledge of disposal practices, degradation rates, transport processes and dilution rates it is not possible to sensibly predict likely riverine concentrations. However, pesticide transport is being modelled by WRc (NRA project ref A14.002) and a review of sheepdip practices is also being undertaken (NRA project ref A07.2) - these areas of research, in conjunction with the kind of estimates made in this study, may well allow such predictions.

Reported sheep-related pollution incidents in 1988 are shown in Maps 5a and 5b. The scarcity of such incidents is very unlikely to reflect the true impact of sheepdip contamination on river biota, but more likely to reflect the insidious nature of pesticide impact and the general remoteness of sheep farming. It should be noted that the relatively low estimated waste sheepdip loadings evident in Scotland should not be considered to represent a lack of pollution risk. Sheep farming is a very important land use in much of Scotland and, as discussed in section 5.3.2, Tweed RPB have found that a high proportion of dippers in their area are likely to cause pollution (pers. comm. Ian Currie, Tweed RPB).

j) Physical factors

Maps 6a, 6b and 6c show the UK distribution of land-slope, annual rainfall and winter rainfall acceptance potential (WRAP) by river catchment. The westerly and northerly distribution of high land-slope is evident from Map 6a, and a similar distribution of high annual rainfall is apparent from Map 6b. Map 6c highlights the low permeability peat soils of upland areas to the west and north, and also clay soils in lowland areas such as the Wield (south east England). The distributions of these three factors, all important contributors to farm pollution risk, have been used in combination with the distribution of total organic waste loading (in terms of BOD) to produce an overall index of farm pollution risk.

k) Organic pollution risk

Initial attempts have been made to combine livestock parameters with physical parameters to produce an overall picture of pollution risk, but in the short time allowed for this study it has not been possible to produce a realistic distribution. Appendix C gives details of the weightings used in these initial attempts. In order to combine the risk posed by waste from different livestock types, BOD was used as the livestock parameter; however, this takes no account of the mobility of the pollutant. It is envisaged that further attempts will be made during 1991 to produce a valid distribution of pollution risk, and that both waste strength and mobility will be considered when combining risk factors. In the meantime, a good indication of pollution risk can be gained from the organic waste loading maps presented in this report, which include consideration of waste produced by individual livestock types and the combination of waste produced by all livestock types.

l) Sheepdip pollution risk

Map 7c shows the combination of waste sheepdip loading and physical factors to produce a distribution of sheepdip pollution risk for surface waters. This shows the majority of Welsh catchments having the highest pollution risk, combining high sheep densities with high rainfall, high landslopes and low soil permeability. Much of northern England (particularly to the west), southern Scotland and south west England also show relatively high pollution risk.

5.3.4 Regional attitudes to farm pollution control

Below is a summary of regional attitudes to various options for farm pollution control, derived from consultation with regional pollution control staff. Appendix E lists those who participated in the consultation. It should be pointed out that the views expressed by those interviewed do not necessarily reflect regional policy.

i) Legislation

Legislation governing water pollution control was generally thought by those pollution control staff interviewed to be adequate in England and Wales, but there was a lack of control over non-point source pollution which could not be rectified without more regulation of catchment activities. There are numerous examples of restrictions on livestock density and slurry application to land in Europe. In many European countries slurry application is banned through the winter (see Section 4.2), whereas in the UK this is invariably the season of greatest activity, since livestock farmers do not want to compromise growth of grass/silage by application in spring and summer.

The Water Act (1989) has potential for catchment control through the designation of protection zones, but its usefulness will depend upon the strength of subsequent enabling legislation. The **Severn-Trent Region** is a special case in terms of catchment control, since the Severn-Trent Act (1983) allows for binding management agreements to be made between landowners and the NRA. Influence over agricultural planning was seen as fundamental to effective catchment control by the NRA regions, and their current position as statutory consultees did not provide sufficient influence. Agricultural exemptions from planning still gave cause for concern.

The new regulations to control silage, slurry and fuel oil installations were regarded as useful, but are thought by a number of NRA regions to be too lenient in some respects.

Wessex Region feel that although the Water Act (1989) has simplified the prosecution process, their powers to 'remedy or forestall' pollution suffer from a bureaucratic time delay which makes it very difficult to act in time to prevent incidents. **Yorkshire Region** would like to see an extension to the use of prohibition orders, where bans can be imposed on specific activities which threaten specified water uses. At present they can only be applied to land disposal of sewage and trade effluents, not agricultural waste.

Forth RPB felt that the power to serve improvement notices on prosecuted polluters was needed, which would allow subsequent prosecution on the basis of a maintenance of high pollution risk. Denmark has legislation that allows prosecution of any potential polluter on the basis of pollution risk (see Section 4.2.1). Such powers in the UK would be likely to have a great impact on farm pollution incident statistics.

ii) Prosecution

It was widely felt that the low level of fines imposed by magistrates for farm pollution offences is a major hindrance to farm pollution control. Some persistent polluters prefer to be fined than invest in preventative measures, implying that at least for some farmers this may be the most cost-effective option. Fines awarded in **Yorkshire, North West, South West** and **Welsh Regions** and throughout **Scotland** and **Northern Ireland** were particularly low, although improvements had been seen in some NRA regions recently (in **Anglian Region,** where NRA staff have been increasing the awareness of magistrates, in **Thames** and in **Northumbrian Regions**). It remains to be seen whether the recent increase in the maximum level of fine from £2000 to £20 000 in the magistrate's court (Environment Act 1990) will be used effectively. The relatively recent moves to award costs to the NRA were seen as a positive step and provided a useful source of revenue; however, **Northumbrian Region** noted that this did not act as a deterrent to the farmer since payment of costs are often covered by insurance policies. In **Scotland,** costs cannot be recovered by RPBs since prosecutions are taken on by the Crown.

Thames Region noted that although financial penalties needed to be substantial, it was important that they did not interfere with the farmer's ability to pay for remedial measures. For this reason it was felt that fines should be closely linked to the ability to pay. Maximum publicity of successful prosecutions was considered a very effective deterrent in a number of NRA regions (eg **Anglian** and **Yorkshire**), since many farmers value their position in the local community and bad press can tarnish their image. This can also stir other farmers in the neighbourhood into taking remedial action. **Anglian Region** have contacted pressure groups on previous occasions to ensure good media coverage for successful prosecutions.

iii) Education

The farming community's ignorance of the impact of farm pollution was seen as a major obstacle to improved river quality. Many farmers still believe that slurry helps the river by 'fertilising' it. Most NRA regions felt that farmers did not understand pollution control legislation, and **South West Region** thought that the code of good agricultural practice was not widely understood (this is currently being revised by MAFF in association with the NRA).

In addition, low financial penalties were felt to hamper the improvement of awareness through educational initiatives, since certain farmers were unlikely to take notice unless there was a real possibility of incurring a substantial financial penalty. For this reason, there was a mixed opinion on the usefulness of educational/publicity campaigns involving 'mailshots' and presentations at agricultural shows, since many felt that they were a case of 'preaching to the converted'. However, **NRA Anglian Region** have found presentations to groups of 'Young Farmers' to be useful in enhancing the awareness of the next generation of farmers.

Individual farm visits were seen as the ultimate educational tool, since they target the problem catchment/farmers and allow personal contact. **NRA South West Region** have found their region-wide campaign very useful in educating the farming community. **NRA North West Region** upgraded 40 km of the Wampool from NWC class 2 to 1B following an intensive campaign of farm visits, although this did coincide with drier weather which naturally leads to fewer farm pollution problems. However, follow-up visits showed that farmers had made waste management improvements. **Yorkshire Region** found water quality improvements (from NWC class 4 to 2) on the Wiske following an intensive campaign which led to 34 grant-aided developments. Other NRA regions have found it difficult to discern water quality improvements following campaigns, largely because farm pollution is often localised in the unclassified headwaters of catchments.

The level of advice that should be given to farmers about required remedial measures causes difficulty for pollution control staff, since the NRA consider it important that their regulatory role is not compromised by being associated with detailed remedial plans. There is a danger, now that ADAS are charging for their advice on pollution prevention (although the first consultation is free), that farmers will be reluctant to seek independent advice and risk causing pollution. The attitude of the NRA is perhaps not wholly consistent, since written approval is frequently given to pollution prevention plans under the Farm and Conservation Grant Scheme. A similar disclaimer to that used for grant aid approvals could be used when detailing advice on remedial measures.

The inclusion of courses on pollution prevention at agricultural colleges was seen as a good way of incorporating awareness into the farming community at an early stage, although most colleges contacted in England and Wales so far have apparently been non-committal about collaboration with the NRA. In comparison, the relationship between Scottish Agricultural Colleges (SACs) and river purification boards is at an advanced stage. The Scottish Farm Waste Liaison Group (SFWLG), responsible for the publishing of annual farm pollution statistics in Scotland (eg SFWLG 1989), consists of 2 representatives from the RPBs, 2 from the SACs, and 2 from DAFS.

iv) Grant aid

The Farm and Conservation Grant Scheme, which pays for 50% of the construction costs of pollution prevention facilities if approved by the NRA, was generally seen in a favourable light. However, there are several important omissions that limit the usefulness of the scheme:

- The separation of clean water (mainly roof run-off from farm buildings) from the dirty water collection system, by appropriate guttering and channelling, is not eligible for grant aid since it is seen by MAFF as construction for clean water rather than polluted water. This is a very important omission from the scheme, since numerous pollution incidents are caused by excessive strain on waste storage capacity due to the incorporation of rainwater.

- Existing facilities in need of maintenance, repair or upgrading are not eligible for aid, which provides no incentive to the farmer to keep his waste management system in order. Routine waste management is vital to pollution prevention, and farmers are generally reluctant to spend time on what it seen as non-productive work.

- Grant allocation is not graded depending upon the importance or relevance of the work to pollution prevention. Schemes are either given 50% of construction costs or nothing at all. Graded allocation would provide greater incentive to undertake the most effective measures and would help to target aid at problem farms or catchments.

Yorkshire Region felt that more use could be made of EC Set-Aside money in pollution control; using it to restrict livestock numbers is one example. There is also plenty of scope for more encouragement of the setting up of buffer zones alongside riverbanks, although this is already a method of selecting Set-Aside land suggested to the farmer by MAFF. **Yorkshire** thought that there was also a need for rationalisation of Nitrate Sensitive Area and Set-Aside grants.

v) Waste treatment and management

Waste treatment was generally seen as a high risk option of disposal since farmers are reluctant to undertake the necessary routine maintenance work. Few farms have consented discharges to watercourses in any region, and applications for consent would not be looked upon favourably.

Weeping-wall stores were seen as a low-maintenance and effective method of solids separation. Low-rate irrigation systems are becoming increasingly popular throughout England and Wales for the disposal of dirty water and silage effluent, and when used properly are an effective method of disposal. However, the spray gun of such systems needs regular relocation to avoid over-application, and failure to do this has resulted in a number of land run-off incidents. Incidents have also been reported where the nozzle of the spray gun has been detached to allow a higher rate of application, thus destroying the principle of the system and again leading to over-application. In addition, such systems are abused by their use on under-drained land and by using them to apply slurry, for which they were not designed.

Clean water separation was seen as a vital part of waste management, and even though it was not currently included in the F&CGS, its investment could be rationalised by making the farmer aware of the savings to be made from lower required storage capacity and not causing pollution incidents.

A reversion to straw-based systems of waste management was seen as the most effective pollution control measure. Slurry-based systems involve the storage of enormous volumes of highly mobile waste which have the potential to cause catastrophic pollution, and all too often realise that potential. The main obstacles to a large-scale reversion are: the cost of livestock housing modifications; the cost of straw (particularly transportation); and the reluctance of farmers to apply straw-based wastes at any time other than when the land was ready for ploughing and reseeding. The availability (and therefore cost) of straw has worsened due to the intensification of farming practices which has seen cereal (and straw) production and livestock production largely detached and geographically isolated from each other. This has led to a large surplus of straw in regions such as East Anglia, with a dearth in areas of intense livestock production (where it is most needed) such as the South West.

The change to big-bale silage production from clamps was welcomed in all NRA regions as it reduces the possibility of major silage liquor releases by compartmentalising it. In 1989, 10% of silage was produced by big-bale in England and Wales (Habitat 1990), and the figure is likely to be much higher for 1990. The highly visual nature of big-bales is causing aesthetic problems, however, and the Council for the Protection of Rural England has protested at their increasing presence (Habitat 1990). Big-bales also produce large amounts of plastic waste which require disposal.

The development of the mobile 'Sentinel Plant' for the treatment of spent sheepdip was seen positively by pollution control staff, although there was concern that it was likely to be extremely costly to run. Problems with clogging during trials may be overcome by prefiltration.

The use of constructed wetlands and buffer zones for the protection of river quality were thought to be promising options by most NRA regions, although more investigation into their application was required.

vi) Catchment management

Regulation of farming practices, including restrictions on livestock density and land spreading of wastes, was considered a prime necessity. Simple catchment management models were seen by some regions as a way of placing such catchment controls on an objective footing. **Yorkshire Region** saw simple models combining with catchment inventory databases that would have the ability to calculate waste production and land availability (for slurry spreading) for individual farms and would be able to continually update this information. Changes in pollution control staff can mean large losses of local knowledge, and such databases would help to minimise the impact of such changes. **South West Region** saw simple catchment models as the basis for Farm Waste Management Plans, where each farm would have an approved system of waste storage and disposal that would be monitored by the NRA. **Northumbrian Region** thought that the development of a simple computerised package that could place pollution risk assessment on a more objective footing would be useful.

6. RAPID BIOLOGICAL ASSESSMENT

6.1 Introduction

The effective control of surface water pollution from livestock farming is hampered by the large number of farms involved and their distribution over large areas with poor accessibility. The detection of impacted streams by the use of biological indicators has been proposed as part of a pro-active pollution control strategy. Biological methods based on the benthic macroinvertebrate fauna are particularly appropriate because they have a proven ability to detect the effects of episodic pollution such as the rain-generated events typical in agricultural catchments (Metcalfe 1989).

The effectiveness of biological indicator systems has been demonstrated in studies of acidification in the headstreams of the Welsh uplands (Wade, Ormerod and Gee, 1989) and in surveys of farm pollution in summer conditions in West Wales (Reynolds, 1989). Such systems are cheaper, more rapid and more accurate in their operation than intensive chemical sampling and have potential as means of targeting pollution control effort to the worst affected parts of catchments.

West Wales was chosen as a region in which to develop a protocol which could be adopted nationally because of the intensity of dairy farming in the area and its impact upon salmonid populations in headwater streams (Wightman 1988). These streams are naturally fairly homogeneous in both physiography and chemistry, and hence in biota, such that observed differences in fauna are likely to reflect the impact of pollution rather than natural variability. This section describes the development of a bankside biological assessment system for the detection of farm pollution impact in late winter/early spring.

6.2 Methods

6.2.1 Site selection

After discussion with the relevant NRA pollution control staff, 55 sites on streams in West Wales were selected for survey (Figure 6. 1). Sites were chosen so as to reflect a wide range of pollution impact, pollutant type (eg parlour washings, lagoon overflow etc) and geographical area. Sites were restricted to those likely to support salmonids and unlikely to be affected by other sources of pollution found in rural catchments eg sewage treatment works. Stream width was in the range 1.0-6.0 m, most sites being between 2.0 and 4.5 m.

6.2.2 On-site methods

Field-work was carried out between 27 February and 6 April 1990. The procedure at each site was as follows:

(i) A spot water sample was taken which was later analysed for a range of standard determinands.

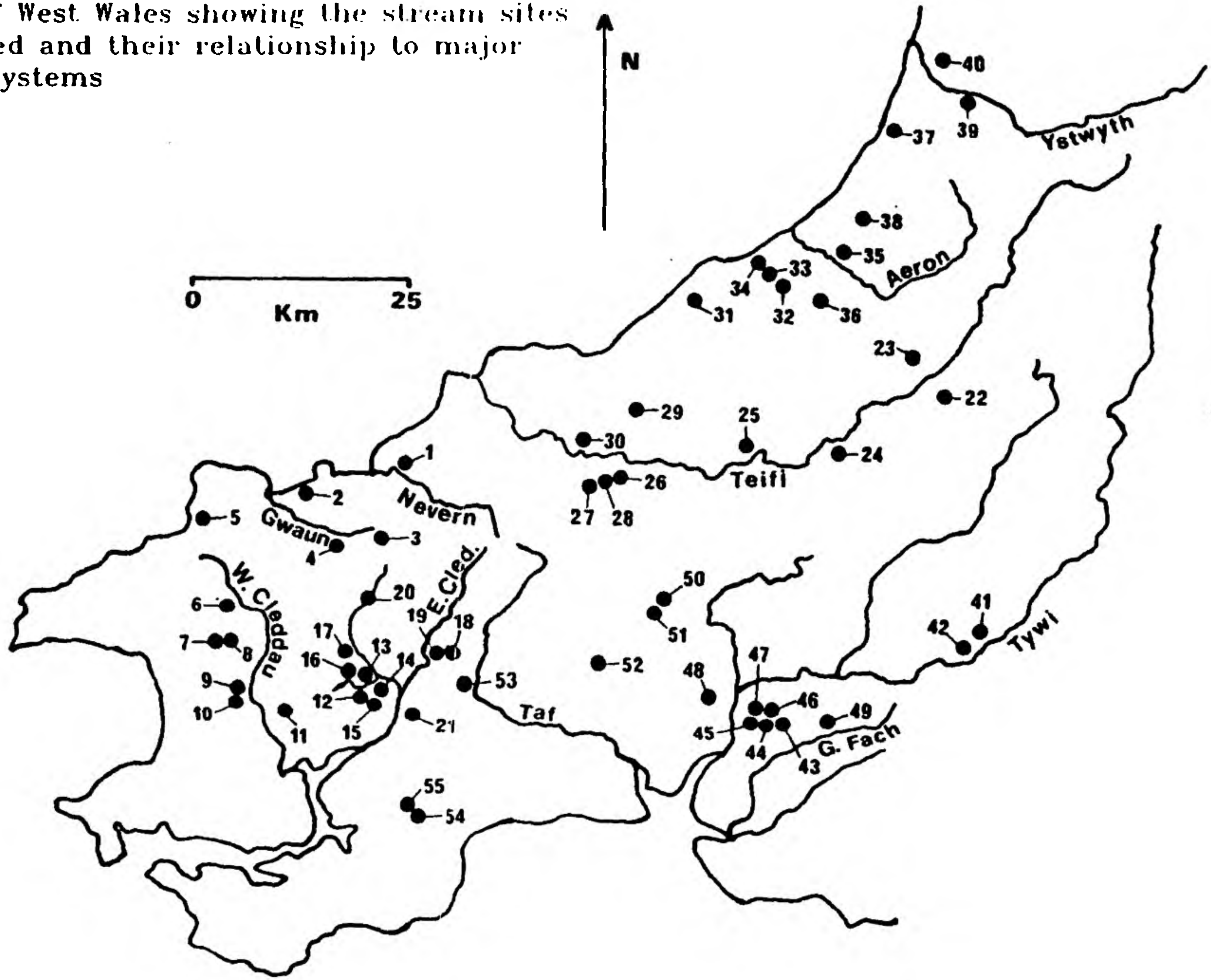
(ii) The percentage cover of 'sewage fungus' was assessed and small samples collected for microscopic identification.

(iii) Other environmental data such as substratum composition and width were recorded.

(iv) Three separate 1 minute kick samples were taken from riffles such that the relative merits of 1, 2 and 3 minute sampling periods for the development of an indicator key could be assessed.

(v) Lengths of stream in the range 30-60 m were electrofished semi-quantitatively to obtain minimum salmonid densities. Such estimates have been shown to correlate well with more time-consuming quantitative depletion estimates (Strange, Aprahamian and Winstone 1989).

Figure 6.1 Map of West Wales showing the stream sites sampled and their relationship to major river systems



6.2.3 Invertebrate sample processing

Macroinvertebrate samples were sorted and identified in the laboratory. Many groups were identified to species or genus level but difficult taxa such as chironomids and simuliids were left at family level. So far, two of the three sets of 55 replicate one-minute samples have been processed, the data being stored on a data archive known as BAETIS which has been developed within NRA Welsh Region.

6.2.4 Data analysis

The invertebrate samples from the 55 sites were classified using a multivariate classification technique known as TWINSPAN (Hill 1979) which has been widely used in freshwater ecology (eg Wright *et al*, 1984). Four separate TWINSPAN analyses were run with two different sampling periods (1 minute and two minute) and taxa grouped at two different taxonomic levels -'species' and 'family' (Table 6.1). At both 'species' and 'family' level certain taxa were grouped at higher taxonomic levels. Percentage sewage fungus cover was included in all four data sets. TWINSPAN generates an indicator key which can be used to classify new sites into the derived groups. Where TWINSPAN is run using quantitative data cut levels are specified such that different abundance categories of a taxon are entered separately into the analysis as 'pseudospecies.' In the present analysis 'pseudospecies' were set to be logarithmic abundance categories, ie 1-9, 10-99, 100-999, etc. A TWINSPAN option was invoked which prevented abundance category 1 'pseudospecies' (1-9 individuals) appearing as indicators. This can simplify the keys and reduce the possibility of chance occurrence of single individuals leading to misclassification when the derived keys are applied in practice.

Table 6.1 - Data sets used in TWINSPAN analysis

Data set	Sampling period (minutes)	Taxonomic level
SPP1	1	'species'
FAM1	1	'family'
SPP2	2	'species'
FAM2	2	'family'

To determine whether the derived TWINSPAN groups reflected different degrees of farm pollution, between-group differences in the means of a range of biotic and abiotic variables were tested by analysis of variance after transformation where necessary. The substratum composition data was reduced to a single value for each site by allocating each substratum class a number from 1 to 7 in order of decreasing particle size (bedrock, boulders, cobbles, pebbles, gravel, sand and silt) and calculating a mean class taking into account the proportions of each class. The results of these analyses were used to determine which of the four indicator keys would be most effective in distinguishing different degrees of farm pollution.

Once the optimal key had been selected the distribution of different invertebrate taxa between the stream groups was investigated using X^2 tests. Analyses were carried out at different levels of abundance eg *Baetis* spp. (1-9 individuals in kick sample), *Baetis* spp. (2) (10-99) and *Baetis* spp. (3) (100-999).

6.2.5 Follow-up site assessments

Between 24 April 1990 and 17 May 1990, the majority of the streams found to be impacted were investigated so as to identify the sources of pollution.

6.2.6 Assessment of summer indicator key

In conjunction with NRA staff assistance has been given with a student project designed to determine the impact of agricultural pollution in the Taf catchment (West Wales). The study involved the use of the summer indicator key developed by Reynolds (1989a) and thus provided an opportunity to test the effectiveness of this complementary system. Electrofishing surveys were carried out at selected sites to establish the relationship between the classification system and salmonid abundance.

6.3 Results

6.3.1 Development of the indicator key

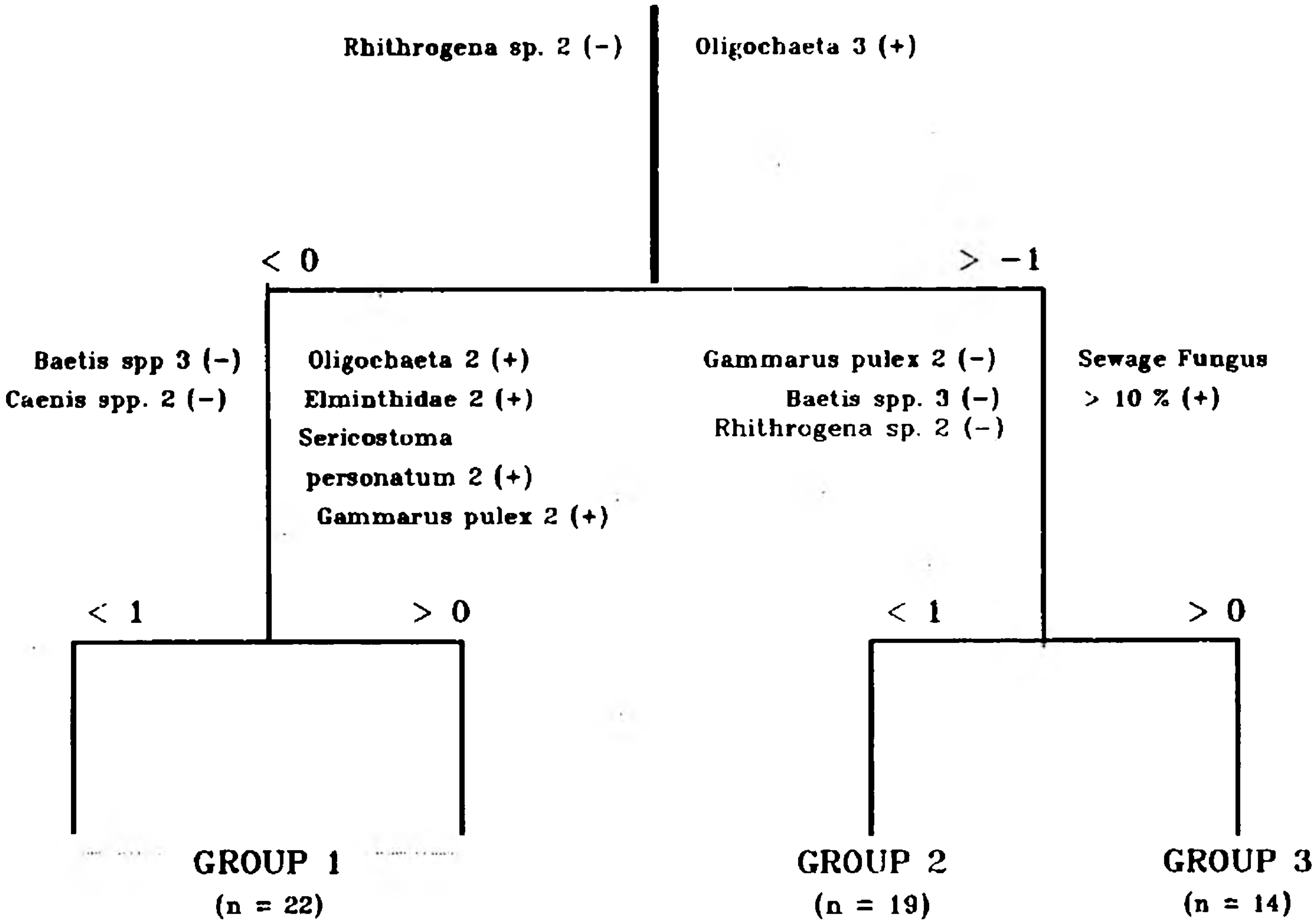
Initial TWINSPAN analyses produced indicator keys which incorporated taxa not readily identifiable in the field. These taxa were masked out as potential indicators and subsequent re-analysis resulted in more practical versions, one of which is illustrated (Figure 6.2). Taxa to the left of each division line score -1, taxa to the right score +1 - the nett total for a site indicates whether it will be placed to the left or right of the division. The even pattern of division indicates that there are no marked outlier sites in the data set.

6.3.2 Characteristics of TWINSPAN stream groups

Preliminary assessment of the stream groups indicated that in each key the two site groups to the left of the initial division were very similar in biotic and physicochemical terms. These two groups were thus combined so as to produce three groups (1,2 and 3 in Figure 6.2).

For all four TWINSPAN classifications, there were very significant differences between the three groups generated in a number of variables which might be considered to reflect the effects of farm pollution, ie BMWP (Biological Monitoring Working Party) score, Average (BMWP) score per taxon (ASPT), total

Figure 6.2 TWINSPAN indicator key derived from the biological analysis of 55 sites in West Wales (SPP1 dataset).



Numerals after the taxon names indicate log abundance category
(1 = 1-9, 2 = 10-99, 3 = 100-999)

ammonia concentration, percentage sewage fungus cover and minimum total trout density (Table 6.2). There were less significant differences in dissolved oxygen concentration and BOD, with no significant difference in suspended solids.

There were also significant differences in a number of variables not directly reflecting agricultural pollution, ie distance from source, conductivity, pH and total hardness (Table 6.2) but there were no significant differences in altitude, slope and width.

Table 6.2 - Relationship between environmental variables and TWINSPAN groups from four separate analyses.

Variable	Transformation	SPP1	FAM1	SPP2	FAM2
a) Pollution-dependent variables					
Oxygen	-	**	**	**	***
BOD5	-	*	**	**	N.S.
Total Ammonia	log	***	***	**	**
Susp. solids	log	N.S.	N.S.	N.S.	N.S.
BMWP-2mk	-	***	***	***	***
ASPT-2mk	-	***	***	***	***
S. Fungus cover	-	***	***	***	***
Min Trout density	log	***	***	***	***
b) Pollution independent variables					
Altitude	-	N.S.	N.S.	N.S.	N.S.
Slope	-	N.S.	N.S.	N.S.	N.S.
Width	-	N.S.	N.S.	N.S.	N.S.
Dist. from source	-	*	*	**	**
Catchment Area	-	*	*	**	N.S.
pH	-	***	**	**	***
Conductivity	-	***	**	***	*
Total Hardness	-	***	***	***	N.S.

Asterisks indicate probability level from analysis of variance -
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

It is noticeable that there is little to choose between the four analyses in their ability to discriminate between different levels of pollution. This is reflected in the consistency with which the four analyses allocate sites to groups. Across the four analyses, 37 sites (67%) remained faithful to one of the three groups whilst 11 sites (20%) moved between the two polluted groups (2 and 3). Only 6 sites (10.9%) moved between Groups 1 and 2 whilst only a single site moved between the two extremes (1 and 3).

This consistency means that the simplest and easiest bankside key can be selected - that from analysis of one minute samples processed to 'species' level (Figure 6.2). More detailed environmental and biological data for the groups resulting from this analysis are presented (Table 6.3, Figure 6.3). The results of the X^2 tests (Table 6.4) support the hypothesis of a relationship between stream group and degree of pollution. A number of pollution-sensitive taxa show preference for Groups 1 or 1 and 2, whilst a few tolerant taxa such as the leech *Helobdella stagnalis*, Oligochaetes and Chironomids show preference for Groups 2 and 3 (Table 6.4).

6.3.3 Site assessments

In general, the follow-up assessments carried out in May indicated that most of the streams found to be polluted in the survey were showing signs of recovery, probably because waste management problems had been reduced by drier weather. It was often still possible to identify polluting farms by the presence of slurry in drainage ditches etc. Pontfaen Brook (Site 4) was still suffering from serious pollution from silage effluent and proved suitable for more intensive study (Section 7). For most sites in Groups 2 and 3 it was possible to identify probable sources of pollution either during these assessments or from discussion with NRA pollution control staff (Table 6.5).

6.3.4 Modifications to the indicator key

During a field trial of the system in the Gammon catchment (tributary meeting Nevern at SN081398) on 30 January 1991, five previously unknown illegal

Table 6.3 - Relationships between TWINSPAN groups from data set SPP1 and biotic and environmental variables

Variable (units)	Trans-form	Group 1	Group 2	Group 3	F	p
a) POLLUTION-DEPENDENT VARIABLES						
BMWP	-	150 (132-168)	122 (97-148)	88 (61-116)	29.72	0.001
ASPT	-	6.4 (6.2-6.7)	5.7 (5.3-6.1)	5.7 (5.2-6.2)	22.01	0.001
Oxygen (mg l^{-1})	-	11.0 (9.9-12.2)	10.7 (10.1-11.3)	10.0 (9.2-10.8)	5.68	0.006
BOD (mg l^{-1})	-	0.9 (0.2-1.7)	1.5 (0.8-2.1)	1.4 (1.1-1.8)	4.42	0.017
Ammonia (mg l^{-1})	log	0.02 (0.01-0.06)	0.12 (0.03-0.47)	0.11 (0.02-0.54)	12.04	0.001
Solids (mg l^{-1})	log	6.1 (3.7-10.1)	7.4 (4.7-11.5)	7.9 (4.8-13.2)	1.52	0.229
S Fungus (% cover)	-	1 (0-4)	27 (0-66)	55 (15-96)	13.92	<0.001
Min Trout (N/100 m^{-2})	log	14 (8-25)	6 (2-18)	2 (1-5)	20.08	<0.001
b) POLLUTION-INDEPENDENT VARIABLES						
Altitude (m)	-	85 (28-141)	50 (19-81)	82 (22-142)	2.87	0.065
Slope (%)	-	3.3 (0-7.4)	1.5 (0.5-2.5)	2.7 (1.2-4.3)	2.37	0.103
Width (m)	-	3.2 (2.0-4.4)	2.8 (1.7-3.9)	2.4 (1.5-3.2)	2.89	0.065
Dist source (km)	-	5.0 (2.5-7.6)	4.0 (1.5-6.5)	2.6 (1.2-3.9)	4.91	0.011
C Area (km^{-2})	log	6.7 (3.3-13.4)	4.6 (2.0-10.6)	3.1 (1.4-6.8)	4.30	0.019

Table 6.3 continued

Variable (units)	Trans-form	Group 1	Group 2	Group 3	F	p
pH	-	7.1 (6.6-7.5)	7.4 (7.2-7.7)	7.4 (7.3-7.5)	7.93	0.001
Hardness (mg l^{-1})	-	48 (32-64)	77 (49-105)	57 (40-75)	10.05	<0.001

Group values are means with standard deviation ranges in brackets. F statisic (F) and probability values (p) from analysis of variance.

Table 6.4 - Frequency of occurrence of selected invertebrate taxa in the three TWINSPAN groups generated by analysis of the SPP1 data set.

TAXON	GROUP 1	GROUP 2	GROUP 3	X^2	p
Leuctra spp.	*****	**	***	17.7	< 0.001
Protonemoura spp.	***	*	*	10.0	< 0.01
Chloroperla spp.	*****	**	***	13.1	< 0.01
Hydropsyche spp.	*****	**	**	21.8	< 0.001
Sericostoma personatum	****	*	*	16.2	< 0.001
Brachyptera risi	***	**	**	6.9	< 0.05
Isoperla grammatica (2)	***	*	*	7.9	< 0.02
Hydropsyche spp. (2)	***	*		17.2	< 0.001
Rhithrogena sp. (3)	**	*		10.9	< 0.01
Amphinemeura spp.	****	**	**	8.9	< 0.02
Perlodes microcephala	**	*		7.2	< 0.05
Leuctra spp. (2)	***	*	*	13.7	< 0.01
Chloroperla spp. (2)	***		*	17.3	< 0.001
Rhithrogena sp. (1)	*****	****	****	6.6	< 0.05
Isoperla grammatica	*****	***	**	8.9	< 0.02
Ecdyonurus spp.	****	***	*	15.3	< 0.001
Caenis spp.	***	*		7.1	< 0.05
Hydraena gracilis	****	***	*	17.2	< 0.001
Rhithrogena sp. (2)	*****	***		32.0	< 0.001
Elminthidae (2)	***	**		8.9	< 0.02
Gammarus pulex (1)	****	*****	***	13.9	< 0.01
Elminthidae (1)	*****	****	**	10.8	< 0.01
Rhyacophila dorsalis	*****	****	**	15.3	< 0.001
Plectrocnemia spp.	***	***		9.3	< 0.01
Pisidium spp.	***	***	**	9.4	< 0.01
Nemoura spp.	***	****	*	10.6	< 0.01
Potamopyrgus sp. (2)	**	***	*	8.8	< 0.02
Gammarus pulex (2)	**	****	*	11.3	< 0.01
Ancylus fluviatilis	****	***	*	12.0	< 0.01
Dicranota spp.	*****	***	***	7.9	< 0.02
Baetis spp. (3)	****	***	*	11.6	< 0.01
Asellus spp.	*	**	*	6.8	< 0.05
Habrophlebia fusca		***		26.1	< 0.001
Potamopyrgus spp.	***	****	***	6.0	< 0.05
Helobdella stagnalis	*	***	**	10.4	< 0.01
Oligochaeta (3)	*	*****	***	27.1	< 0.001
Chironomidae (3)	*	****	**	10.9	< 0.01
Oligochaeta (2)	***	*****	*****	14.6	< 0.001
Gyrinidae (1)	***	**	*	5.9	N.S.
Glossiphonia complanata	*	**	**	5.5	N.S.
Oligochaeta (1)	*****	*****	*****	1.4	N.S.

Table 6.4 continued

TAXON	GROUP 1	GROUP 2	GROUP 3	X2	p
Baetis spp.	*****	*****	*****	0.0	N.S.
Chironomidae	*****	*****	*****	0.0	N.S.
Lumbricidae	***	***	***	0.4	N.S.
Brachyptera risi	****	****	****	0.7	N.S.
Limnephilidae	****	***	***	4.5	N.S.
Paraleptophlebia spp.	**	**	*	1.6	N.S.
Erpobdella octoculata	**	***	*	5.0	N.S.
Chironomidae (2)	****	*****	*****	5.5	N.S.
Simuliidae (2)	***	****	***	1.3	N.S.
Simuliidae	****	*****	*****	3.3	N.S.
Ceratopogonidae	**	***	***	1.8	N.S.
Baetis spp. (2)	*****	*****	****	4.0	N.S.

Asterisks indicate percentage occurence (* 1-20% of sites in group, ** 21-40%, *** 41-60%, **** 61-80%, ***** 81-100%). For certain taxa, abundance categories are treated as different taxa ie, (2) indicates >9 individuals in a 1 minute kick sample, (3) >99. X^2 values and associated probabilities are given.

Table 6.5 - Biological characteristics of stream sites in west Wales arranged by TWINSPAN group.
(The sources of pollution thought to be responsible for the observed biological impacts are given)

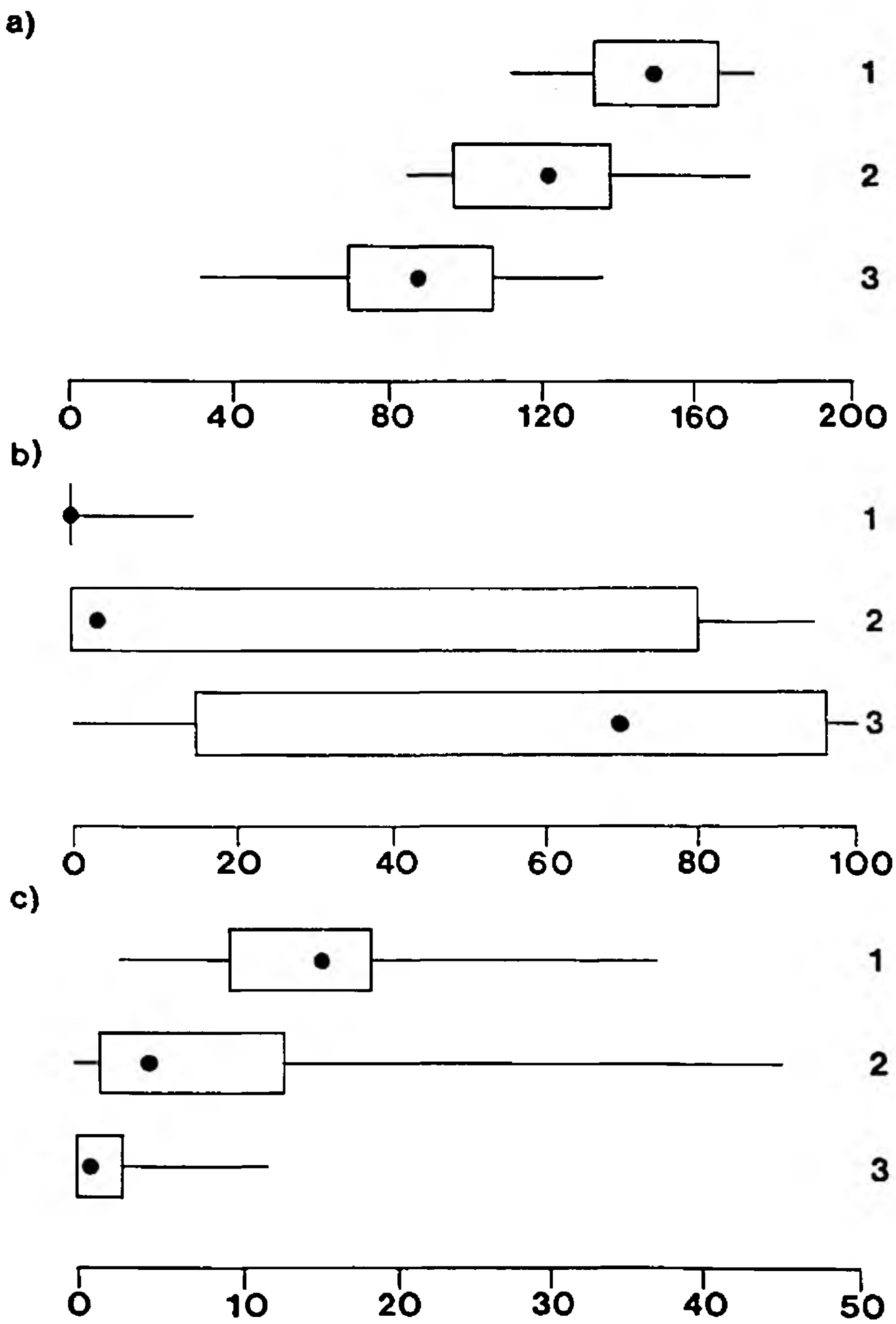
SITE	STREAM	NGR	BMWP	SEWAGE FUNGUS (%)	MIN TROUT (/100 m^2)	POLLUTION SOURCE
GROUP 1						
3	Afon Cwmau	SN037339	170	0	17.3	
6	W. Cleddau Trib	SM933276	176	0	13.2	
7	Nant y Coy BrooK	SM921242	117	0	30.7	
9	Camrose Brook	SM939191	161	0	16.3	
13	Deepford Brook	SM049200	147	5[2]	3.9	Fish kill in April 1988
19	Afon Rhydabil	SN107232	119	0	16.7	
20	Syfynwy	SN047269	146	0	5.1	
22	Nant Eiddig	SN593452	174	0	10.1	
23	Nant Creuddyn	SN567492	149	0	16.5	
24	Afon Iar	SN500414	170	0	19.9	
25	Afon Cerdin	SN421415	166	0	9.8	
29	Afon Dulais	SN315467	142	0	15.9	
31	Afon Soden	SN373568	129	0	5.7	
35	Nant Cilcennin	SN500600	138	0	12.9	
36	Afon Feinog	SN466565	133	0	20.5	
37	Afon Carrog	SN562719	156	0	12.8	
38	Afon Arth	SN541630	157	0	14.7	
39	Nant Adal	SN624749	136	0	18.0	
40	Nant Paith	SN604787	148	0	36.9	
48	Nant y Ci	SN386187	157	0	2.8	
51	Pontgarreg Fach	SN316275	113	15[2]	21.9	Leaking lagoon
55	Cresswell Trib.	SN096077	176	0	8.4	

Table 6.5 continued/2

SITE	STREAM	NGR	BMWP	SEWAGE FUNGUS (%)	MIN TROUT (/100 m^2)	POLLUTION SOURCE
GROUP 2						
5	Aberbach Stream	SM895361	167	< 1	12.5	Yard run off
8	Nant y Coy Brook	SM922242	139	80_3	44.8	Chronic silage effluent discharge
10	Knock Brook	SM938191	104	80_3	14.9	Whey spread to land
11	Fenton Brook	SM973174	132	0	0	Fish kill in 1989 + yard washings
14	Deepford Brook	SN072198	92	95_3	5.9	Various - intensive dairying
15	Cotland Mill	SN054193	138	0	12.9	Possible yard runoff
16	Holmes Stream	SN042208	85	70_3	13.4	Inadequate storage of slurry
30	Afon Hirwaun	SN258424	129	0	4.5	Variety of intermittent discharges
32	Drywi	SN445585	96	5	3.2	Uncertain - history of inputs
34	Drywi	SN438593	121	0	1.5	Uncertain - history of inputs
41	Nant Coch	SN661252	93	10	1.1	Deliberate discharges from lagoons
42	Gurrey Fach	SN632231	130	0	4.1	Silage effluent & yard washings
43	Nant Cwmffrwd	SN445165	144	3	0	Leaking slurry stores
44	Nant Cwmffrwd	SN443165	122	5	0	Lagoon leakage + yard washings
45	Nant Cwmffrwd	SN422174	143	1	7.9	Parlour & dairy washings
47	Nant y Glaston	SN422175	102	85_3	4.2	Cowshed washings
49	Gwendraeth Trib	SN491162	97	80_3	32.3	Farm identified - source uncertain
53	Afon Rhydbennau	SN150196	175	1	10.3	
54	River Creswell	SN096076	115	0	1.5	
GROUP 3						
1	River Gammon	SN083400	61	100	2.7	Spreading of slurry, whey etc.
2	Aberbach stream	SM997386	78	100	4.0	Yard washings & whey from pig farm
4	Pontfaen Brook	SN027329	115	80	2.5	Parlour washings + silage effluent
12	Churchill Brook	SN050197	95	60	11.5	Overflowing slurry lagoon
17	Slade Brook	SN037224	71	30	6.1	Dairy & yard washings + road runoff
18	Afon Rhydabil	SN116232	137	0	0	Poorly contained parlour washings
21	E. Cleddau trib	SN119181	80	20	1.2	Slurry spreading & yard runoff?
26	Durog	SN292382	120	0	0	Uncertain - history of pollution
27	Durog	SN277375	108	80	0	Whey spread to land
28	Durog	SN283378	74	100	0	Whey spread to land
33	Drywi	SN440592	98	0	1.5	Uncertain - history of pollution
46	Nant y Glaston	SN425175	32	95	0	Cowshed washings
50	Pontgarreg Fach	SN321280	65	80	0	Farm identified - source uncertain
52	Afon Fenni	SN251221	102	30	0	Fish kill in 1989 + lagoon overflow

Subscripts for sewage fungus cover denote changes in group occasioned by modifications to key.

Figure 6.3 Distribution of a) BMWP score, b) sewage fungus cover (%) and c) minimum total trout density (No/m3) within each TWINSPAN group.



NB Medians (dots), ranges ('whiskers') and first and third quartiles (boxes) are shown.

discharges were discovered during an assessment of 10 sites. Although a successful exercise it was felt necessary to incorporate sewage fungus at two extra stages in the system so as to avoid the necessity for invertebrate assessments in cases of gross pollution and such that sites could not be classified into Group 1 if sewage fungus was found to be present in visible quantity at the site either above or below stones (Figure 6.4). Sewage fungus is a definite indicator of organic pollution and its presence even at low abundance should prevent sites being classified in the unpolluted group. These modifications would result in 2 sites from Group 1 being placed in Group 2 and 6 sites in Group 2 being placed in Group 3 (Table 6.5).

Following a further field trial involving pollution control staff and a bailiff the possibility of using the family Heptagenidae itself rather than *Rhithrogena* was investigated so as to ease identification in the field. Examination of raw data from the 55 sites showed that this would not lead to any differences in classification, so the simplification has been made (Figure 6.4).

6.3.5 Assessment of summer indicator key

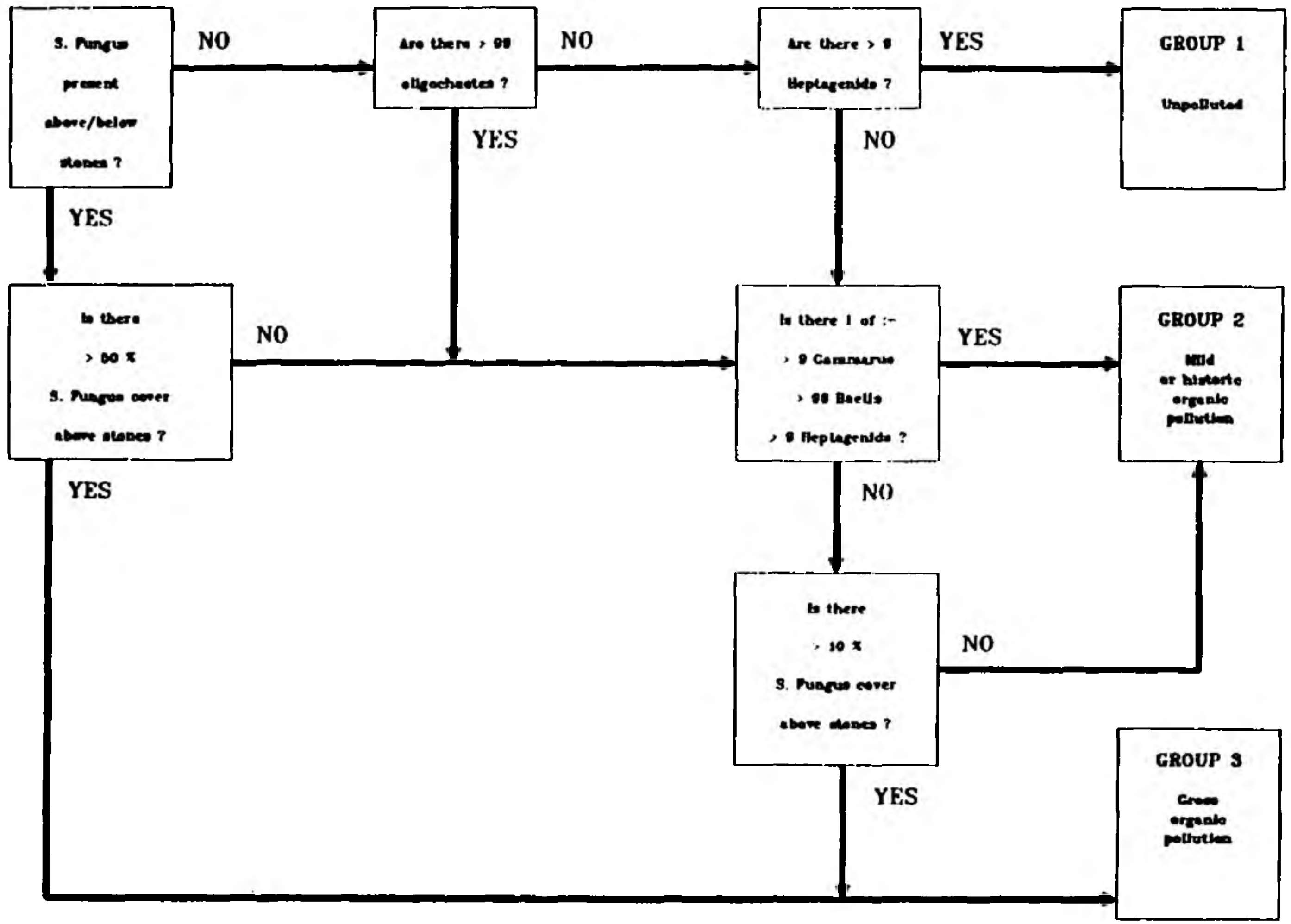
The survey of the Taf identified few sites impacted by farm pollution. The summer indicator system again proved effective in distinguishing sites of different biological status as reflected by BMWP scores (Richardson 1990).

This reinforced the promising findings of an earlier assessment exercise (Reynolds 1989b). The indicator system did not, however, prove an effective predictor of salmonid densities although few sites in the most polluted group were assessed.

6.4 Discussion

TWINSPAN classification was successful in defining three groups of different biological status as reflected in differences in BMWP scores, ASPT, trout density and sewage fungus cover. Group 1 sites generally had BMWP scores in excess of 120, were generally without sewage fungus and held healthy

Figure 6.4 Adaptation of the TWINSPAN indicator key for use in the rapid assessment of farm pollution in streams of West Wales .



populations of trout (Figure 6.3) - they could be considered to represent unpolluted sites. By contrast Group 3 sites were generally grossly polluted with BMWP scores generally below 100, abundant growth of sewage fungus and small or non-existent trout populations. Group 2 sites were intermediate reflecting mild or perhaps historical pollution (Figure 6.3). In the case of two sites (8 and 49) heavy growth of sewage fungus was found in conjunction with good trout populations. These appeared to be cases of recent pollution which had not so far affected fish stocks. Fish may respond quite gradually to loss of feeding opportunities and spawning sites caused by growth of the fungus whereas affects on macroinvertebrates appear to be manifested more rapidly.

The selected indicator key (based on one-minute kick samples) incorporated indicator taxa whose distribution and abundance is generally held to be related to organic pollution. For example, *Rhithrogena semicolorata* (the most abundant Heptagenid), *Baetis* spp., and *Gammarus pulex* all showed reduced abundance below a chronic input of silage effluent whilst oligochaetes showed a large increase (see Section 7). *Rhithrogena* has been shown to be especially sensitive to low dissolved oxygen due to the use of its gills as a suction device for maintaining its position in high current velocities (Jaag and Ambuhl, 1964). It may experience oxygen stress when the stream bed is coated with respiring growths of sewage fungus, although the infrequency of the species at polluted sites might also relate to loss of free stone surfaces which the animals scrape to collect food.

Despite the evidence above, there is a possibility that the observed TWINSPAN groupings might reflect the influence of factors other than farm pollution. There were certainly significant differences between the groups in distance from source, catchment area, pH, conductivity and hardness. However, the differences in pH, conductivity and hardness are unlikely to be significant in biological terms. Sites in Group 3 were closest to source and had the smallest catchment areas which reflects the fact that farm pollution in West Wales tends to have most influence on small streams with low dilution capacity (Wightman, 1988).

The indicator system developed in this study (Figure 6.4) could be used to rapidly identify impacted sections of stream. Survey work can be carried out entirely on the bankside such that many sites can be visited rapidly within a catchment so as to pin-point polluting farms. Results can be rapidly reported and assessed due to the simple system of classification. It is envisaged that it will be usable at least between January and April, a period when farm pollution tends to be most evident - further work could be carried out to establish its seasonal limitation.

7. DETAILED SITE INVESTIGATIONS

7.1 Introduction

Intensive studies of a range of farm pollution problems are required so as to examine the effects of particular farming practices on stream chemistry and biota. This initial study sought also to determine the most effective methods to employ in farm pollution impact assessment work to be undertaken later in the contract period.

7.2 Study area

Pontfaen Brook, a tributary of the Afon Gwaun in south west Wales (NGR: SN032324), was identified during the follow up site assessments (see Sections 6.2.5 and 6.3.3) as being suitable for detailed study for the following reasons:

(i) It was obvious that the source of pollution was leaking silage effluent and so effects specific to this type of pollutant could be investigated.

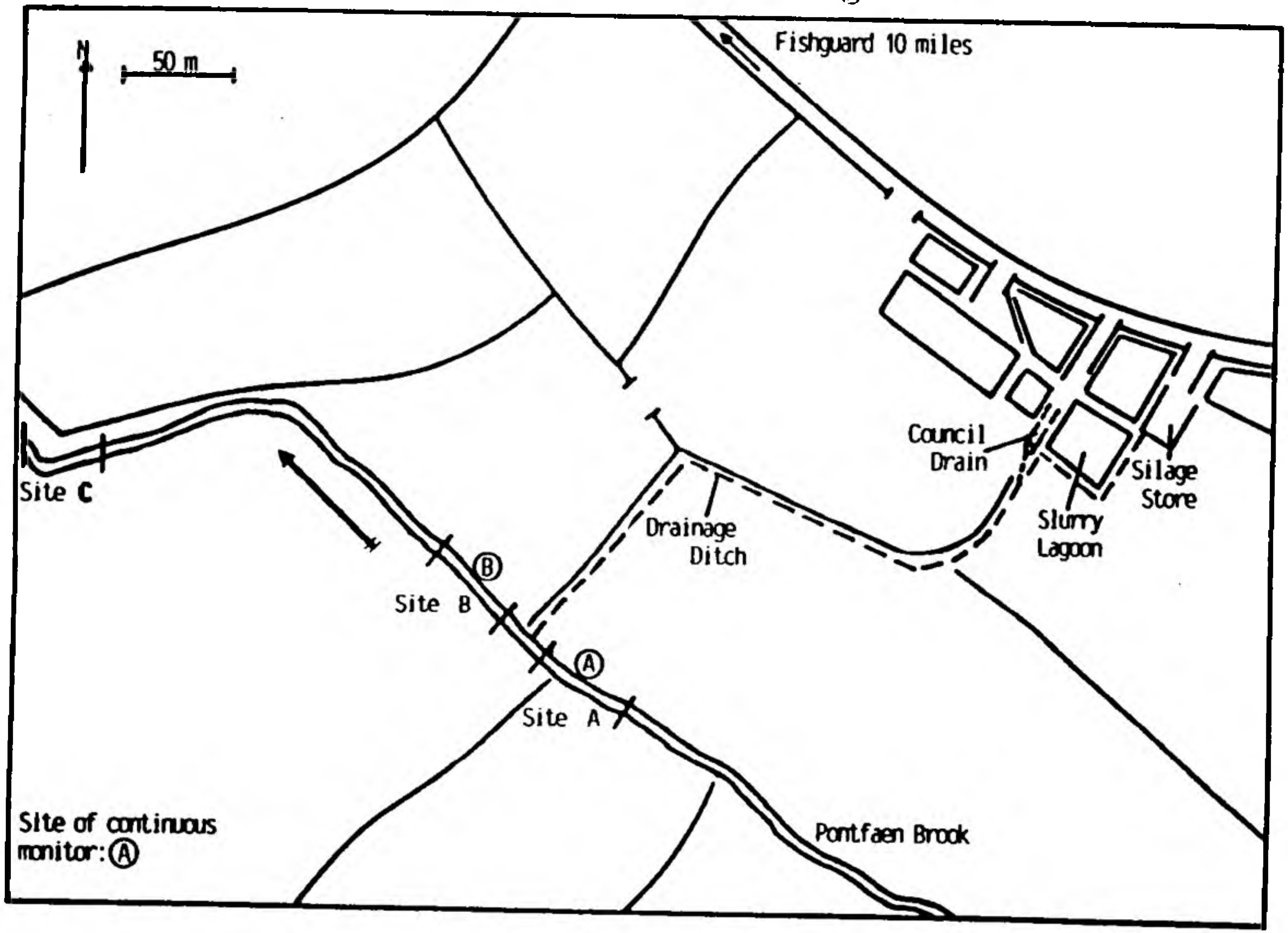
(ii) Pollutant entered the stream at a single point enabling polluted and unpolluted stretches of stream to be easily defined.

(iii) The unpolluted upstream reference zone provided suitable habitat for salmonids and a diverse invertebrate assemblage.

(iv) The position of the site, near to a road and surrounded by rough pasture, enabled easy access.

The study began in early June 1990. Effluent was initially observed leaking through a gap in the wall of a silage store at Trewern Farm (SN034325). It was carried 300 m along a drainage ditch which discharged into Pontfaen brook (Figure 7.1). Below this input an abundant growth of sewage fungus was observed. When remedial work carried out on 13 June 1990 failed to reduce this

Figure 7.1 Pontfaen Brook and the surrounding area.



growth a second polluting discharge was discovered. A council road drain contaminated with silage effluent was found to be discharging to the drainage ditch after passing beneath a slurry lagoon (Figure 7.1). Most of the silage effluent appeared to be entering the drain from an old cross-drain originally installed to drain a damp area adjacent to the silage store, an area which is now part of the slurry lagoon. This cross-drain was sealed up on 3 August 1990. However, a small input of silage effluent was still entering the road drain. It was apparently seeping through the floor of a second silage clamp between the road and the lagoon. Intensive survey work was completed by the beginning of December 1990.

7.3 Methods

7.3.1 Water quality monitoring

Two pHOx 100 DPM continuous monitoring units were installed at Sites A and B (above and below the contaminated ditch) together with TINYLOG data loggers (Figure 7.1). Initially these were equipped to measure pH, temperature, dissolved oxygen and ammonium but conductivity was added later when new equipment became available. From September 1990, real time data were available from Site B following the installation of METEORBURST telemetry equipment. A rainfall recorder with TINYLOG logger was included at Site A.

Weekly spot samples were taken from Pontfaen Brook at Sites A and B, from the drainage ditch and from the council drain. These were analysed for a number of standard determinands at the NRA Llanelli laboratory. To complement the spot samples, stream, ditch and pipe flow were estimated by the depth-area method for the stream and using timed bucket fills for the ditch and pipe.

A Rock and Taylor autosampler was used to collect samples of stream water during the course of two episodes of heavy rainfall. This followed the observation of peaks in conductivity and ammonium ion concentration coupled with rainfall. For the first event on 5/6 October 1990 the equipment was hand-triggered but for the second on 23/24 November 1990 the sampler was triggered remotely using the METEORBURST telemetry system. The sampler was programmed to collect a sample every 30 minutes, up to a maximum of 48 samples. A full set of samples was collected for the second event but equipment failure resulted in only 23 samples from the first covering the first 11 hours only. Samples were analysed at the Llanelli laboratory for pH, conductivity, total ammonia, Total oxidised Nitrogen (TON), Nitrite, orthophosphate and dissolved Organic Carbon (DOC).

7.3.2 Biological monitoring

Three sites of approximately 40 m in length were selected (Figure 7.1). Two of these were in the vicinity of the continuous monitors, A and B, and a third, Site C, was located 250 m downstream, just upstream of a further input of silage effluent. Several aspects of the stream biota were examined:

(i) Sewage fungus - Detailed visual estimations of the percent sewage fungus cover on the stream bed were made monthly at all three sites over 10 contiguous 2-m sections of stream. Rough estimates of cover were made weekly. During the first three months, samples were examined microscopically in an attempt to identify and quantify the species of heterotrophic micro-organisms present.

(ii) Benthic macroinvertebrates - Three minute kick samples were taken every month from riffles at Sites A, B and C and the invertebrates identified to family level in order that BMWP (Biological Monitoring Working Party) scores could be calculated. In June only, five replicate cylinder samples were also taken, from riffles at Sites A, B and C, to allow population densities of individual species to be compared between sites.

(iii) Fish populations - At the beginning of the study the three sites were electrofished quantitatively. Densities (100 m^{-2}) were calculated using the Seber and LeCren catch depletion method (Bagenal 1978). Detailed information on the habitat characteristics of the stream sections was also gathered so that the Welsh NRA HABSCORE system (Milner *et al* 1985) could be used to calculate expected densities of salmonids which were then compared with the observed catch.

7.4 Results

7.4.1 Water quality

(i) pH - Values of pH both above and below the input fluctuated between 6.0 and 7.5 as revealed by continuous monitoring, spot samples and auto samples. It is unlikely that this would have a direct deleterious effect on invertebrate populations or fish.

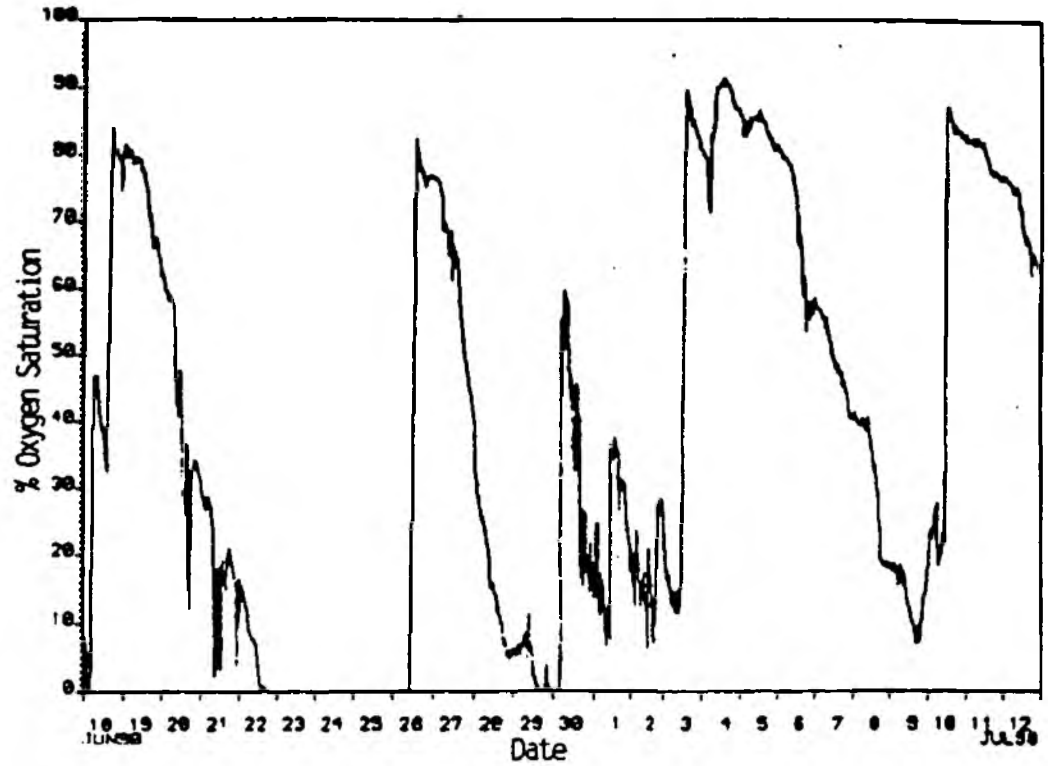
(ii) Dissolved oxygen - Growth of sewage fungus on the down stream DPM sensor head seriously affected dissolved oxygen measurement in the early weeks of the study (Figure 7.2). The pattern obtained was due to physical removal of the fungus during servicing and its subsequent regrowth. Copper-based anti-fouling paint was used in an attempt to prevent this. The downstream head was painted on 10 July but fouling still continued to affect the readings until the beginning of August (Figure 7.2). By this time the sewage fungus had disappeared from the stream as a whole. Dissolved oxygen data obtained from spot samples showed that there were relatively high oxygen concentrations at both Site A and Site B throughout the study (Figure 7.3). At neither site did the concentration fall below about 8 mg l^{-1}.

(iii) Conductivity - When conductivity data became available in early August it was apparent that at Site B (below the input) conductivity maintained a base level of 100-120 µS cm^{-1} but that during periods of high rainfall episodic peaks of up to 200 µS cm^{-1} were observed. At Site A (above the input) rather smaller peaks in conductivity were observed but the base level was comparable. The autosample data for the first event captured exhibited a peak of 187 µS cm^{-1} coupled to rainfall intensity but there was little observable increase during the second event.

(iv) Ammoniacal nitrogen - Spot sample data revealed that although high concentrations of ammoniacal Nitrogen were present in the council drain and in the ditch, concentrations in the Brook upstream and downstream of the input were similar and did not exceed 1.0 mg l^{-1} (Figure 7.4). Calculated concentrations of the toxic component - unionised ammonia -

Figure 7.2 Continuous monitoring of oxygen saturation at Pontfaen Brook, site B.

a) June 18 - July 12



b) July 12 - August 7

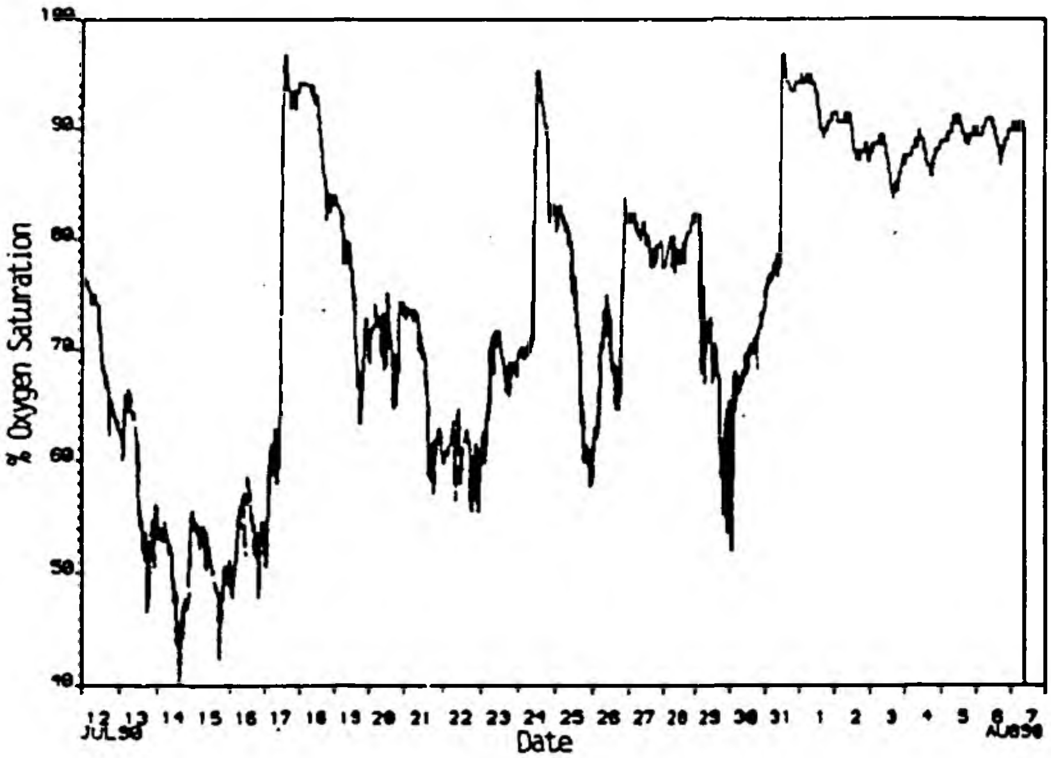
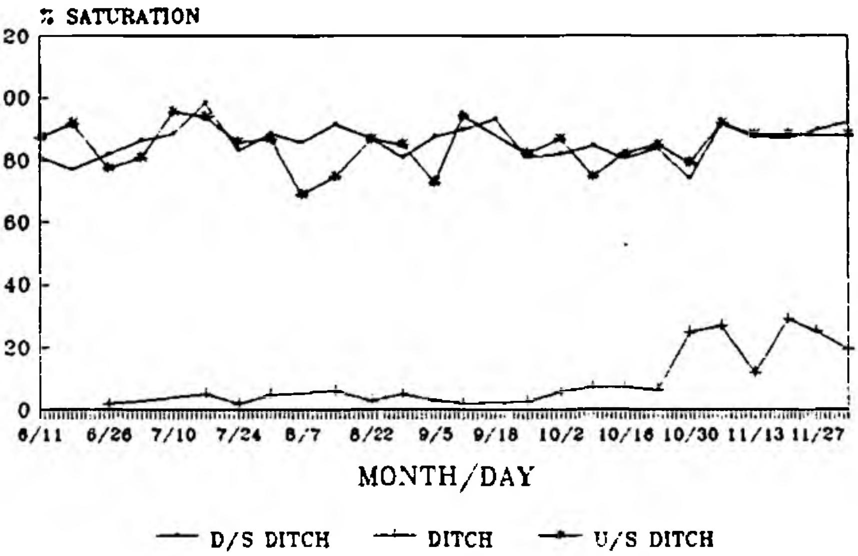


Figure 7.3 Dissolved oxygen levels at Pontfaen Brook from spot sampling.

a) Oxygen saturation (%)



b) Oxygen concentration (mg/l)

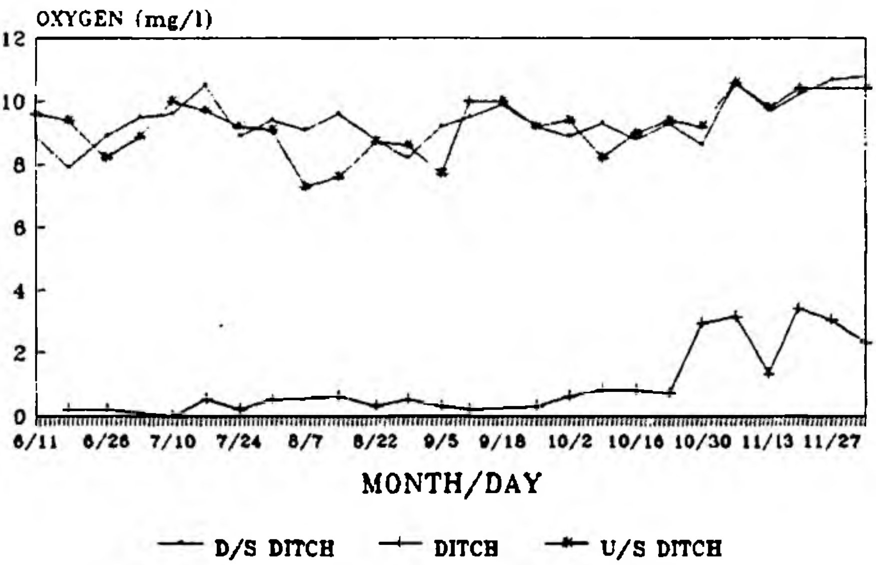


Figure 7.4 Ammoniacal nitrogen concentrations at Pontfaen Brook.

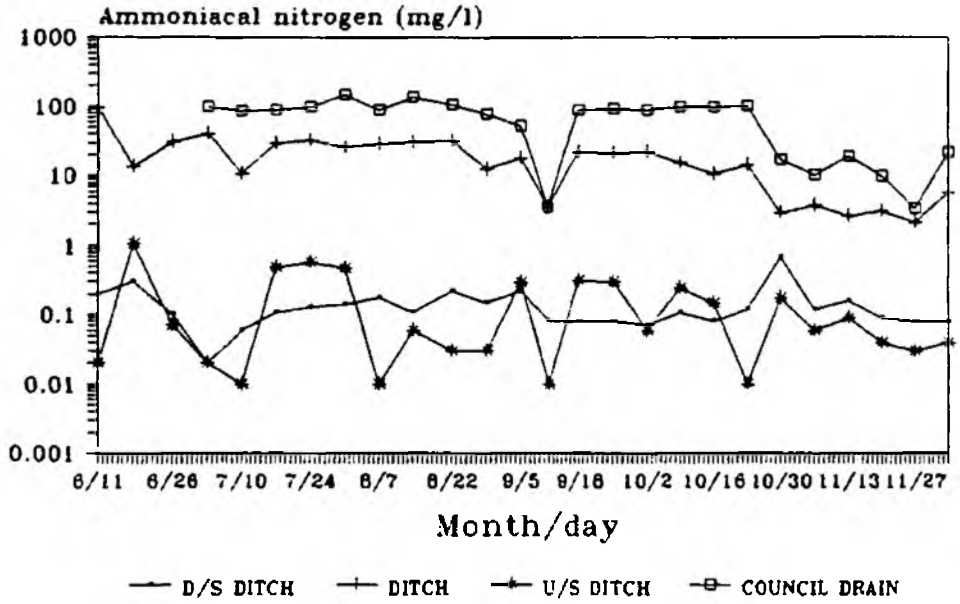
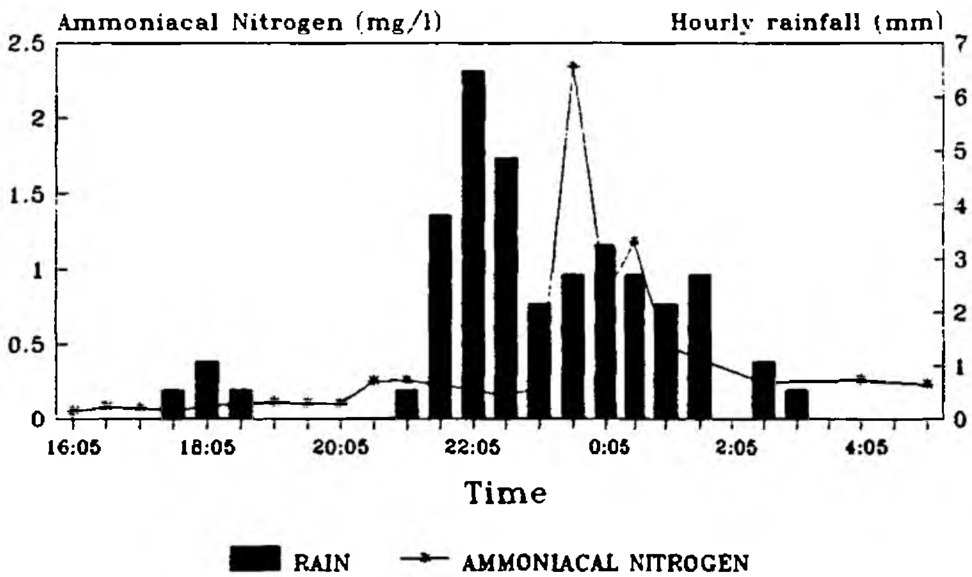


Figure 7.5 Ammoniacal nitrogen concentrations at Pontfaen Brook during event 1 (5/6 October).



did not exceed 0.004 mg l^{-1} in the stream. Continuous monitoring revealed divergences of ammonium ion concentration (effectively equal to total ammonia) from the base level during rainfall episodes at both Sites A and B. The insensitivity of the instrument at low concentration precluded accurate estimation of the peaks but they appeared small. During the two rainfall events maximum ammoniacal nitrogen concentrations recorded were 2.34 and 0.57 mg l^{-1} for the first and second events respectively (Figures 7.5, 7.6). In neither event did calculated concentrations of unionised ammonia exceed the maximum of 0.004 mg l^{-1} recorded during spot sampling.

(v) BOD - The maximum BOD recorded in the ditch was 3521 mg l^{-1} recorded when first sampled on 11 June 1990. This large value corresponded to a BOD downstream at Site B of 13.6 mg l^{-1} as compared with 1.6 mg l^{-1} recorded at the upstream control Site A. BOD in the ditch exhibited a fairly steady decline during the course of the study leading to an equalisation of the BOD at Sites A and B by the end of July (Figure 7.7). In order to quantify BOD input to the stream the ditch BOD loading was calculated as the product of BOD and flow rate. The contribution this made to the downstream BOD was calculated as the product of the BOD and the ratio of the ditch flow to the main stream flow (Figure 7.8). Increases in ditch load and downstream BOD in September and October corresponded to increased rainfall (Figures 7.8, 7.9).

(vi) Other determinands - Nitrite, orthophosphate and DOC concentrations all exhibited marked peaks lagging slightly behind maximum rainfall intensity as revealed by analysis of the automatic samples from both of the captured rainfall events. In the case of DOC peaks of 13.8 and 10.1 mg l^{-1} were observed as compared with initial concentrations of 2-3 mg l^{-1}. Levels appeared to be sustained considerably longer after maximum rainfall intensity than was the case for the other two determinands. Chloride exhibited a marked peak in concentration during the first rainfall event but this effect was very muted during the second event as was the case for conductivity.

Figure 7.6 Ammoniacal nitrogen concentrations at Pontfaen Brook during event 2 (23/24 November).

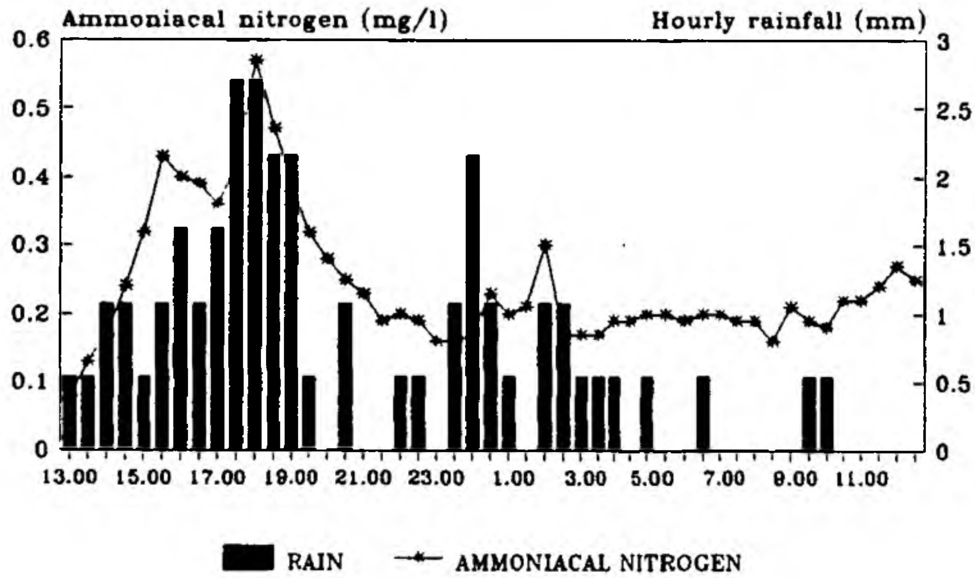


Figure 7.7 BOD concentrations at Pontfaen Brook.

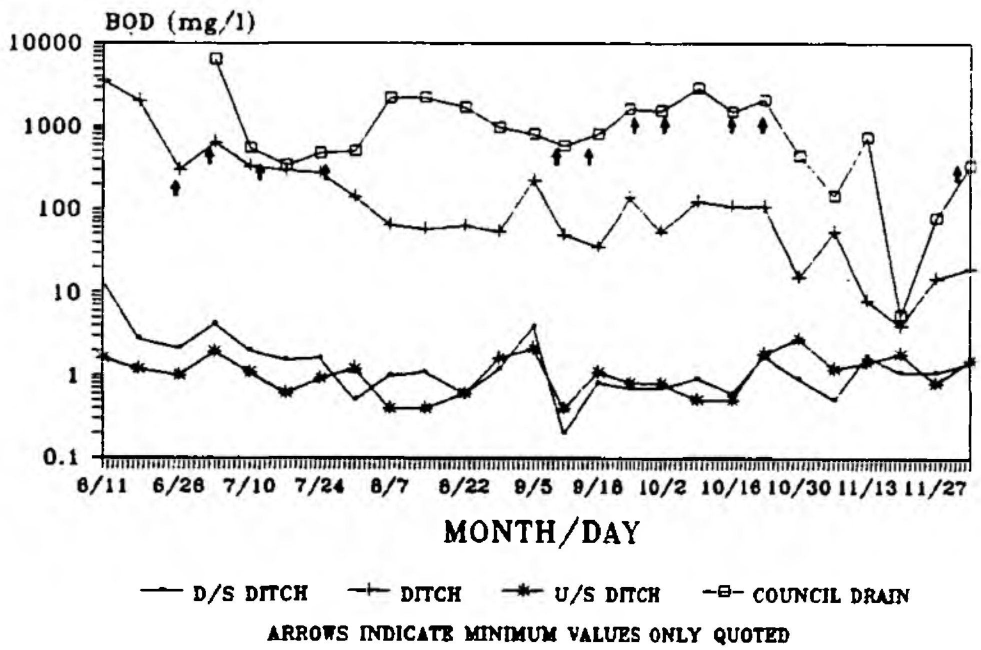


Figure 7.8 Ditch BOD load and its effect on downstream BOD in Pontfaen Brook.

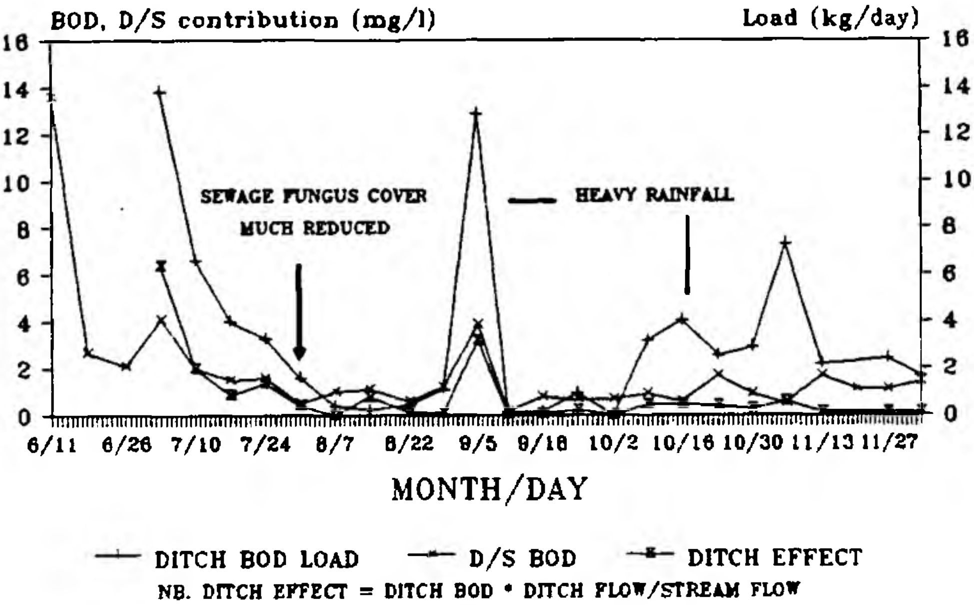
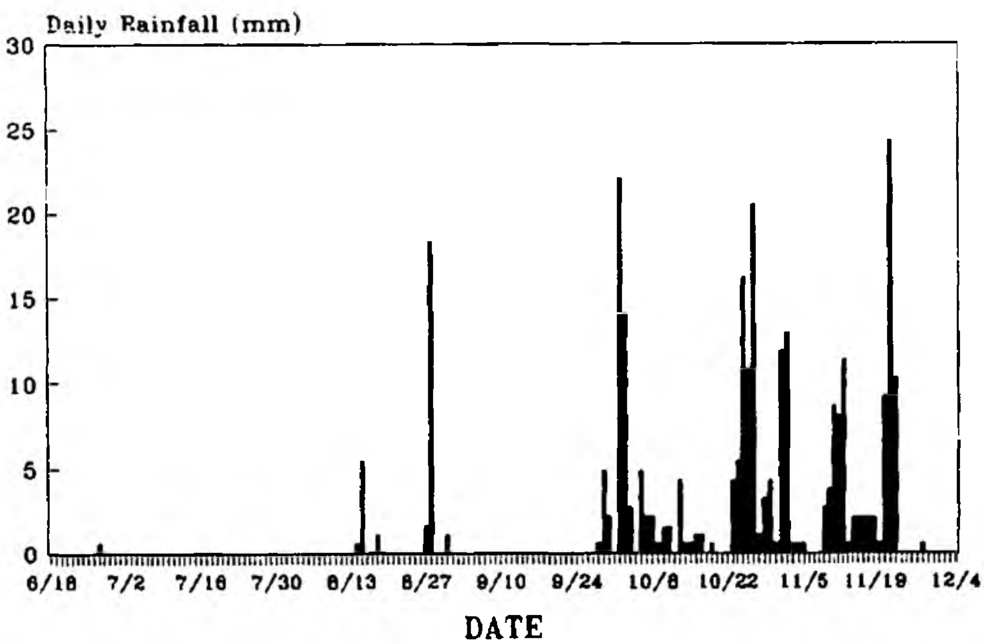


Figure 7.9 Daily rainfall at Pontfaen Brook, 18 June – 4 December 1990.



7.4.2 Sewage fungus

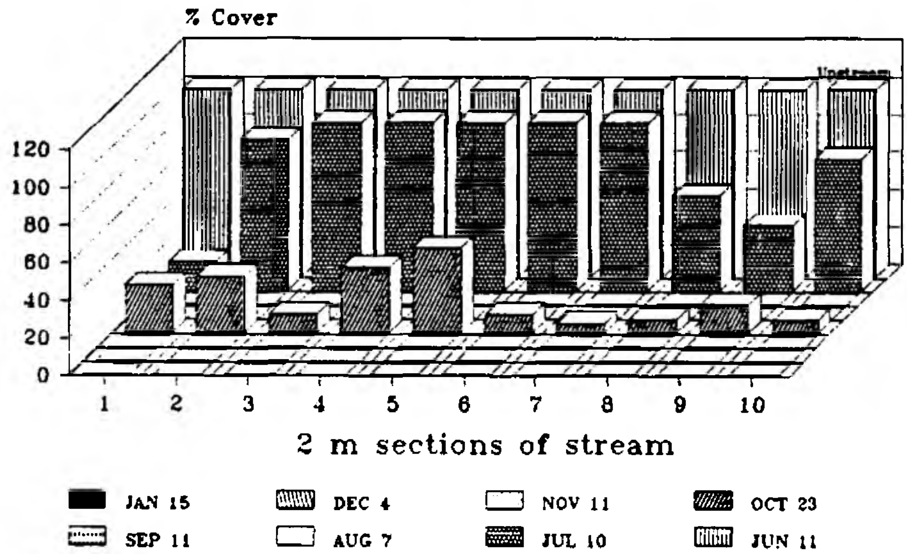
At the beginning of the study there was close to 100% cover at both the downstream sites (B and C) with no fungus at the upstream site, A. Fungus remained abundant downstream until mid July after which it gradually declined until it had all but disappeared by early August except for a small quantity on vegetation immediately downstream of the input ditch. This decline corresponded to a reduction in BOD loading from the ditch and a reduction in the ditch contribution to downstream BOD (Figures 7.10, 7.11). Microscopic analysis revealed that the Phycomycete, *Leptomitus lacteus* and the colonial bacterium *Sphaerotilus natans* were the most common components of the fungus. As time passed the proportion of *L. lacteus* to *S. natans* decreased indicating an increase in localised oxygen concentrations within the sewage fungus (Table 7.1).

Table 7.1 - Microscopic analysis of sewage fungus from Pontfaen Brook

Date	Site B Taxa present	% Abundance	Site C Taxa present	% Abundance
June 18	*Leptomitus lacteus*	96	*Leptomitus lacteus*	95
	Beggiatoa sp	1	*Beggiatoa* sp	1
	Thiothrix sp	3	*Thiothrix* sp	3
	Spirochaetes		*Fusarium* sp	
	Protozoa (many)		*Spirochaetes*	
	Bacteria (many)		Protozoa (many)	
	Diatoms (few)		Bacteria (many)	
July 10	*Leptomitus lacteus*	99	*Leptomitus lacteus*	60
	Sphaerotilus natans	1	*Sphaerotilus natans*	1
	Protozoa		*Zoogloea* sp	5
	Bacteria		Protozoa (few)	
Aug 7	*Leptomitus lactus*	65	Normal stream fungi,	
	Sphaerotilus natans	30	no protozoa or bacteria	
	Beggiatoa alba			
	Protozoa			
	Bacteria			

Figure 7.10 Sewage fungus growth in Pontfaen Brook.

a) Site B



b) Site C

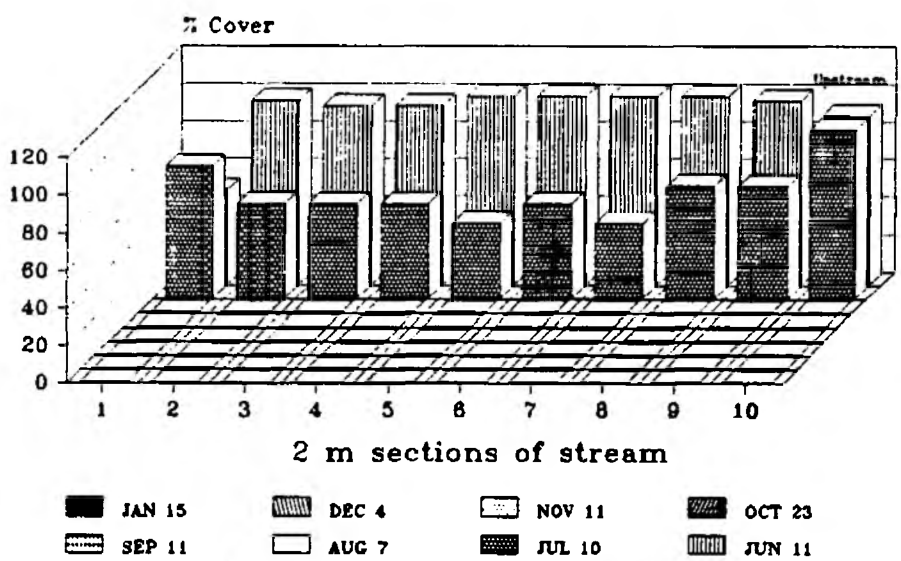
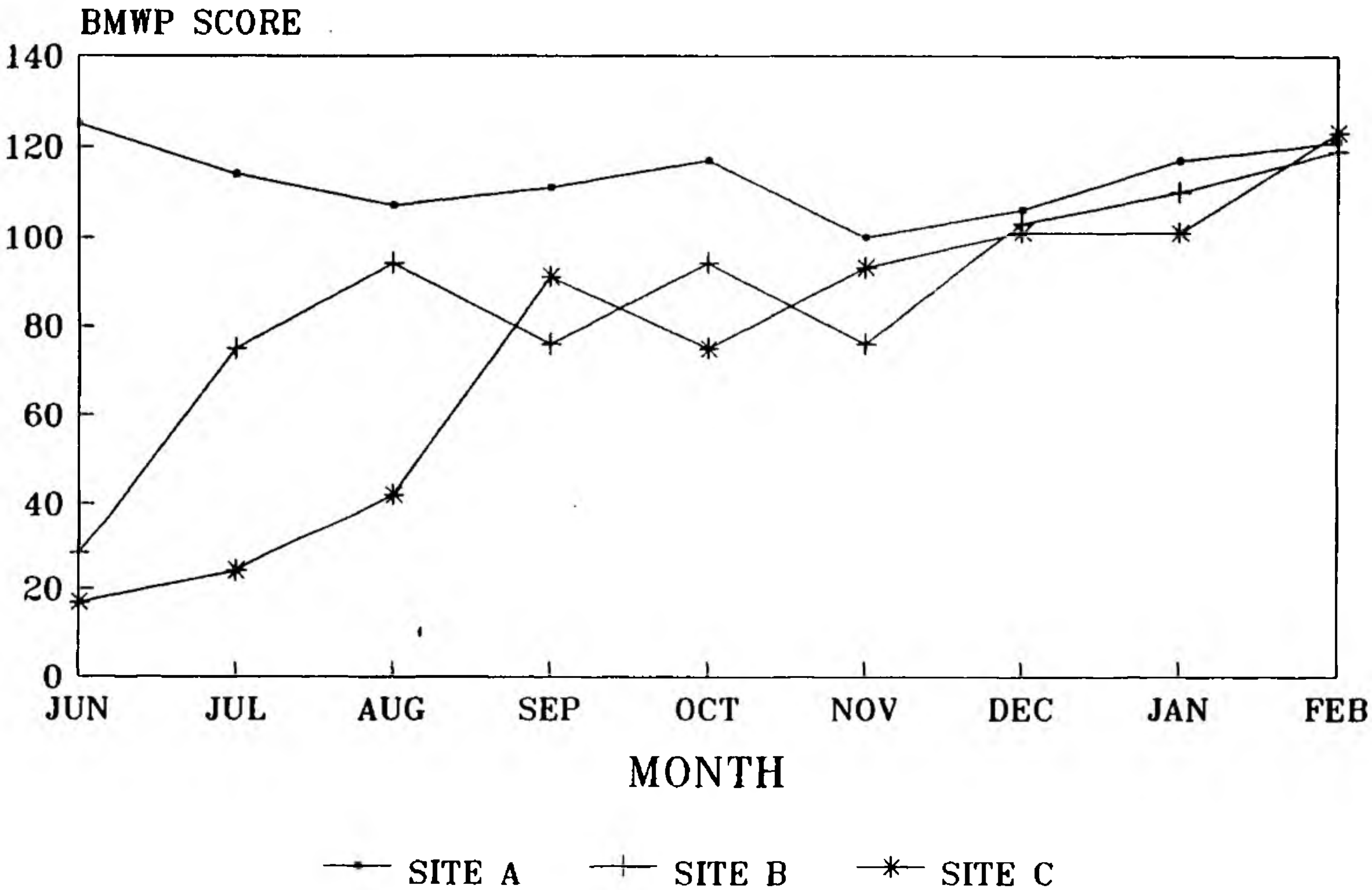


Figure 7.11 Biotic (BMWP) scores at Pontfaen Brook, June – December 1990.



There was a small recurrence of sewage fungus at Site B in September following a period of very heavy rainfall. A larger recurrence occurred in October with a maximum abundance on 23 October (Figure 7.10). This corresponded to a more sustained autumnal increase in rainfall which continued throughout the remainder of the study period (Figure 7.9). The sewage fungus had died back completely by November. No sewage fungus was recorded at Site C after July 1990.

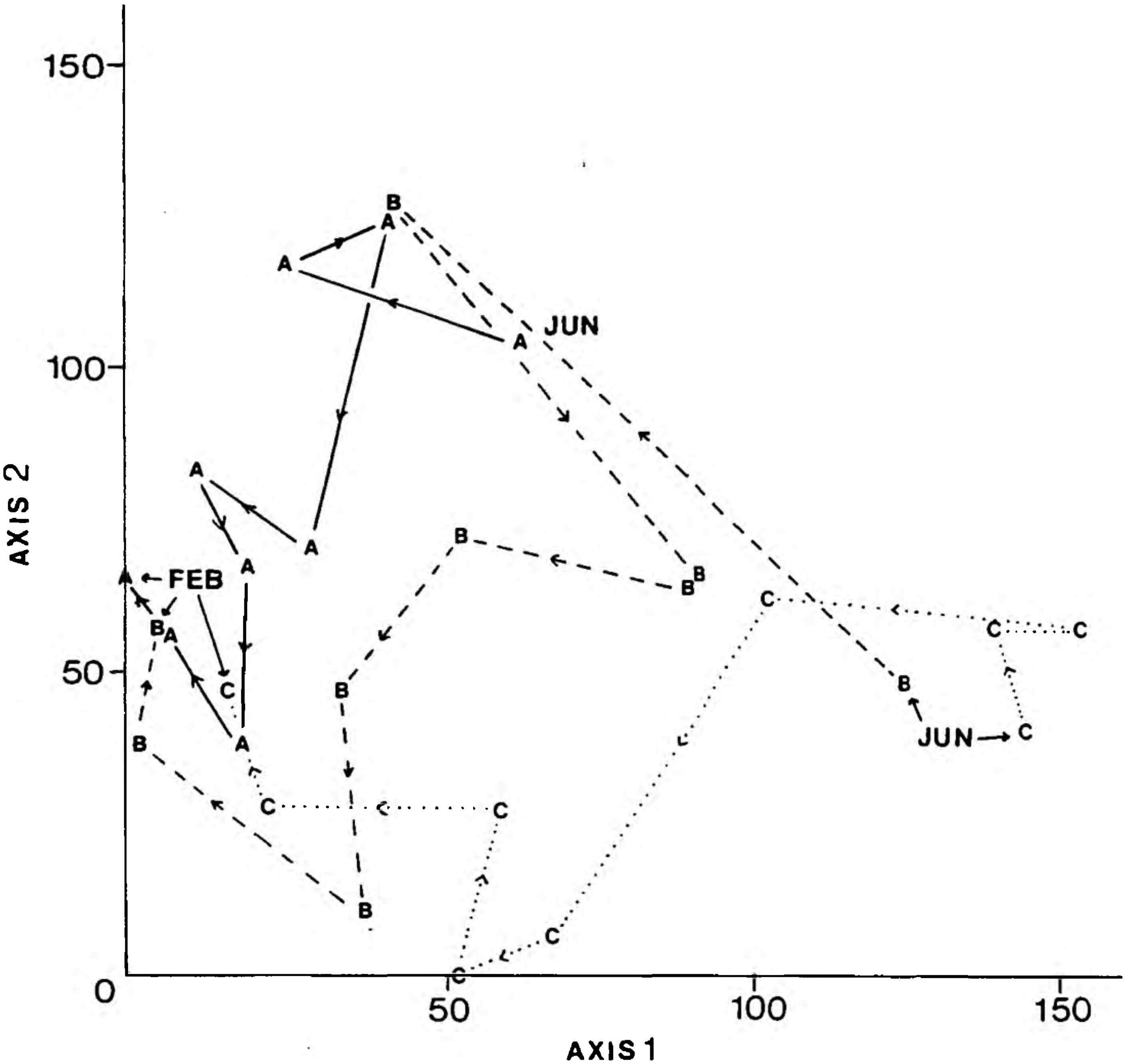
7.4.3 Macroinvertebrate populations

Initial sampling in June 1990 revealed a diverse invertebrate assemblage at Site A and impoverished assemblages at Sites B and C. At Site A BMWP score was 125 whilst Sites B and C scored 28 and 17 respectively (Table 7.2). Also two groups of organisms tolerant of low oxygen concentrations, oligochaetes and chironomidae, showed an enormous increase in density, from 76 and 55 m^{-2} at Site A to 17 700 and 11 700 m^{-2} at Site B (Table 7.3). These were also abundant at Site C with densities of 7000 m^{-2} for the oligochaetes and 6900 m^{-2} for chironomids. There was a contrasting reduction in several taxa intolerant of organic pollution, for example the mayfly *Rhithrogena semicolorata* and the stonefly, *Chloroperla torrentium* respectively, fell from 270 and 287 m^{-2} to zero at both Sites B and C (Table 7.3).

The invertebrate populations at the two downstream sites began to recover early in the study and by December the BMWP scores for Sites B and C (103, 101) were similar to that for Site A (106) (Figure 7.11). The recovery at Site B appears to be the more rapid probably because it is closer to the unpolluted reach of the stream which is a potential source of drifting colonists.

Analysis of the monthly macroinvertebrate data from the 3 sites by Detrended Correspondence Analysis (DECORANA) generated the two principal axes shown in Figure 7.12, which account for 81.3% of the variation in the data set. Sites B and C can be seen to move through ordination space over time and finally coverage with Site A by January. The first axis is quite closely related to BMWP score ($r = -0.87$, $p<0.001$), whilst the second axis perhaps reflects seasonal changes in fauna.

Figure 7.12 Recovery of the macroinvertebrate fauna at Pontfaen Brook.



Plot of axes 1 and 2 derived from DECORANA analysis of monthly macroinvertebrate data for sites A (upstream of ditch), B and C (both downstream of ditch), Jun 90 - Jan 91. Note how the sites converge towards the end of this period.

Table 7.2 - Invertebrate community analysis of Pontfaen Brook

Taxa	Site A	Site B	Site C
Ancylidae	1		
Oligochaeta	2	4	3
Gammaridae	1	1	
Heptagenidae	2		
Ephemerellidae	2		
Baetidae	2	2	1
Leuctridae	3		
Perlodidae	2		
Chloroperlidae	1		
Veliidae	1		
Dytiscidae	2		
Hydrophilidae	1	1	
Elminthidae	2		
Rhyacophilidae	2		
Polycentropodidae	1		
Limnephilidae	2		
Hydropsychidae	2		
Tipulidae	1	1	1
Simuliidae	2	2	2
Chironomidae	2	3	3
BMWP SCORE	125	28	17
ASPT	6.25	4	3.4

Taxa scores are logarithmic abundance categories (ie 1=1-9, 2=10-99)

7.4.4 Fish populations

Pontfaen Brook is not typical of those sites used in the construction of the HABSCORE model. Altitude is high relative to the distance from the sea. To accommodate this, the model had to extrapolate and this may have resulted in an over estimation of the expected fish densities (Table 7.4). Nevertheless it would appear that all three sites had observed trout densities far below what might be expected. Fry were especially scarce with only one individual being caught at Site A, none elsewhere. It is suggested that all three sites have impacted trout populations but that impact is greater at Sites B and C which deviate markedly more from the predicted for the >0+ cohort (Table 7.4).

Table 7.3 - Quantitative sampling of Pontfaen Brook, using a cylinder sampler

Taxa	Site A		Site B		Site C		P
Taxa positively affected by effluent from the ditch:							
Oligochaeta	76	(20-300)	17724	(1660-110880)	6998	(4080-16560)	0.01
Chironomidae	55	(20-140)	11727	(2140-24000)	6863	(3360-11040)	0.01
Taxa showing no significant change:							
Ancylus fluviatilis	6	(0-20)	--		--		*N.S.
Lumbricidae	10	(0-60)	--		--		N.S.
Simulidae	1017	(180-6280)	524	(0-5780)	297	(0 - 2400)	N.S.
Baetis rhodani	220	(80-540)	78	(0-880)	13	(0 - 240)	N.S.
Leuctra moselyi	6	(0-20)	--		--		*N.S.
Leuctra fusca	5	(0-40)	--		--		*N.S.
Isoperla grammatica	14	(0-80)	--		--		*N.S.
Limnebius truncatellus	3	(0-20)	--		--		*N.S.
Helophorus sp.	3	(0-20)	--		13	(0-240)	N.S.
Limnius volkmari	6	(0-20)	--		--		*N.S.
Silo pallipes	5	(0-40)	--		--		*N.S.
Plectrocnemia conspersa	3	(0-20)	--		--		*N.S.
Potamophylax sp.	5	(0.40)	--		--		*N.S.
Hydropsyche siltalai	6	(0-20)	--		--		*N.S.
Pedicia rivosa	3	(0-20)	--		--		*N.S.
Taxa negatively affected by effluent from ditch:							
Gammarus pulex	48	(0-140)	--		--		0.01
Rithrogena semicolorata	270	(60-740)	--		--		0.01
Leuctra inermis	23	(0-100)	--		--		0.05
Drusus annulatus	71	(0-480)	--		--		0.01
Chloroperla torrentium	287	(140-580)	--		--		0.01
Hydraena gracilis	13	(0.40)	--		--		0.05
Elmis aenea	67	(0-180)	--		--		0.05
Rhyacophila dorsalis	15	(0-20)	3	(0-20)	--		0.01
Dicranota spp.	48	(0-100)	12	(0-80)	--		0.05

p - level of significance of the difference between Sites A and B (Kruskal-Wallis test).
* Taxa only at control site but at low density so insufficient replicates for a significant result

Table 7.4 - HABSCORE analysis of Pontfaen Brook

	Site A Age class 0+	Site A Age class (>0+<20 cm)	Site B Age class 0+	Site B Age class (>0+<20 cm)	Site C Age class 0+	Site C Age class (>0+<20 cm)
Observed catch (No 100 m^{-2})	1	22	0	10	0	7
% of model sites with less than this	10	79	3	46	3	33
HABSCORE estimated population (No 100 m^{-2})	217	70	284	70	163	61
% of model sites with a lower estimate	100	100	100	100	99	100
Difference in terms of sd between observed and expected.*	-6.6	-3.5	-8.3	-5.0	-7.4	-5.1

* A value of >1.6 indicates a significant difference at the 90% confidence level.

7.5 Discussion

Turner (1989, unpublished data) has shown that various invertebrates sensitive to low dissolved oxygen exhibit down stream drifting behaviour in response to oxygen concentrations which fall below 7 mg l^{-1}. Spot sample data from Pontfaen Brook demonstrated that oxygen concentrations were continually above this value and consequently above the long term lower lethal limit of 5 mg l^{-1} for salmon and trout survival (Alabaster and Lloyd 1982). In addition the maximum unionised ammonia concentration calculated for Pontfaen Brook was 0.004 mg l^{-1} both from spot sample data and from samples taken automatically during rainfall events. This value is an order of magnitude lower than the EQS value for the protection of fresh water fish recommended by WRc (WRc 1988), or the concentration quoted in Alabaster and Lloyd (1989) of 0.025 mg l^{-1} below which no adverse effects to salmonid fisheries are thought to occur.

Caution should be exercised when interpreting water quality information derived mainly from discrete samples but the data suggest that the impact recorded on the stream fauna in the early months of the study was not due to general water quality but was more likely a result of localised stress due to the presence of dense mats of sewage fungus. Respiration of sewage fungus slimes has been estimated at 10 to 20 times greater than that of commonly occurring aquatic plants (WPRL 1969). This can lead to oxygen deficiency within the substratum preventing hatching of salmonid eggs and adversely influencing invertebrates sensitive to low dissolved oxygen concentration. These effects are in addition to the habitat disruption and loss of feeding niches resulting from thick growth of fungus (Curtis 1969).

As the study progressed, the ditch BOD load initially showed a steady decrease along with the downstream BOD concentration. As this dropped below 2 mg l^{-1} the sewage fungus cover also began to decrease and was absent during August. The apparent threshold of 2-3 mg l^{-1} BOD supports the findings of other workers who have observed significant growths of fungus at similar relatively low BODs, thresholds being related to the nature of the organic substrate responsible (WPRL 1969, Quinn and McFarlane 1988). The peak in ditch BOD load on 5 September was the result of a period of heavy rainfall during late August/early September (Figures 7.9, 7.10). Close inspection of Pontfaen Brook showed a small amount of sewage fungus in isolated patches downstream of the ditch but these were absent the following week.

Rainfall became heavier and more sustained after the beginning of October. This, in conjunction with the restoration of the lower section of the drainage ditch towards the middle of the month, appears to have increased the ditch BOD load and downstream BOD sufficiently to promote a short-lived recurrence of sewage fungus which reached an observed peak on 23 October. Rainfall continued throughout the autumn but the sewage fungus had disappeared by the beginning of November. This was possibly because most of the organic material which had built up during the summer in the ditch had been disturbed by the restoration work and flushed out of the system by the heavy rainfall. Also the silage clamp known to have been leaking effluent into the council drain was finally emptied of silage at this time.

Although this study demonstrates a direct relationship between the decline in load of BOD to the stream and an improvement in biological status the the factors affecting the BOD loading remain unclear. Declining flows during the summer months, remedial work on the farm and progressive emptying of one of the silage clamps may all have interacted to produce the initial sharp reduction in BOD loading in the ditch and downstream BOD. Future monthly visits to the site for biological sampling and general observation may serve to elucidate the mechanisms involved. Whatever the mechanisms, it is strongly recommended that the council drain responsible for much of the input is diverted from its present path to avoid future contamination of the drainage ditch

The results of this study contrast with the findings of earlier work describing the impact of farming practices on Clarbeston stream, a sub-tributary of the E. Cleddau (West Wales). In this case there were substantial episodic peaks in ammoniacal nitrogen concentration and depressions in dissolved oxygen in the water column. These resulted from a complex pattern of daily discharge of parlour washings to the stream and rain-generated inputs of yard water contaminated with slurry (Schofield and Bascombe 1990). At Pontfaen the input of silage effluent was more continuous, resulting in a chronic effect on the steam biota apparently due to the growth of sewage fungus rather than direct effects of water quality. Further work is required to investigate the effects of other discrete farm waste management problems on stream quality.

8. SALMONID RECOLONISATION STUDIES

8.1 Introduction

Following acute pollution events resulting in large scale fish kills on two streams in South West Wales, a series of electrofishing surveys were carried out to investigate the recovery of their salmonid populations. The main objectives were to assess the extent of fish mortalities, the rapidity of natural recolonisation and the relative contributions made to recovery by localised migration and spawning. Such information would be of general value to the NRA in terms of assessing the benefits of restocking and in the assessment of compensation claims following fish kills.

The two study streams were Deepford Brook, a sub tributary of the Eastern Cleddau, and the Afon Fenni, a tributary of the river Taf. Deepford Brook was subject to an input of cattle slurry on 28 April 1988. The spill originated from collapsed slurry lagoon at North Lamborough Farm (SN165236) and entered the the brook some 2 km from its source via a drainage ditch (Figure 8.1). It was estimated that 2703 trout fry (*Salmo trutta*) and 2777 trout parr were killed along with 480 salmon fry (*Salmo salar*) and 67 salmon parr. However as stocks in the tributaries were unaffected it was considered a suitable site for recovery studies.

A slurry spill occurred on the Afon Fenni on 21 August 1989. It originated from Trehoose Farm (SN245249) and entered the stream in its upper reaches less than 1 km from source (Figure 8.2). The pollution in this case was more serious and 9040 trout fry and 5314 trout parr were estimated dead. One hundred and twenty salmon parr were also thought to have been killed. A previous survey (NRA 1989) had found no salmon fry in the stream and so these were assumed absent at the time of the kill.

Figure 8.1 Electrofishing sites on the Deepford Brook.

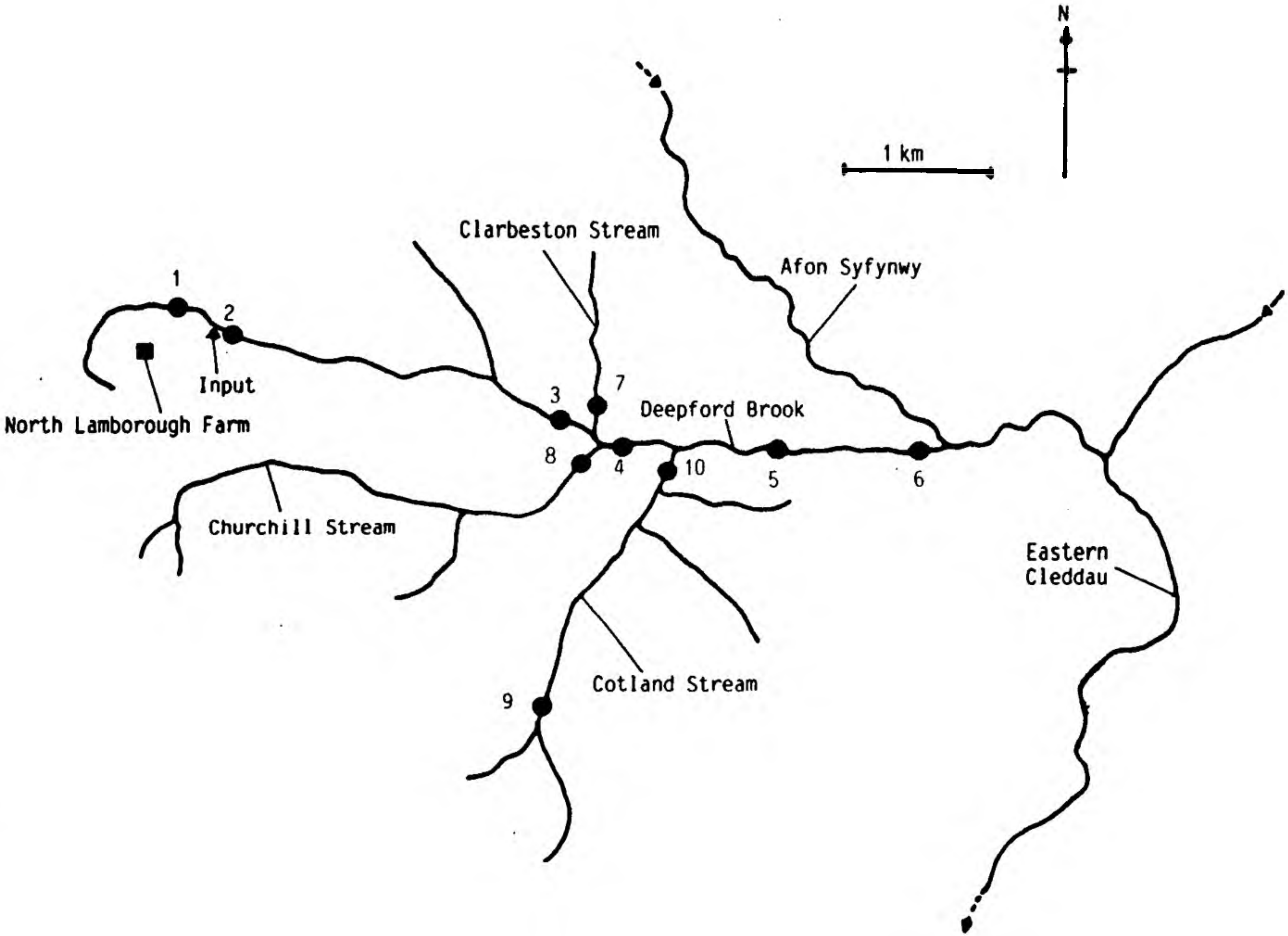
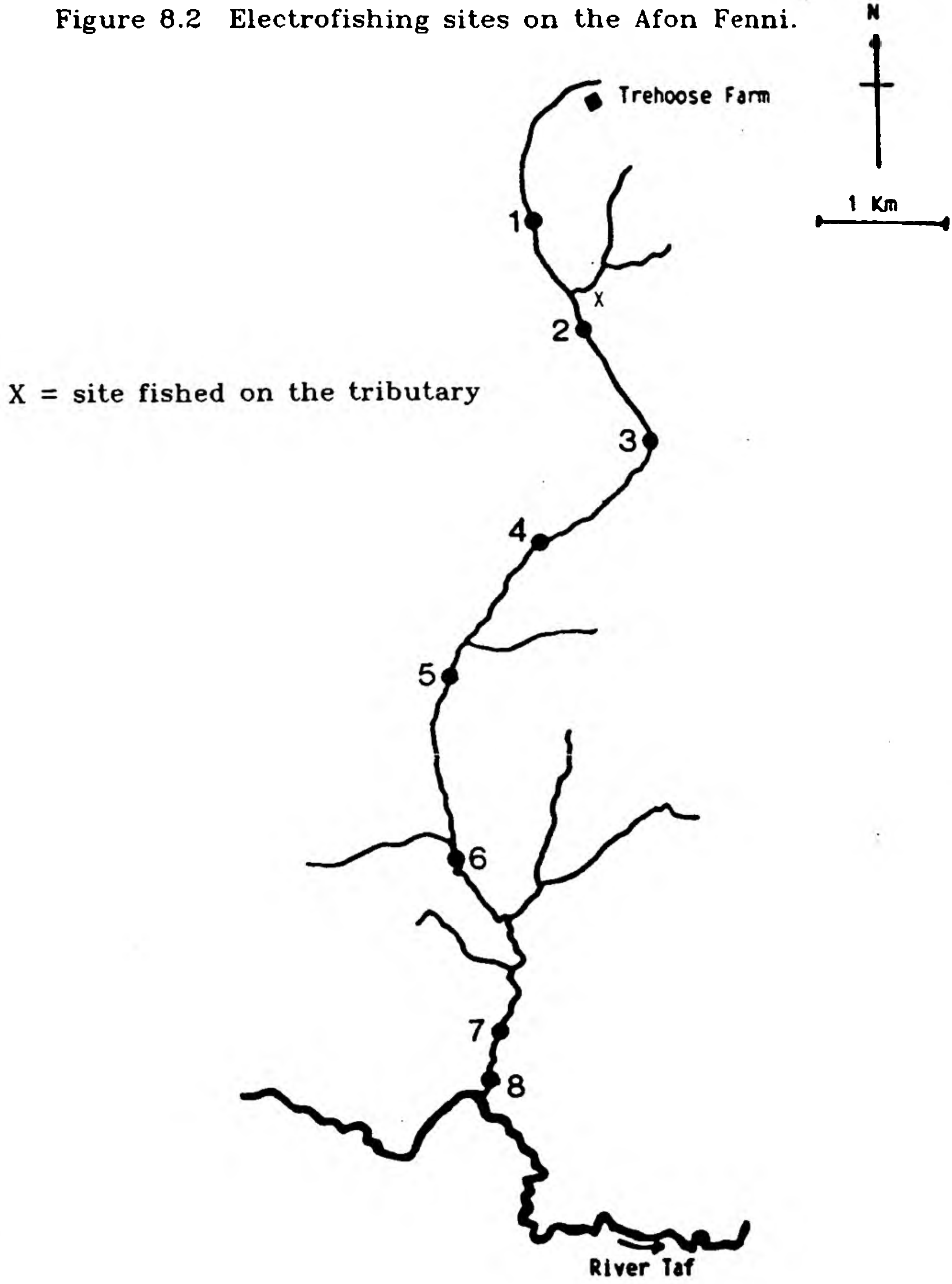


Figure 8.2 Electrofishing sites on the Afon Fenni.



8.2 Methods

Ten electrofishing sites were selected on Deepford Brook (Figure 8.1, Table 8.1). These were initially fished on 5/6 May 1988 to show the extent of the fish kill and the stocks left in the brook and tributaries. Successive surveys were then undertaken on 19/20 September 1988, 22/23 August 1989 and between 26 September and 4 October 1990 to assess the extent of colonisation from the tributaries and the degree of spawning success in the affected reach.

Table 8.1 - Electrofishing survey sites on Deepford Brook

Site	OSGR	Location	Width (m)
1	SM 027 206	Deepford Brook 50 m above effluent input	1.0
2	SM 029 205	Deepford Brook 50 m below effluent input	1.4
3	SM 049 200	Deepford Brook above road bridge	2.4
4	SM 043 198	Deepford Brook between Cotland Mill Stream and Churchill Stream.	2.5
5	SM 060 198	Deepford Brook at Drim Farm, below confluence with Cotland Mill Stream.	3.2
6	SM 071 199	Deepford Brook 50 m upstream of Syfynwy confluence.	3.6
7	SM 050 200	Clarbeston Stream at Confluence with Deepford Brook.	---
8	SM 050 198	Churchill Stream at Lower Lamborough	2.4
9	SM 048 184	Cotland Mill Stream at Duckspool Farm	1.8
10	SM 054 197	Cotland Mill Stream 200 m upstream of Deepford Brook.	2.8

Eight sites were selected on the Afon Fenni (Table 8.2) and initial fishing by bailiffs took place on 25/26 August 1989. Following this a second survey was carried out on 17/18 October 1990 which included the fishing of a tributary near the top of the brook to assess its potential as a source of colonists.

The initial survey of the Afon Fenni, carried out by the bailiffs, was semiquantitative and the results were adjusted accordingly using the methods of Strange, Aprahamian and Winstone (1989). All other fishings were quantitative. Sites of approximately 50 m length were delineated by 1 cm mesh stop nets and two or three electrofishing runs were performed to ensure catch depletion of more than 50% between runs. All salmonids were measured and population densities of 0+ and >0+ were estimated using the Moran-Zippin method or the Seber-LeCren method for two catches (Bagenal 1978).

Table 8.2 - Electrofishing survey sites on Afon Fenni

Site	OSGR	Location	Width (m)
1	SN 241 239	Afon Fenni 100 m downstream of Liechclawdd.	---
2	SN 245 230	Afon Fenni at Maencoch.	2.2
3	SN 251 220	Afon Fenni at Nantyreglwys Mill.	2.9
4	SN 241 211	Afon Fenni at Rhydycaeshyd.	3.5
5	SN 234 199	Afon Fenni at Pistyll Gwyn.	3.6
6	SN 234 184	Afon Fenni at Llwyncrwn.	4.1
7	SN 238 169	Afon Fenni at Pont y Fenni.	4.2
8	SN 236 163	Afon Fenni just above the Confluence with the Taf.	3.8

8.3 Results

8.3.1 Deepford Brook

The results of the first three electrofishing surveys on Deepford Brook have been reported elsewhere (Schofield and Bascombe 1990). The results of the September 1990 fishing (Figure 8.3) reveal a depressed 0+ trout population below Site 2 and a depressed >0+ trout population below Site 3. When compared with the classification scheme for Welsh streams developed by Strange *et al* (1989) (Table 8.3), none of these lower sites score higher than D and the populations present are classed as either 'poor' or 'absent' (Table 8.4). Trout fry were also absent from Site 8 although older fish were present. Flows in Clarbeston Stream (Site 7) were so low that fishing did not take place.

Table 8.3 - Classification system for salmonids in NRA Welsh Region

a) Abundance categories (numbers 100 m^{-2}) for juvenile salmonids.

	FRY (0+)	PARR (>0+)
Excellent	>100	>25
Good	50.01-100	15.01-25
Moderate	25.01-50	5.01-15
Poor	0.01-25	0.01-5
Absent	0	0

b) Classification matrix for juvenile salmonids.

		Fry (0+) Excellent	Good	Moderate	Poor	Absent
	Excellent	A	A	A	B	C
	Good	A	A	B	B	C
Parr	Moderate	A	B	B	C	D
(>0+)	Poor	B	B	C	D	D
	Absent	C	C	D	D	D

Figure 8.3 – Densities of 0+ and >0+ trout from the Deepford Brook catchment, September 1990.

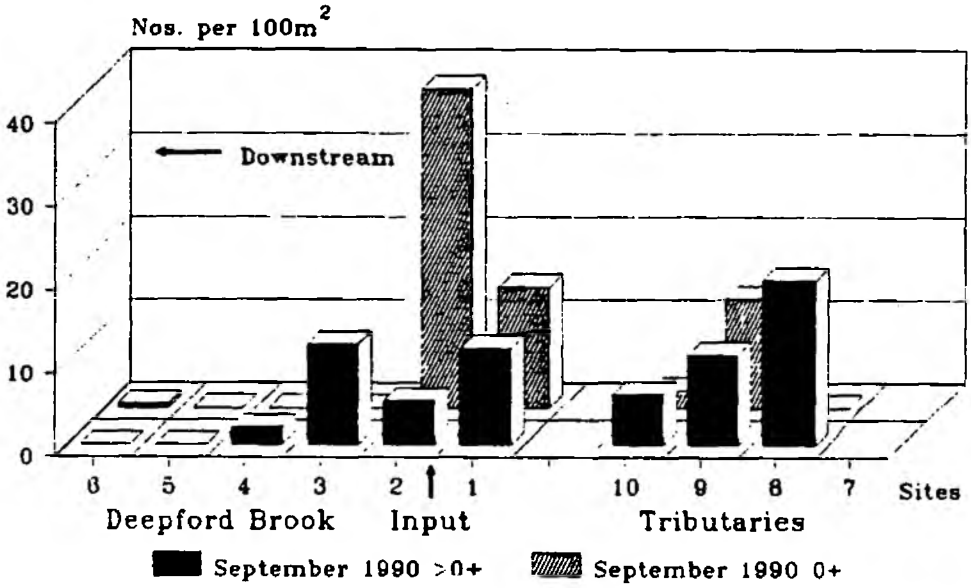
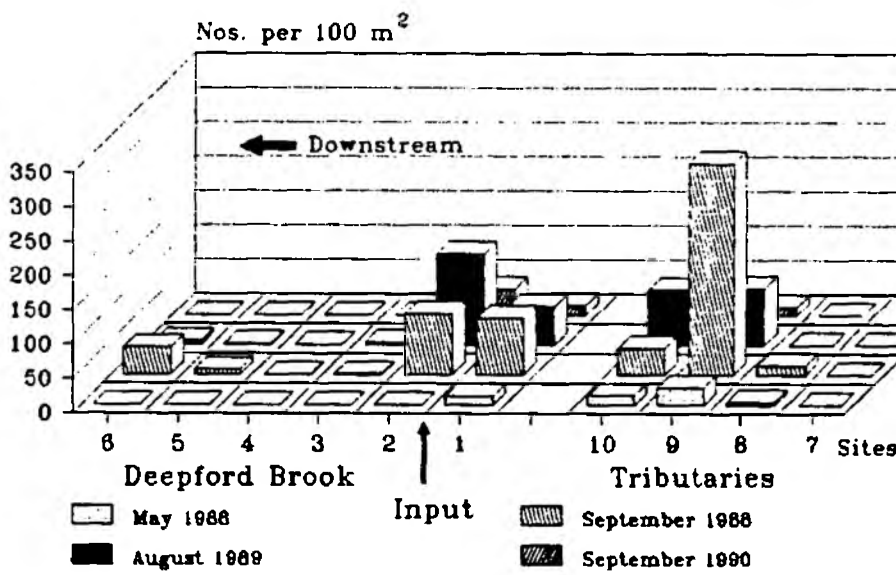


Figure 8.4 Densities of 0+ trout from the Deepford Brook catchment, May 1988 – September 1990.



When the September 1990 data are compared with that from previous years the most striking feature of all the surveys is the lack of 0+ fish in the lower reaches of the brook (Figure 8.4). There is also a marked reduction in >0+ fish at the bottom two sites (5,6) (Figure 8.1) between September 1989 and September 1990 (Figure 8.5). A possible explanation for this is chronic pollution known to be entering the Brook in its lower reaches.

Table 8.4 - Abundance of trout at sites on Deepford Brook and Afon Fenni

Stream	Year	Site	0+ Category	>0+ Category	RFMP CLASS
Deepford Brook	1990	1 (U/S)	Poor	Moderate	C
		2	Moderate	Moderate	B
		3	Absent	Moderate	D
		4	Absent	Poor	D
		5	Absent	Absent	E
		6 (D/S)	Poor	Absent	D
		7 T	-	-	-
		8 R	Absent	Good	C
		9 I	Poor	Moderate	C
		10 B	Poor	Moderate	C
Afon Fenni	1989	1 (U/S)	Absent	Absent	E
		2	Absent	Absent	E
		3	Absent	Absent	E
		4	Absent	Absent	E
		5	Absent	Absent	E
		6	Absent	Poor	D
		7	Absent	Poor	D
		8 (D/S)	Absent	Moderate	D
	1990	1 (U/S)	Absent	Absent	E
		2	Poor	Moderate	C
		3	Absent	Poor	D
		4	Poor	Good	B
		5	Moderate	Poor	C
		6	Poor	Poor	D
		7	Poor	Poor	D
		8 (D/S)	Poor	Poor	D

U/S = Upstream D/S = Downstream

Figure 8.5 Densities of >0+ trout from the Deepford Brook catchment, May 1988 - September 1990.

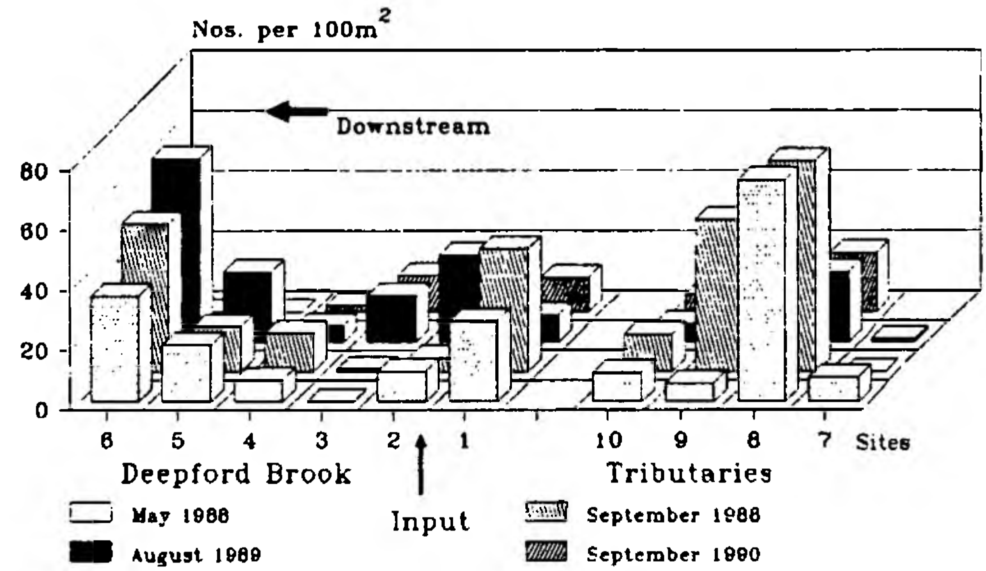
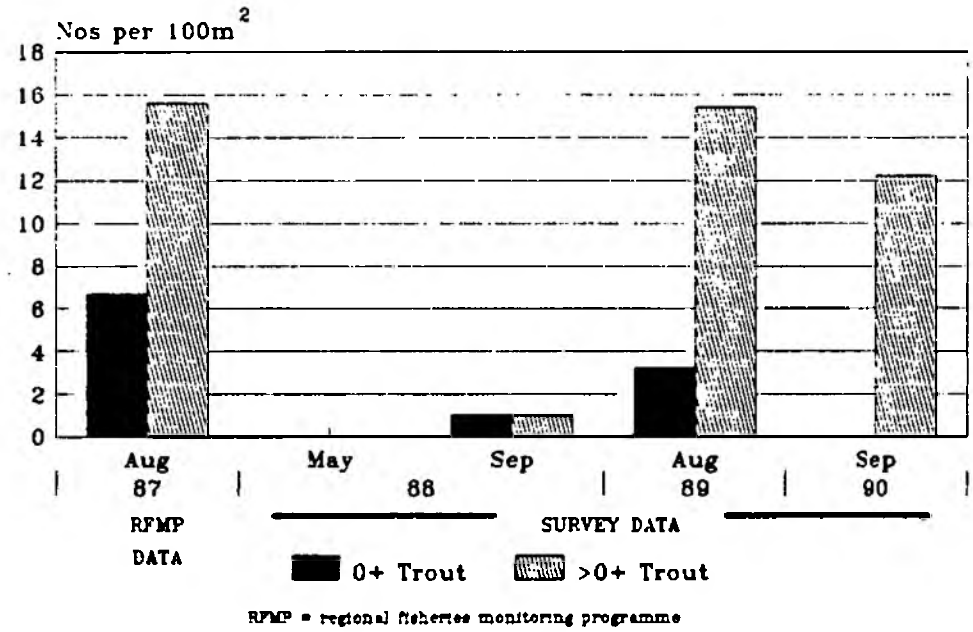


Figure 8.6 Trout densities at site 3 on the Deepford Brook, including pre-pollution data.



Following the spill >0+ trout populations were hardest hit at Site 3. Site 2, it was assumed, was rapidly recolonised by fish from Site 1, (Schofield and Bascombe 1990). Survey data for Site 3 were compared with data collected as part of the NRA Regional Fisheries Monitoring Programme (RFMP) (NRA 1989), which unfortunately were not available for other sites. It can be seen that >0+ populations have more or less returned to pre-pollution levels by August 1989, although only half the number of fry are present and these are absent the following year (Figure 8.6).

Salmon were only found in the lower reaches of Deepford Brook and were most common at Site 6 (Figures 8.7, 8.8). However it is uncommon to find salmon present in streams with a width less than about 3-4 m (Wightman 1987), and so they were not expected at sites further upstream (see Table 8.1 for stream widths).

8.3.2 Afon Fenni

Following the input of slurry to the Afon Fenni no live salmonids were found for a distance of 7 km below the source of pollution and carcasses were present at all but the most downstream site. No live 0+ trout were present at any of the sites and >0+ fish only at the bottom three sites (Figure 8.9).

The following year trout were found at all the sites apart from Site 1. High numbers of 0+ fish at some upstream sites indicate that the pollution did not affect spawning in the autumn of 1989 (Figure 8.9). Population densities at Site 3 were lower than those at adjacent sites but this was possibly due to chronic pollution observed in the spring of 1990 (Rutt *et al* 1990). When compared to the classification system of Strange *et al* (1989), Sites 5, 4 and 2, which immediately following the pollution were in Category E (no salmonids), were in Categories C, B and C respectively the following year (Table 8.4).

There was no change in the bottom three sites which all scored D. This was possibly due to the presence of fry at the sites being offset by a reduction in the numbers of >0+ fish, which would have moved into the Taf or migrated to sea as smolts and not been replaced from upstream.

Figure 8.7 Densities of 0+ salmon from the Deepford Brook catchment, May 1988 - September 1990.

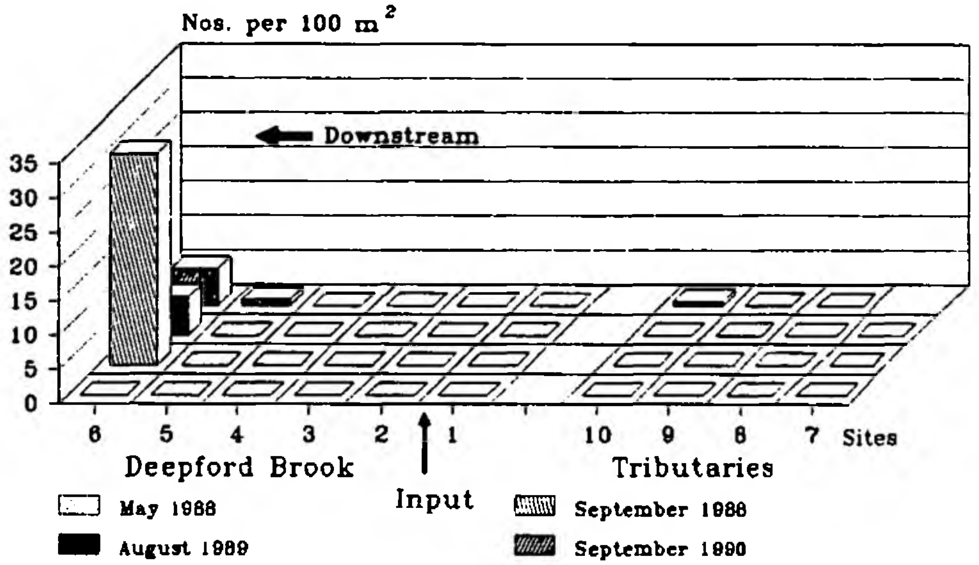


Figure 8.8 Densities of >0+ salmon from the Deepford Brook catchment, May 1988 - September 1990.

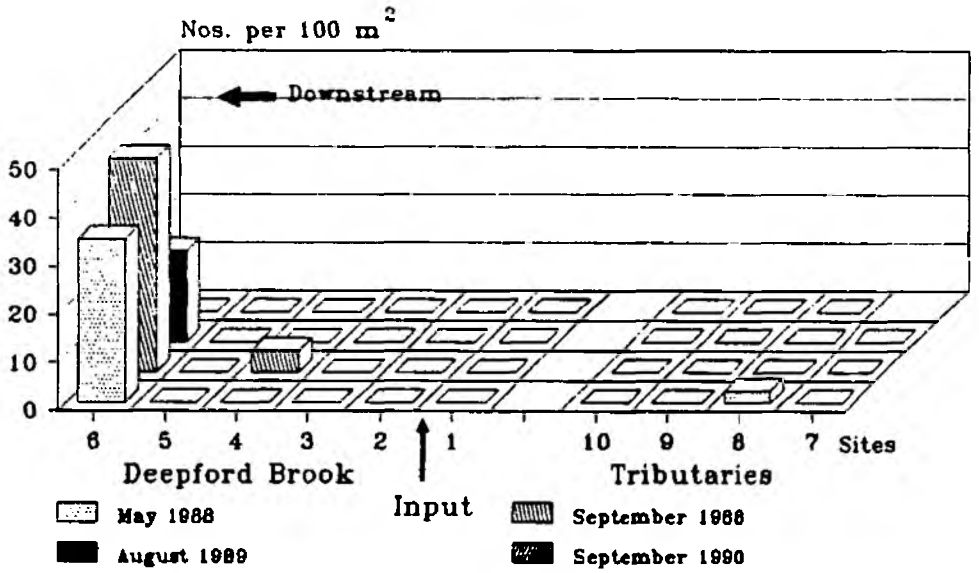


Figure 8.9 Trout densities on the Afon Fenni, August 1989 and October 1990.

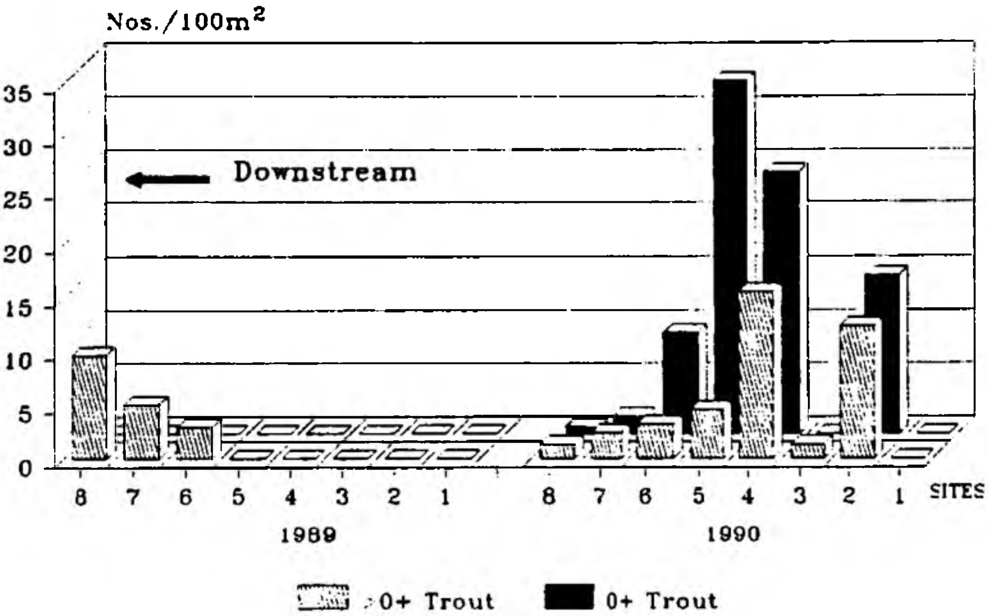
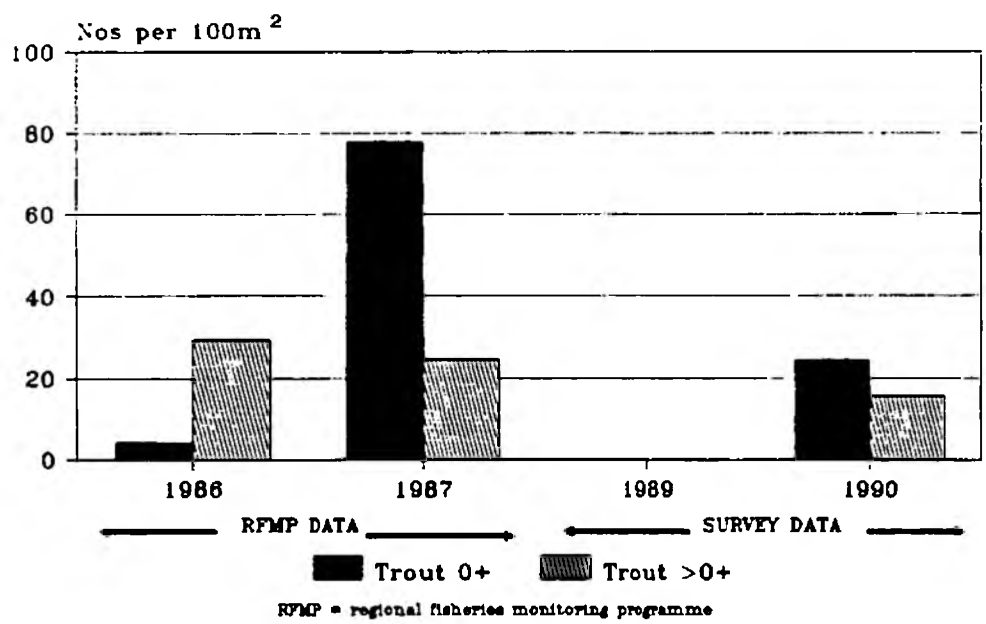


Figure 8.10 Trout densities at site 4 on the Afon Fenni, including pre-pollution data.



The brief electrofishing survey on the top tributary (X on Figure 8.1), revealed populations of 19.7 0+ and 4.9 >0+ trout per 100 m^2 suggesting that this might be a possible source of colonists moving downstream into the Afon Fenni.

When data for Site 4 from the 1990 fishing are compared to RFMP data (NRA 1989) from previous years it can be seen that although trout fry are not at the levels they were in 1987 they are above those in 1986 and the site may be considered to have recovered (Figure 8.10). Again, earlier RFMP data were not available for other sites on the stream.

Salmon were also found in the lower reaches during the 1990 survey but, as with Deepford Brook, the Afon Fenni is probably too small further upstream for them to occur (Figure 8.11) (see Table 8.2 for stream widths).

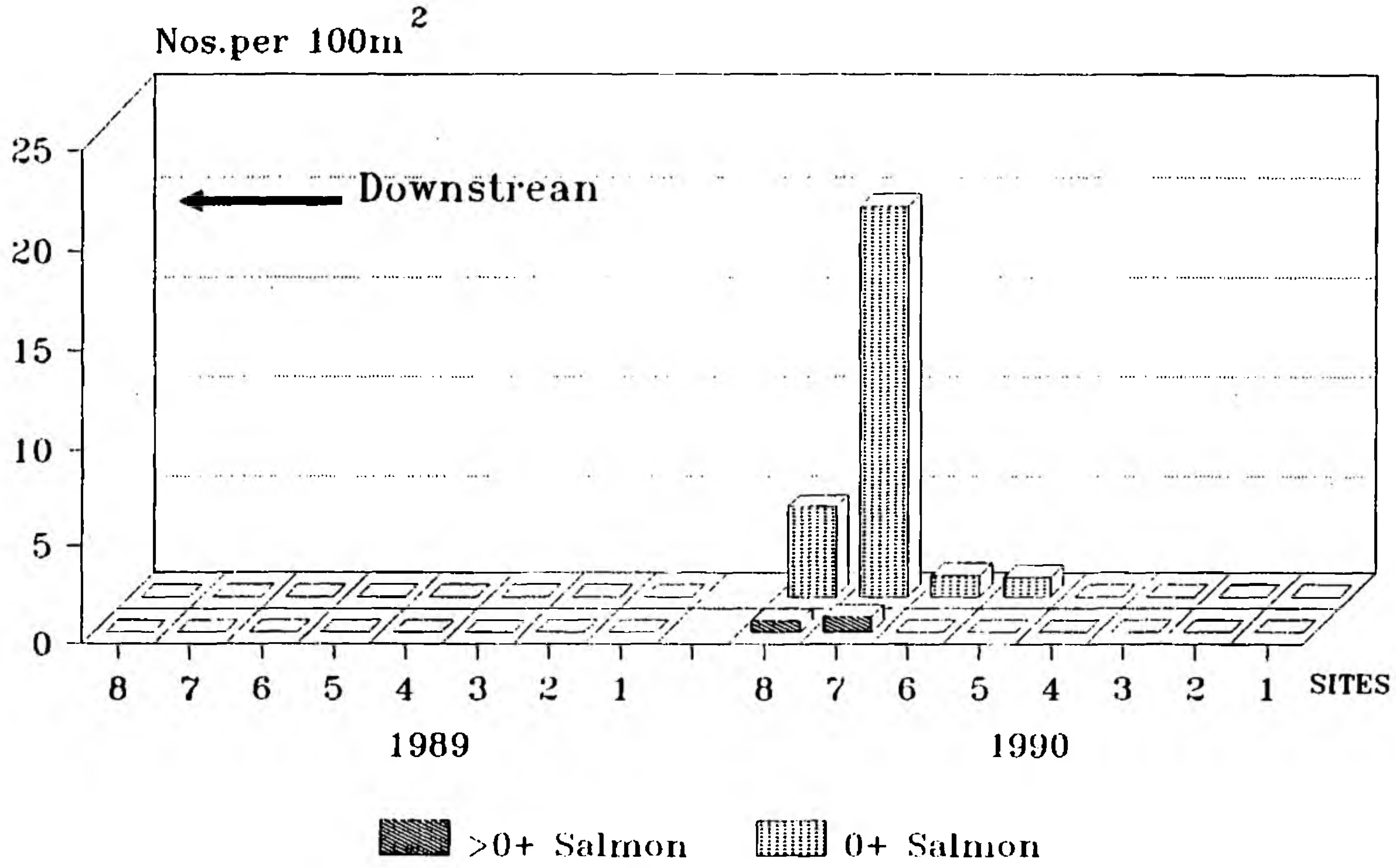
8.4 Discussion

There are two mechanisms for recolonisation: firstly migration by >0+ fish from unaffected stretches of a stream and its tributaries, and secondly by the recruitment of fry following successful spawning. These will be dealt with in turn.

8.4.1 Localised migration

In the case of Deepford Brook there is evidence that localised migration of trout began immediately between Sites 1 and 2. At Site 3, >0+ populations had returned to pre-pollution levels within twelve months although chronic inputs of dairy waste appear to have depleted populations at Sites 4 to 6 when they were fished in 1990. Several chronic inputs have been identified during work carried out in the area and include, for example, an overflowing slurry lagoon discharging into Churchill Brook (Site 8) which was serious enough to cause the growth of sewage fungus (Rutt *et al* 1990) and a ditch discharging slurry to Deepford above Site 5.

Figure 8.11 Salmon densities on the Afon Fenni, August 1989 and October 1990.



Localised migration has also occurred in the Afon Fenni. The upper sites having probably been colonised by fish migrating from the tributary (X in Figure 8.2). This would account for the higher numbers of >0+ fish in the upper reaches of the stream and the lower numbers at the bottom three sites (Figure 8.9), too far down to have been colonised by fish from the tributary, within the year. This highlights the possible significance of small tributaries as spawning grounds for salmonids and a possible source for recolonisation. The low numbers of fish at Site 3 may be due to chronic pollution noted by Rutt *et al* (1990).

In 1989 the relatively large numbers of >0+ fish at the bottom three sites were possibly forced down stream in an attempt to escape the pollution. The following year most of these may have moved down into the Taf and, with few immediately upstream to replace them, the population in 1990 has been reduced.

8.4.2 Spawning

In Deepford Brook, during all fishings, the low numbers of fry in the downstream sites suggest unsuccessful spawning. This may be a result of unsuitable habitat or again due to chronic pollution inputs. Fry populations are better at sites further upstream. These include 1 and 2 on the upper Deepford and 9 and 10 on the Cotland stream and this suggests that these are less affected by chronic pollution. The fry population at Site 8 was depressed and as already mentioned, this was probably due to chronic pollution from an overflowing slurry lagoon.

On the Afon Fenni no spawning had occurred at Site 1. Again this may be due to chronic pollution, as at Site 3, or it may be a result of unsuitable habitat. Spawning has occurred at the rest of the sites but only one site (5) had a 'moderate' fry population as defined by the category system - the rest were poor (Figure 8.9, Table 8.4).

Site 4 on the Afon Fenni appears to have returned to pre-pollution levels (Figure 8.10). A possible explanation for the difference between the numbers of fry in the survey and NRA data for 1987 is that the NRA survey was undertaken during the summer rather than in September by which time the fry will have suffered density dependent mortality (Elliott 1990) which can produce significant changes in abundance of this class over short periods of time.

8.4.3 Salmon

Salmon only occurred at the bottom sites of both streams. As mentioned previously they were not expected further up as the widths are too narrow (Wightman 1989). From this work it is unclear how the salmon populations on both streams were affected by the spills but a point to note is the presence, in 1990, of 0+ salmon at Sites 5 and 6 on Deepford Brook when trout are absent. A possible explanation is that a further pollution input removed local trout populations but did not affect the spawning the of the anadromous salmon in the autumn of 1989.

8.4.4 General

Overall there is good evidence for salmonid recolonisation on the Afon Fenni by both localised migration and spawning. Fry densities appear low but this may be normal for the type of habitat found in this stream. Chronic pollution in Deepford Brook however, continues to affect fish populations in its lower reaches. It is important for both streams, that the influence of habitat on salmonid populations is determined so that the effect of chronic pollution can be fully understood. In this study the abundance classification system of Strange *et al* (1989) has been used to give an indication of what 'reasonable' populations are. However future use of the NRA HABSCORE system (Milner, Hemsworth and Jones 1985) in the two catchments should help to give a better estimate of target populations which can be matched against the observed populations to give a better assessment of the recovery of the fisheries. With this information and a further seasons fishing, conclusions may be drawn about policy towards restocking and compensation claims.

9. SLURRY TRANSPORT STUDIES

9.1 Introduction

A study of the drainage pathways taken by slurry applied to pasture was instigated as a response to the need for information to calibrate a farm management model ('FARMS') being developed by WRc (Cole, Montgomery and Slade 1990).

9.2 Methods

Monitoring equipment was installed on three fields of differing soil type and slope characteristics as follows:

Field 1 (Cegin soil type, 1 degree slope) - 4 sets of two 40-cm and two 80-cm access tubes for collecting soil solution samples arranged at intervals upslope (Sites 1-4), together with 4 corresponding overland flow samplers. Two field drains discharging into the stream were also monitored.

Field 2 (Denbigh soil type, 4 degree slope) - as for Field 1 but no field drains (Sites 6-9 numbered upslope).

Field 3 (Denbigh soil type, 9 degree slope) - 4 overland flow samplers arranged at intervals downslope (Sites 10-13).

Samples were collected at weekly intervals between 19 January and 19 April 1990 to ensure collection of data before slurry spreading up to the first cut of silage. Access tubes were evacuated with a hand-held pump such that soil water was forced in over a 2-3 hour period. Volumes of overland flow were recorded on each sampling occasion. Samples were analysed for pH, BOD, ammoniacal nitrogen, Total Oxidised Nitrogen (TON), nitrite, orthophosphate and Dissolved Organic Carbon (DOC). Hourly rainfall was recorded between 14 February and 19 April.

9.3 Results

Due to delays in installation, problems with flooding and lack of sufficient rainfall, data for overland flow was not obtained on all sampling occasions but the soil solution data was comprehensive. Results presented are restricted to BOD and ammoniacal nitrogen levels which are the most important determinands from the point of view of impact upon receiving water courses.

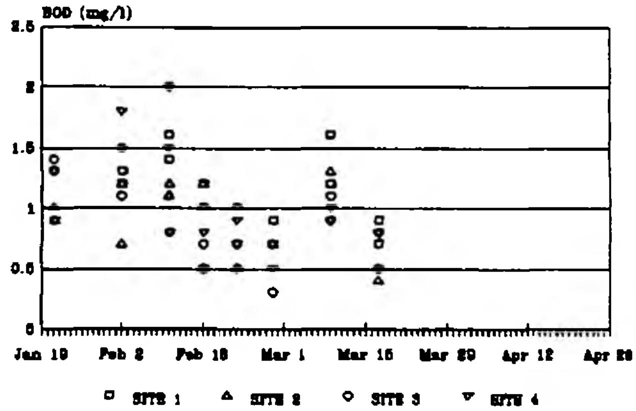
(i) Field 1 - Due to water-logging, slurry was not applied to this field during the sampling period and therefore BOD was not measured after 15 March to relieve pressure on the laboratory. BOD never exceeded 2.5 mg l^{-1} in the soil solution samplers and ammoniacal nitrogen rarely exceeded 0.1 mg l^{-1} (Figures 9.1 and 9.2). Values of both determinands in the land drains were similarly low. Very little data were obtained from the overland flow equipment due to water logging. Values obtained were in the ranges 3.8-9.4 mg l^{-1} for BOD and 0.44-1.24 mg l^{-1} for NH_3-N.

(ii) Field 2 - Slurry was applied to the top and bottom parts of this field on 25 February covering two sets of samplers only (6 & 9), as spreading was curtailed by the resumption of heavy rain (see Figure 9.3). The overland flow sample from Site 6 taken the day after spreading had a BOD in excess of 205 mg l^{-1}, and ammoniacal nitrogen was recorded as 30.6 mg l^{-1} (Figures 9.4 and 9.5). A week later after slurry had been spread on the rest of the field the maximum BOD recorded for overland flow was only 25.0 mg l^{-1} and the maximum NH_3-N value was 26.4 mg l^{-1}. Throughout the sampling period BOD rarely exceeded 2.0 mg l^{-1} in the sub-surface samples (max 3.0 mg l^{-1}) and NH_3-N generally remained below 0.1 mg l^{-1} (Figures 9.4 and 9.5).

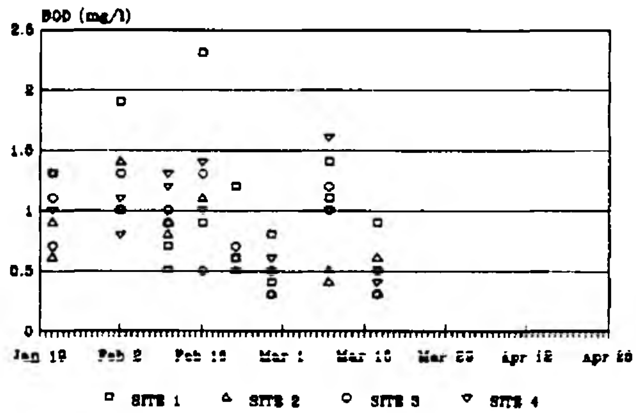
(iii) Field 3 - Slurry was spread on this field on 24 February. When sampled two days later after heavy rain (Figure 9.3), all but the bottom-most overland flow sampler contained water with a BOD in excess of 250 mg l^{-1} (Figure 9.6). The four sites had levels of ammoniacal nitrogen between 16.5 and 113 mg l^{-1} (Figure 9.6). A week later the BOD of the run-off

Figure 9.1 Slurry transport studies at Clarbeston - BOD in field 1 (Cegin soil type, 1 degree slope) 19 January - 26 April 1990

(a) 40 cm depth access tubes



(b) 80 cm depth access tubes



(c) field drain

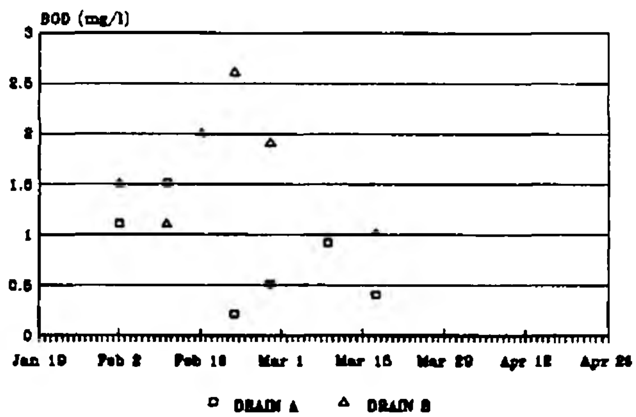
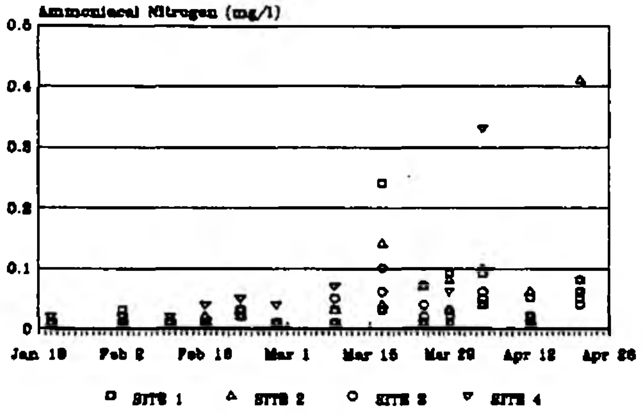
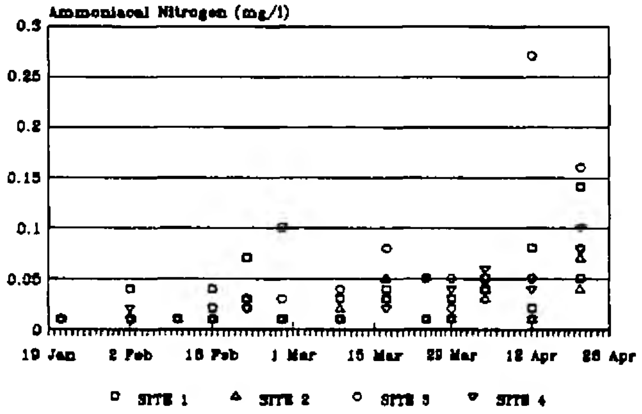


Figure 9.2 Slurry transport studies at Clarbeston - ammoniacal nitrogen in field 1 (Cegin soil type, 1 degree slope) 19 January - 26 April 1990

(a) 40cm depth access tubes



(b) 80cm depth access tubes



(c) field drains

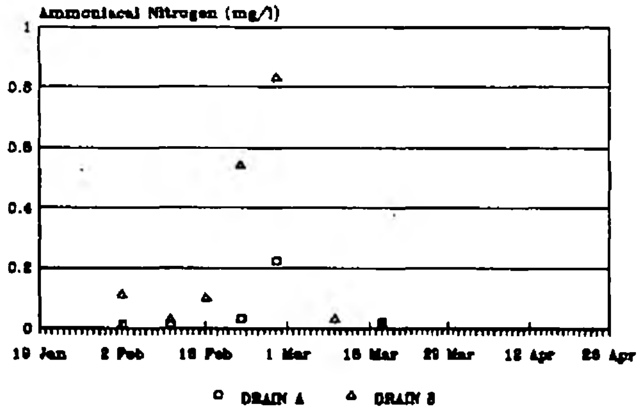


Figure 9.3 Daily rainfall at Clarbeston
14 February – 24 April 1990

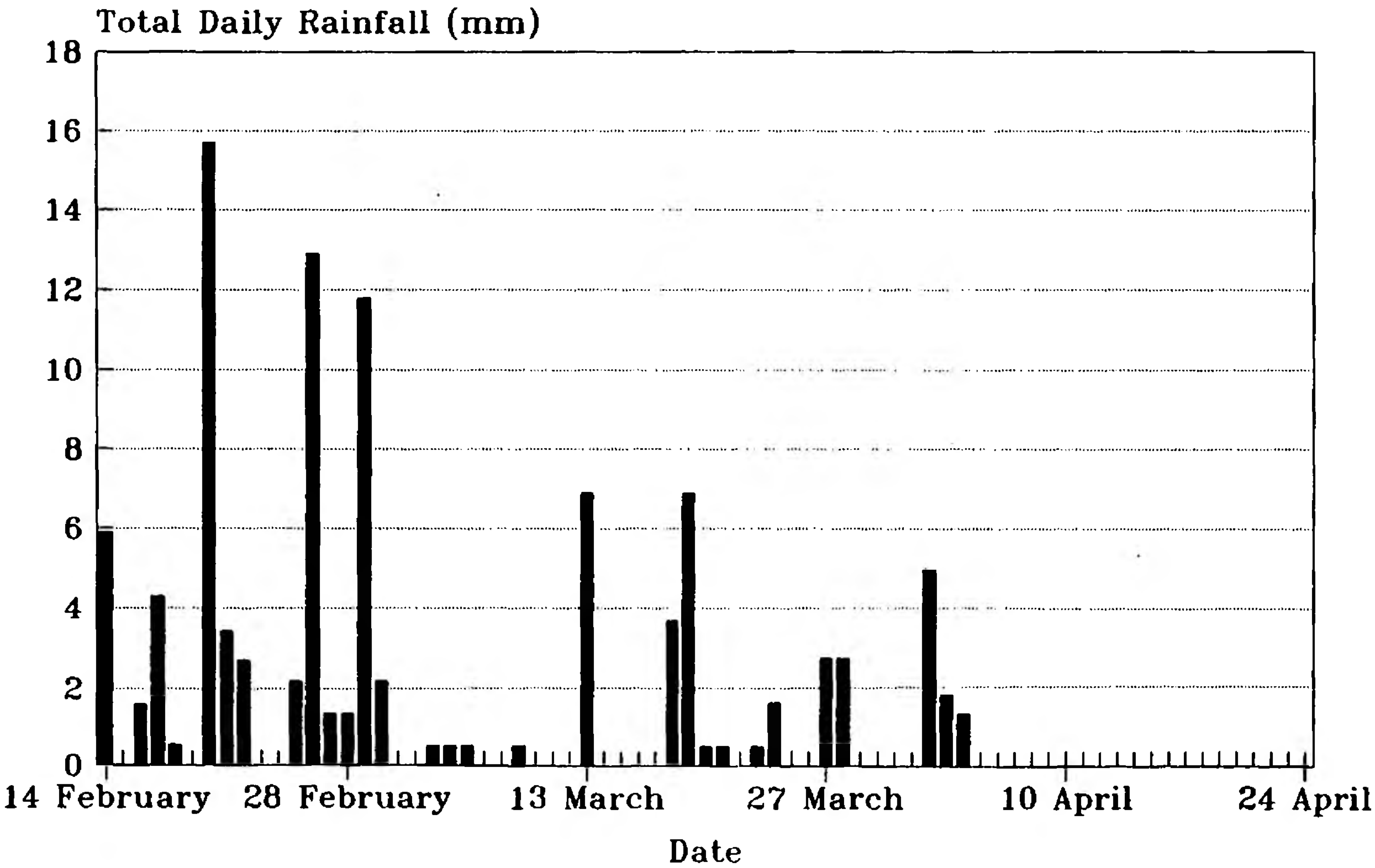
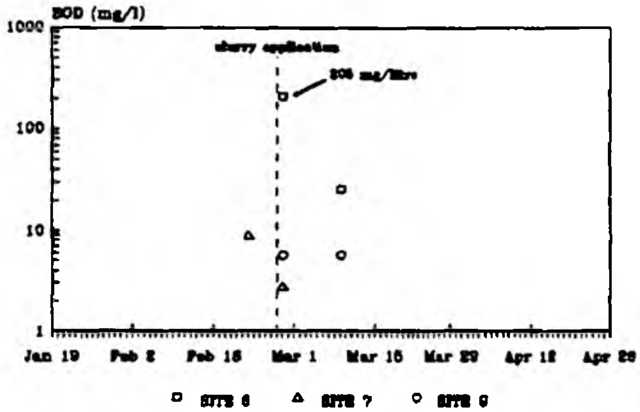
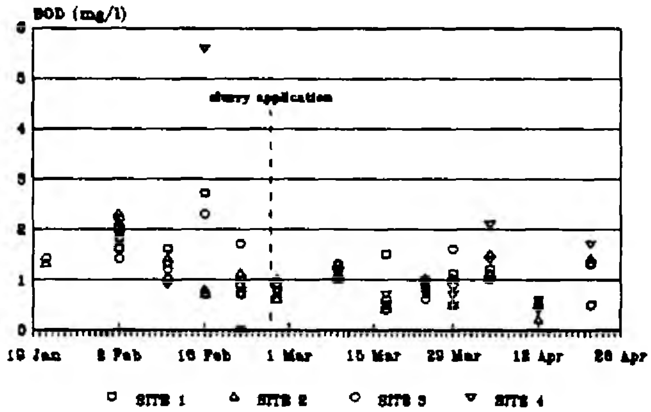


Figure 9.4 Slurry transport studies at Clarbeston – BOD in field 2 (Denbigh soil type, 4 degree slope) 19 January – 26 April 1990

(a) overland flow samplers



(b) 40cm depth access tubes



(c) 80cm depth access tubes

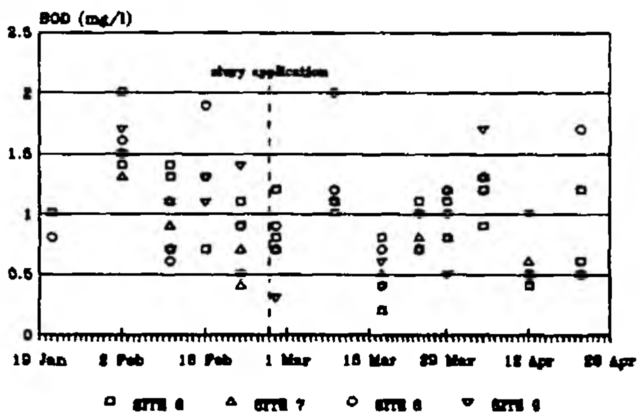
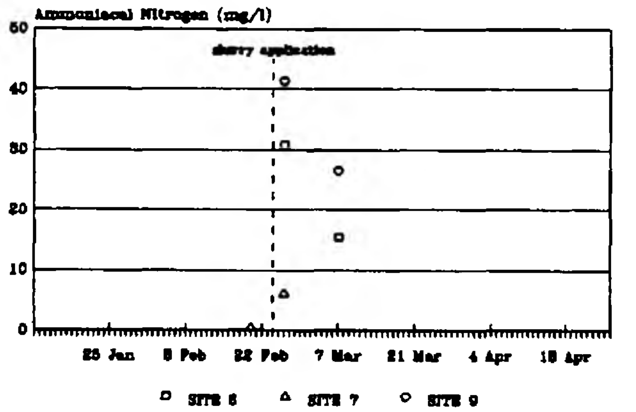
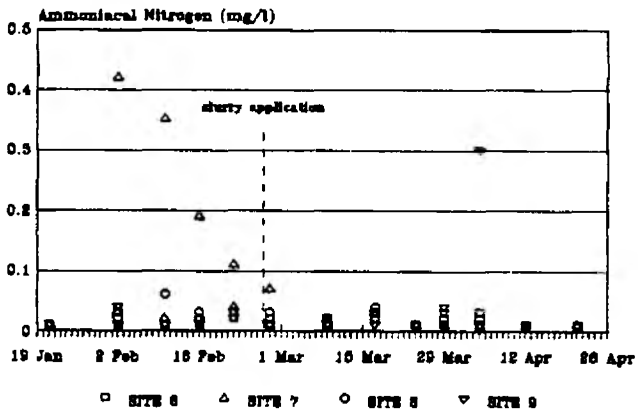


Figure 9.5 Slurry transport studies at Clarbeston – ammoniacal nitrogen in field 2 (Denbigh soil type, 4 degree slope) 19 January – 26 April 1990

(a) overland flow samplers



(b) 40cm depth access tubes



(c) 80cm depth access tubes

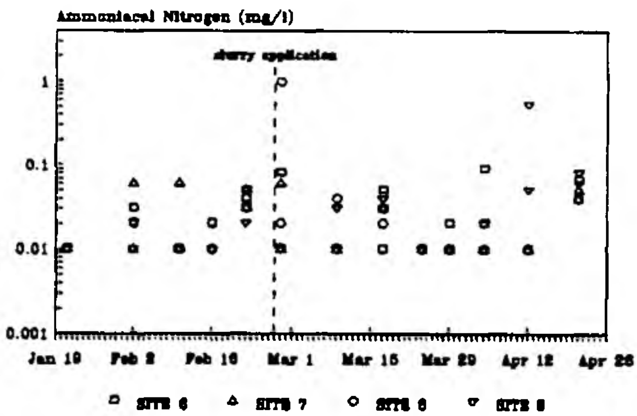
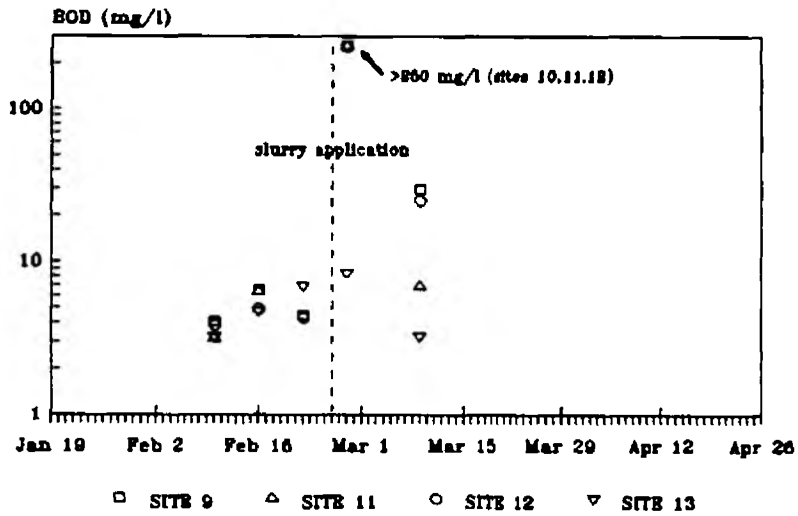
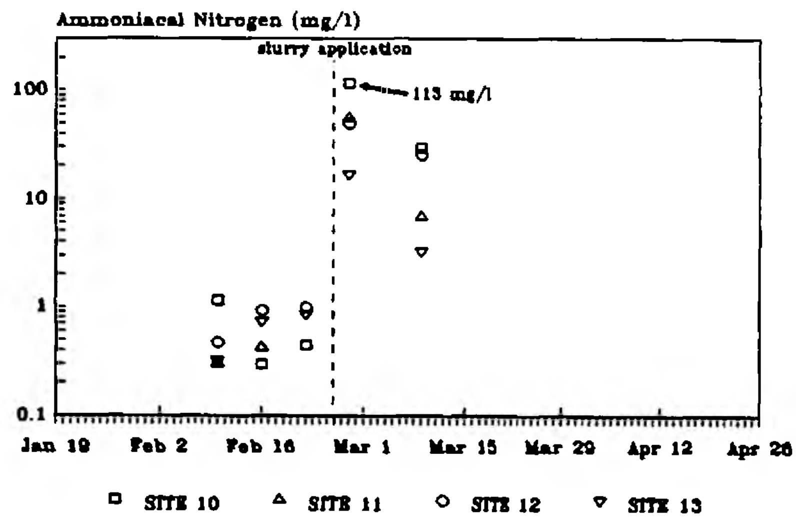


Figure 9.6 Slurry transport studies at Clarbeston – overland flow quality in field 3 (Denbigh soil type, 9 degree slope), 19 January – 26 April 1990.

(a) BOD



(b) ammoniacal nitrogen



had fallen to 3.2-29.0 mg l^{-1} with ammoniacal nitrogen in the range 8.2-49.6 mg l^{-1}. Prior to spreading BOD never exceeded 10.0 mg l^{-1} and ammoniacal nitrogen remained below 1.0 mg l^{-1}.

9.4 Discussion

The results would appear to indicate that neither BOD, nor ammoniacal nitrogen displayed significant increase in soil water at 40 and 80 cm depth on the well-drained Denbigh soil (Field 2) whereas overland flow exhibited high BOD and high ammoniacal nitrogen when slurry spreading was followed by a period of intense rainfall. Overland flow on the steeper Denbigh field (Field 3) also showed significant slurry contamination with BOD in excess of 250 mg l^{-1} and ammoniacal nitrogen up to 113 mg l^{-1}. These values compare with 11 401 mg l^{-1} BOD and 1032 mg l^{-1} ammoniacal N in the applied slurry.

However, drainage through the soil profile cannot be ruled out as a pathway for transfer of polluting material to the adjacent stream. This is because the hydraulic conductivities estimated for the Denbigh soil type are very high: 200, 840 and 450 cm/day for topsoil, immediate subsoil and lower subsoil respectively. Thus with a weekly sampling regime it might be possible to miss a pulse of polluting material descending rapidly through the profile following heavy rain. This low sampling frequency has restricted the usefulness of the data collected in calibrating the 'FARMS' model.

10. BIOLOGICAL RECOVERY OF STREAMS

In order to gain a better understanding of the nature and duration of the biological impact of farm pollution episodes, a PhD thesis was sponsored at the University of Wales which investigated biological responses to simulated pollution incidents. A detailed synopsis of this work is given in Annex A.

A range of responses of freshwater macroinvertebrates and fish were investigated during simulated episodes of reduced dissolved oxygen (DO), increased ammonia and increased sulphide concentrations, all relevant to farm wastes. This was achieved by dosing natural streams after first ascertaining their biological condition, monitoring the impact upon captive animals and invertebrate drift during events, and by describing patterns of recovery.

Catastrophic increases in drift occurred under conditions of reduced DO (<6 mg l^{-1}). In addition, mortalities in caged animals occurred, over a range of stress conditions. Invertebrate responses to increased ammonia and sulphide concentrations (drift and mortality) were less dramatic, but behavioural changes were observed. With captive *Gammarus pulex* (L), the addition of substrate (sand and stones) reduced mortality and a positive correlation was found between toxicity and ambient water velocity. Parasitised individuals of *G. pulex* were more susceptible to the simulated episodes than unparasitised ones.

The recovery of benthic invertebrates following pollution events was rapid (2-3 months). In one series of experiments, which assessed the recolonisation route, 45% came from downstream drift. Within substrate migration (from deeper sediments) upstream movements and aerial sources contributed 31.5%, 15.6% and 7.9% respectively.

Seasonal differences occurred in the response of benthic invertebrates to low DO. In November the drift response to low DO was *c* 2% of that in July (in terms of animal density) despite comparable benthic abundances. Consequently, the impact on the benthos was minimal.

The penetration of pollutants into stream substrates demonstrated extensive spatial patchiness. This indicated that large areas of stream bed could provide a refuge from pollution episodes for the occupying fauna.

Laboratory investigations confirmed that the invertebrate drift observed in the field was a response to low DO and increased ammonia. Furthermore, downward vertical migration within the substrate was also recorded for *G. pulex* (DO, ammonia) and *Ecdyonurus venosus* (Fabricius)(DO).

11. FUTURE WORK

11.1 Rapid biological assessment

(i) Indicator keys will be derived for three-minute kick samples once the final set of one-minute samples has been processed. These keys can then be compared with those for one and two minute samples.

(ii) The selected key, which combines both accuracy of classification and rapidity of use, will be used February 1991 in a large scale assessment of farm pollution in several catchments in West Wales. Polluting farms will be identified, remedial measures recommended and success monitored by a further survey in February 1992.

(iii) The feasibility of the indicator system being used by non-specialists (eg pollution control staff and bailiffs) will be assessed as part of the above exercise.

(iv) Fifty sites in dairy farming areas of the Southwest region of the NRA will be surveyed in February/March 1991 to test the Welsh indicator key and to develop an analogous rapid appraisal system if it proves ineffective in this region.

11.2 Detailed site investigations

(i) Monthly monitoring of biological quality and farming activity at Pontfaen will continue until June/July 1991 when a further electrofishing survey and cylinder sampling exercise will be undertaken.

(ii) Further sites for intensive study will be identified following an assessment of 150 sites in Southwest Wales using the rapid appraisal techniques developed under this contract (Section 6).

(iii) The impact and extent of effect of 20-30 farms will be assessed before and after remedial action using kick sampling to obtain BMWP scores, electrofishing and sewage fungus assessments.

(iv) At a few farms with discrete waste management problems more intensive studies will be undertaken including cylinder sampling and HABSCORE assessments in order to better describe the impact upon streams.

11.3 Salmonid recolonisation studies

(i) A further season of electrofishing will be carried at both sites in September/October 1991.

(ii) HABSCORE assessments will be carried out on both streams during summer 1991.

(iii) Data will be examined in more detail for the final report on the work possibly including examination of temporal trends in age structure at selected sites.

12. CONCLUSIONS TO DATE

12.1 Literature review

(i) The level of central government involvement in farm pollution control is much greater in the European countries considered in detail than is the case in the UK. Involvement takes the form of powerful catchment legislation, centralised waste management infrastructure, levies, grant aid and free waste management consultation.

(ii) Waste management plans for individual farms are used in different guises in a number of these countries, sponsored by government.

(iii) Catchment legislation on the continent involves maximum annual waste application rates to land, prohibition periods on landspreading over winter months and the use of disposal techniques with low associated pollution risk.

(iv) In the UK, no such catchment controls exist, which tends to lead to farmers landspreading inappropriate amounts of waste at times when soil moisture deficit is low, nutrient uptake by vegetation is low and rainfall is high.

12.2 National assessment of farm pollution

12.2.1 Pollution risk

(i) Hotspots of activity associated with the farming of different livestock types are readily discernible from the distribution maps provided. As far as information is available, the distribution of farming activity is reasonably well reflected in the distribution of recorded pollution problems and verbal description of farming problems given by pollution control staff nationwide.

(ii) The distribution maps produced in this study provide a good basis for the targeting of proactive effort at specific areas. They also create a good argument for the selective or graded allocation of Farm and Conservation Scheme grant aid. However, more time is required to provide a robust assessment of pollution risk, combining livestock information with physical factors.

(iii) On the farm level, there is currently little standardisation of risk assessment practices either within or between regions. Although the value of experienced judgement should not be underestimated, such standardisation (as far as it is possible) would help to ensure compatibility of survey results, more appropriate prioritisation of the proactive workload, and an even-handed approach to potential polluters.

(iv) Individual farm visits to assess pollution risk and ensure the application of appropriate remedial measures are vital to the prevention of farm pollution. Furthermore, they are crucial to effective enforcement of the new regulations on the storage of slurry, silage and fuel oil.

(v) At present, insufficient resources are available to pollution control authorities to undertake proactive farm visits on a scale large enough to bring about significant widespread improvements in water quality. However, there are notable exceptions to this, particularly in NRA South West Region where farm pollution is a very high priority and a region-wide campaign has been implemented.

12.2.2 Pollution incidents

(i) The data collation exercise in this study has highlighted serious difficulties in retrieving pollution incident data from archived information. A number of new computerised archives have been commissioned around the NRA regions over the past 6 months, and it remains to be seen how flexible these will be.

(ii) The current gradings of severity for pollution incidents used in the annual farm waste report and in the new national NRA incident category system are based on interference with a mixture of water uses. This is confusing and does not give a clear indication of the impact on any one use (eg fisheries, ecology, abstraction). This situation detracts from the power of pollution incident statistics to make statements about the significance of farm pollution problems.

(iii) The current classification of incidents used in the annual farm waste report leads to a large number of incidents being categorised as 'other' types. It is recognised that it will not be possible to identify the cause of pollution in a proportion of cases, but the number of miscellaneous incidents hampers the statistical value of the data.

12.2.3 Pollution control

(i) Pollution control legislation in the UK is generally geared to prosecution after the event (ie after pollution has occurred), in the hope of providing a deterrent to repeat offenders and other would-be polluters. The value of this deterrent is greatly diminished by the low level of fines administered upon conviction.

(ii) New regulations on the storage of slurry, silage and fuel oil will be an aid to pollution **prevention,** since they will allow pollution control authorities to prosecute farmers posing a certain level of pollution risk (as defined by the storage specifications in the regulations). However, there is doubt within the NRA that the storage specifications are stringent enough to keep pollution risk at an acceptable level.

(iii) The Farm and Conservation Grant Scheme, although a valuable contributor to farm pollution prevention, has a number of inadequacies which limit its effectiveness.

(iv) Fines are generally set too low by magistrates to be an effective deterrent to farmers who pollute. This has a detrimental effect on the usefulness of educational campaigns, which can be effective if the necessary stimulus created by the threat of firm punishment is present.

12.3 Rapid biological assessment

(i) TWINSPAN classification of the macroinvertebrate data produced three site groups which showed differences in variables related to farm pollution.

(ii) The associated indicator key incorporated taxa whose distribution and abundance are considered to be related to organic pollution.

(iii) Non-pollution related factors may have had some influence on site classification but balance of evidence suggests that this does not limit the usefulness of the key in detecting organic pollution from farms.

(iv) The selected indicator key based upon TWINSPAN classification of data describing macroinvertebrate and sewage fungus distribution should provide the basis for a rapid and accurate means of assessing farm pollution in West Wales during late Winter and early Spring (January-April).

(v) A system such as that described above would be a great asset in targeting pollution control resources.

12.4 Detailed site investigations

(i) Detailed investigation has identified a major impact of a chronic discharge of silage effluent upon the biota of Pontfaen Brook.

(ii) Continuous monitoring, weekly spot sampling and automatic sampling during rainfall events did not reveal any features of the chemistry of the water column likely to be directly affecting the stream fauna.

(iii) The observed impact on stream fauna may therefore have been a secondary effect caused by extensive growths of sewage fungus, rather than direct effects of water quality.

(iv) The extent of sewage fungus cover declined in relation to a decline in the loading of the input and of downstream BOD. The threshold for sewage fungus growth of 2-3 mg l^{-1} BOD supported the findings of other workers.

(v) The decline in sewage fungus corresponded to a steady improvement in the invertebrate fauna of the stream.

12.5 Salmonid recolonisation studies

(i) Evidence for the recovery of salmonid stocks on the Deepford Brook is equivocal and the lower reaches appear to be suffering from the effects of chronic pollution.

(ii) There is evidence of a significant recovery of trout populations in the upper reaches of the Afon Fenni which has involved both localised migration from tributaries and spawning success.

(iii) Salmon appear to be restricted to the lower reaches of both systems probably due to the effects of stream size.

(iv) Detailed habitat assessments of both systems are required in order to obtain target populations which can be compared with those populations revealed by electrofishing.

(v) A further seasons data and more detailed analysis are required before general recommendations on stocking policy and compensation claims can be made.

12.6 Slurry transport studies

(i) High levels of BOD and ammoniacal nitrogen have been observed in run-off during heavy rainfall following slurry application to land.

(ii) It is possible that pollutant material may pass rapidly down through the soil profile during heavy rainfall on well-drained soils, although this could not be confirmed in this study.

(iii) Further work would be necessary to provide the 'FARMS' model with adequate field-derived data to simulate run-off quality under different conditions.

13. RECOMMENDATIONS

13.1 Farm waste management and control

13.1.1 Pollution risk

(i) More work is required to provide validated distributions of farm pollution risk on a nationwide basis, and also to utilise the database collated in this study to maximum effect.

(ii) Catchments, or groups of catchments, with particularly high waste loadings from livestock (as identified in this report) should be considered as potential Water Protection Zones, where farming practices could be suitably restricted. Special attention should be paid to those catchments naturally yielding oligotrophic river waters.

(iii) Significant increases in resources are required in order to enable pollution control staff to undertake pollution prevention work, most importantly farm visits, on an effective scale. The impact of agriculture on the water environment is unlikely to reduce significantly until such funds are made available.

(iv) Standardised risk assessment procedures should be developed in order to ensure that farms are monitored at an appropriate level of vigilance that is comparable throughout England and Wales. Such procedures should involve:

- o Pollution incident archives - the development of such archives should be coordinated within the NRA to ensure that duplication of effort is minimised and that each NRA region ultimately possesses a flexible, interactive and user-friendly system that can be actively used in pollution prevention and control (see below).

- o Checklist of risk factors - a standardised list of criteria upon which to base the evaluation of pollution risk is required. This would ensure compatibility of results between regions and the production of meaningful national overviews of risk.

- o Objective methods of risk assessment - an objective index of point-source risk is to be developed (NRA reference A17(90)1), and risk assessment methods for diffuse sources, such as slurry acceptance mapping (NRA ref A17.007), are being developed further.

- o Catchment inventory databases - data on risk assessment gathered using the above procedures requires collating in the form of computerised databases that can be readily updated to show a synoptic geographical picture of risk. Such databases would logically make use of Geographical Information Systems (GISs).

13.1.2 Pollution incidents

(i) There is a need for a national review of pollution incident archives, working through the NRA Information Technology Group, in order to ensure that each is capable of the proactive tasks that will be required of it. A list of the requirements of an incident archive should be produced, and deficiencies in each regional system should be identified and, where possible, rectified.

(ii) The classification of farm pollution incidents, in terms of both incident severity and incident type, needs to be reviewed.

- o Pollution type - The very least that is required is an analysis of incidents that do not fit into existing categories (ie 'other' incidents). A separate category of farmyard run-off (due to rainfall rather than washing), separated into pig and cattle categories, would be a useful addition, as would the extraction of 'other pig-related incidents' and 'other cattle-related incidents' from the miscellaneous ('other') class. Where the nature of the incident cannot be identified, it should be recorded as such; a separate category of incidents of 'unidentified cause' should therefore be created.

- Pollution severity - Incidents should be recorded, and subsequently reported in annual status documents, in terms of impacts on various water uses. This should include the number of fish killed and the length of watercourse affected, since these impacts are easily perceived and are of greatest public interest.

(iii) Due to the above requirement, pollution incident archives must have the flexibility to store information (including magnitude of effect) on the impacts on individual water uses, and be able to summarise this information in a usable format for reporting.

13.1.3 Pollution control

(i) The concept of 'farm waste management plans', whereby appropriate and safe storage facilities and routes of waste disposal are formally agreed between the NRA and individual farmers, should be developed in conjunction with the objective risk assessment tools mentioned above.

(ii) Appropriate regulations for the treatment and, most importantly, disposal of farm wastes need to follow the new regulations on the control of pollution from silage, slurry and fuel oil stores. Such regulations should oblige farmers to draw up farm waste management plans for the approval of the NRA. Steps should be taken to promote the types of catchment-based legislation that are prevalent on the continent: these include blanket restrictions on stock density, maximum slurry production and slurry application rates, and obligatory slurry disposal contracts. At the very least, such restrictions should be imposed in Water Protection Zones where appropriate.

(iii) Opportunities should be taken to encourage a change to 'low pollution risk' waste management practices, particularly straw-based methods. The economics of transporting straw over long distances, from centres of production to centres of requirement, needs investigation. The use of big-bale silage storage systems should be encouraged, although consideration should be given to the implications for landscape (big-bales are visually intrusive) and plastic waste production.

(iv) Amendments to the Farm and Conservation Grant Scheme are required to include appropriate grant aid for:

- the maintenance and upgrading of existing storage and treatment installations;

- the separation of clean and dirty water.

(v) Grant aid also needs to be geographically graded in order to target those areas at highest risk from farm pollution.

(vi) The development of riparian buffer zones, which are grant-aidable in a number of countries including the US, should be strongly encouraged and their eligibility for grant aid should be sought through liaison with MAFF. It should be noted that although the setting aside of riparian land is suggested as an option by MAFF for funding under the 'Set-Aside' scheme, it is not actively encouraged and 'Set-Aside' only applies to intensive arable farming, not livestock.

(vii) Coordination of financial incentive schemes should be pursued since there are now a number of schemes which have relevance to farm pollution, the main ones being the Nitrate Sensitive Area, Environmentally Sensitive Area and Farm and Conservation Grant Schemes. Their geographical application and the allocation of monies to specific practices/developments needs to be reviewed. It would also be useful to include agricultural improvement grants in such a review, since these have the potential to conflict with grant schemes that reduce pollution risk.

(viii) In addition to financial incentive schemes that encourage practices of low pollution risk, the concept of financial disincentives (such as manure levies on the continent) that discourage high risk practices should be promoted.

(ix) Education of the farming community should take a high priority. Farm visits aimed at assessing risk can be used as a vehicle for person-to-person contact, which is the most effective form of education. Furthermore, the attitude of the farmer should be assessed and form an integral part of the risk assessment. Collaboration with agricultural colleges should continue to be sought with a view to including tuition on pollution prevention within the course curricula.

(x) Fines need to be set at a level which makes the cost of pollution prevention measures a cheaper option than the risk of prosecution. The recent increase in the maximum level of fines to £20 000 in the magistrates' court will be ineffective if the majority of magistrates persist with the mentality that sets fines well below the previous maximum of £2000. A fining system linked to the ability to pay would help to determine the most appropriate penalty in each case.

(xi) Maximum publicity should be sought for successful prosecutions, indicating the damage wrought and comparing this to the fine administered. In this way the farmer suffers from bad publicity, which is often a greater punishment than the fine, and the public receives constant reminders of the unsuitability of the scale of financial penalties. It should be noted that although the recent move to award costs to the NRA is a positive step, it does not generally act as a deterrent to the polluter since costs are often covered by farm insurance policies. The whole of the farming community may then suffer through increased premiums.

13.2 Rapid biological assessment

(i) Bankside indicator systems developed for new areas should be based upon 1 minute kick samples since these provide adequate discrimination between sites and are rapidly processed on the bankside.

13.3 Detailed site investigations

(i) Future impact assessment working in this study should include kicksampling, electrofishing and sewage fungus assessment.

(ii) More intensive studies should include quantitative sampling of macroinvertebrate populations and HABSCORE assessments.

(iii) The diversion of the council road drain at Trewern from its present path would significantly reduce the risk of future serious pollution from this farm.

13.4 Salmonid recolonisation studies

(i) Future studies of this kind might include intensive capture and marking of populations in the tributaries of a depleted reach to better assess the contribution these make to the recovery of stocks in the main watercourse.

13.5 Slurry transport studies

(i) These studies should be continued in a separate project, and should involve the intensive monitoring of field plots.

14. ACKNOWLEDGEMENTS

Thanks are due to all NRA staff who participated in the regional consultation exercise, and also those who provided the necessary data for the GIS analysis. These people are listed in Appendix E. Assistance from NRA staff with the fieldwork programme in West Wales was essential to the success of the work.

15. REFERENCES

15.1 Literature review

ADAS (1986) Profitable uses of farm manures. Advice Booklet 2081. MAFF.

Allcock, R. (1989) Discussion session. Proceedings of IWEM Annual Symposium 1989 - Agriculture and the Environment, Lavenham Press, Suffolk, 36-37.

Anderson, G.D., De Bossu, A.E., and Kuch, P.J. (1990) Control of agricultural pollution by regulation. In: *Agriculture and water quality - international perspectives* edited by J B Braden and S B Lovejoy. Lynne Rienner, Boulder and London.

Ayers, R.S. and Westcot, D.W. (1985) Water quality for agriculture. Food and Agriculture Organization, Italy, Irrigation and Drainage Paper 29 Rev 1, 174pp.

Bascombe, A.D. Norton, R.L., Seager, J. and Davis, J.M. (1990) Farm waste management - a review of existing problems and potential solutions. WRc Report Nº 2475-M/1.

Basset, P., Janssen, H.M.A. and Klaver, J.C.M (1990) Knelpunten in het grondwaterbeschermingsbeleid: een verkenning. *H2O,* **23**(17), 446-450.

Bastiman, B. (1976) Factors affecting silage effluent production. *Experimental Husbandry* **31**: 40.

Beck, L. (1989a) A review of farm waste pollution. *J. IWEM* **3**, 467-477.

Beck, L. (1989b) Discussion session. Proceedings of IWEM Annual Symposium 1989 - Agriculture and the Environment, Lavenham Press, Suffolk, 39-40.

Besson, J.M., Lehmann, V. and Roulet, M. (1986) Nitrogen losses due to the spreading of cattle and pig slurries after storage, aeration or anaerobic digestion. In: *Efficient Land Use of Sludge and Manure,* edited by A D Kofoed, J H Williams and P L'Hermite. Elsevier Applied Science, London, 37-46.

Bjerke, K.D. (1989) Pesticides, common sense, and groundwater. *Journal of Soil and Water Conservation* **44**(4), 262.

Boxem, T.J. and Remmelink, G.J. (1987) The effect of regular application of cattle slurry on grassland during the growing season on grass yield and daily milk production. In: *Animal manure on grassland and fodder crops* edited by H G v d Meer *et al*. Martinus Nijhoff, Dordrecht.

Braden, J.B., Herricks, E.E. and Larson, R.S. (1989) A risk management model for fish habitat subject to agricultural non-point pollution. University of Illinois, 31 pp.

Brewer, A.J. (1990) Dairy Cow Waste Management, ADAS Report to WRc, 171pp.

Brown, M.P., Longabucco, P., Rafferty, M.R., Robillard, P.D., Walter, M.F. and Haith, D.A. (1989) Effects of animal waste control practices on non-point source phosphorus loading in the West Branch of the Delaware River watershed. *Journal of Soil and Water Conservation*, Jan/Feb, 67-70.

Brown, R.T. and Gibbs, D.F. (1986) A farm scale system for the liquid handling and treatment of piggery wastes. *Transcoed Experimental Husbandry Farm*, 5pp.

Champ, T. (1990) Lough Sheelin - the fisheries perspective. Central Fisheries Board, Ireland (Paper in Draft).

Champ, W.S.T. (1977) Trophic status of fishery lakes. In: *Lake pollution prevention by eutrophication control*. Proceedings of a seminar held in Killarney, Ireland, May 10-11, 1977. National Science Council, Dublin.

Cole, J.A., Hawker, P.J., Lawson, J.D. and Montgomery, H.A.C. (1988) Pollution risks and countermeasures for surface water intakes. *J. IWEM* **2**, 603-611.

Commission of the European Communities (1988) Proposal for a Council Directive concerning the protection of fresh, coastal and marine waters against pollution caused by nitrates from diffuse sources. COM(88)708 Final. *Official Journal of the European Communities* Nº **C54**, 3 March 1989.

Commodity Board for Feeding Stuffs (1989) The Dutch animal feed sector: active with manure surpluses and acid rain. The Hague, the Netherlands.

Danish Ministry of the Environment (1989) Statutory order No 568 of September 22, 1989, on farmyard manure and silage, etc.

Demuynck M (1984) Utilisation in agriculture of anaerobically digested effluent. Commission of the European Communities, 62pp.

Department of the Environment (1991) Control of pollution (silage, slurry and agricultural fuel oil) regulations. HMSO.

Department of the Environment/Department of Health (1990) Cryptosporidium in water supplies. Report of the Group of Experts. HMSO.

Dillaha, T.A., Sherrard, J.H. and Lee, D. (1989) Long-term effectiveness of Vegetative Filter Strips. *Water Environment and Technology* 1(3), 418-421.

Dodd, V.A. and Champ, W.S.T. (1983) Environmental problems associated with intensive animal production units, with reference to the catchment area of Lough Sheelin. In: *Promise and performance: Irish environmental policies analysed,* edited by J Blackwell and F J Convery. Resource and Environmental Policy Centre, University College of Dublin.

Dutch Ministry of Agriculture, Nature Management and Fisheries (DMA) (1990) Policy on agriculture in the Netherlands in the 1990s. (abridged version). Agricultural Structure Memorandum.

Dutch Ministry of the Environment (1990) Progress report on manure legislation and acidification policy. In draft. Gravenhague, the Netherlands.

Egboka, B.C.E., Nwankwor, G.I., Orajaka, I.P. and Ejiofor, A.O. (1989) Principles and Problems of Environmental Pollution of Groundwater Resources with Case Examples from Developing Countries. *Environmental Health Perspectives* **83**, 39-68.

Fane, P. (1989) An overview. UK Irrigation Association and National Farmers Union Conference. Organic Irrigation for Slurry and Dirty Water Disposal, Silsoe, 15 November, 7pp.

Fleming, G.A. (1989) Application of pig slurry to grassland - the soil ingestion factor for animals. In: *Safe and Efficient Slurry Utilisation,* edited by H Vetter, G Steffens and P L'Hermite. Commission of the European Communities, 65-70.

Freeman, L. (1986) Unwanted boom: pollution from farm waste. *Water Bulletin,* 25th July, 8-9.

Furrer, O.J. and Stauffer, W. (1986) Influence of sewage sludge and slurry application on nutrient leaching losses. In: *Efficient Land Use of Sludge and Manure,* edited by A D Kofoed, J H Williams and P L'Hermite. Elsevier Applied Science, London, 108-115.

George, J.R. and Anderson, P.W. (1963) Water quality studies of New Jersey streams. *Public Health Engineering Abstracts* **43**, 359.

Goldstein, A.L. (1986) Upland detention/retention demonstration project - Final Report. Impacts of agricultural land use on water quality and utilisation of wetlands for detention/retention in the Kissimmee river basin. South Florida Water Management District Technical Publication 86-2.

Gonzalez, J.L., Medina, M. and Benitez, I.C. (1989) Slurry composting options. *Biocycle* **30**(7), 53-55.

Gray, K.R., Biddlestone, A.J., Job, G. and Galanos, E. (1990) The use of reed beds for the treatment of agricultural effluents. In: *Constructed wetlands in water pollution control,* edited by P F Cooper and B C Findlater. Pergamon Press, 333-346.

Guiver, K. (1989) Discussion session. Proceedings of IWEM Annual Symposium 1989 - Agriculture and the Environment, Lavenham Press, Suffolk, 6-7.

Hall, J.E. (1986) Soil injection research in the UK. In: *Efficient Land Use of Sludge and Manure,* edited by A D Kofoed, J H Williams and P L'Hermite. Elsevier Applied Science, London, 78-89.

Hammer, D.A. (1989) Constructed wetlands for treatment of agricultural waste and and urban stormwater. In: *Wetlands ecology and conservation: emphasis in Pennsylvania* edited by S K Majumdar *et al.* The Pennsylvania Academy of Science.

Harrod, T.R. (1989) Discussion paper on a national review of disposal of farm waste. Soil Survey and Land Research Centre, Silsoe, 14pp.

Hart, B.T. (1985) Some water quality issues for Australia. *Search,* No. 11/12, 339-342.

Hillman, P.F. and Whyman, G. (1984) Modelling water quality and runoff on an agricultural catchment: The river Wallington, Hampshire, England. Science and Technology, 16, No. 5/7, 529-531.

Hobson, P.N. (1984) Anaerobic digestion of agricultural wastes. *J. Inst. Wat. Pollut. Control* 4, 507.

Hojovec, J. (1989) Agricultursl exploitation of liquid manure (legislation in Czechoslovakia). In: *Hygienic aspects of the treatment and use of organic sludge and liquid agricultural wastes,* edited by D Strauch, H Over and L'Hermite P. Commission of the European Communities, 17-22.

Howells, D.H. (1971) Land use function in water quality management. *Water Resources Bulletin* 7, 162-170.

Humenik, F.J., Smolen, M.D. and Dressing, S.A. (1987) Pollution From Nonpoint Sources. *Environmental Science and Technology* **21**(8), 737-742.

Johnson, K.S. and Harris, D.A. (1989) Prevention of water pollution on the manufacture and use of agrochemicals. Proceedings of IWEM annual symposium 1989 - agriculture and the environment, Lavenham Press, Suffolk, 4-5.

Jolankai, G. (1986) SENSMOD: a simple experimental non-point source model system. International Conference on Water Quality Modelling in the Inland Natural Environment, Bournemouth, England, 10-13 June 1986, Cranfield, BHRA, 77-91.

Joseph, J.B. and Clark, L. (1982) Pig slurry applied as a fertiliser; the effects on groundwater quality in the Yorkshire chalk. North of England Soils Discussion Group, Proceeding No 18.

Kemppainen, E. (1986) Effect of cattle slurry injection on the quantity and quality of barley and grass yield. In: *Efficient Land Use of Sludge and Manure*, edited by A D Kofoed, J H Williams and P L'Hermite. Elsevier Applied Science, London, 64-72.

Klinger, I. and Marchiam, (1986) Use of methanogenic fermentation to upgrade farm animal and slaughterhouse wastes. In: *Odour Prevention and Control of Organic Sludge and Livestock Farming*, edited by V C Nielsen, J H Voorburg and P L'Hermite. Elsevier Applied Science, London, 366-371.

Knight, R.L., McKim, T.W., Kohl, H.R. (1987) Performance of a natural wetland treatment system for wastewater management. *Journal of the Water Pollution Control Federation* **59**, 746-754.

Kovacs, G. (1977) Human interaction with ground water. *Ambio* **6**(1), 22-26.

Kroodsma, I.W. (1986) Treatment of livestock manure; air drying and composting poultry manure. In: *Odour Prevention and Control of Organic Sludge and Livestock Farming*, edited by V C Nielsen, J H Voorburg and P L'Hermite. Elsevier Applied Science, London, 166-174.

Lakshman, G. (1975) Monitoring agricultural pollution using natural fluorescence. *Water Resources Research* **11**(5), 705-708.

Lee, E.W. and Adan, B.L. (1983) Water quality management of Laguna de Bay. *Journal of Environmental Engineering* **109**(4), 886-899.

Lenat, D.R. (1984) Agriculture and stream water quality: a biological evaluation of erosion control practice. *Environmental Management* **8**(4), 333-343.

Littlejohn, J.W. and Melvin, M.A.L. (1987) Phenols From Silage - Implications For the Water Supply. *Waste and Water Treatment* **30**(7), 31-32.

Littlejohn, J.W. and Melvin, M.A.L. (1989) A theoretical evaluation of the pollution potential of sheep dip prearations. *Environmental Technology Letters* **10**, 1051-1056.

Locke, B., Choudhury, R. and Lecamwasam, D.C.D. (1985) Proc Conf Agricultural, Industrial and Municipal Waste Management, Warwick, 93-112.

Loll, U. (1987) Biogasanlagen in landwirtschaftlichen Betrieben. MAFF (1990) News release No 287/90. 16 August 1990.

Mann, H.T. (1975) Aerobic treatment of farm wastes. *J. Wat. Pollut. Ctrl. Fed.* **5**, 2-12.

Mannebeck, H. (1986) Covering manure storing tanks to control odour. In: *Odour Prevention and Control of Organic Sludge and Livestock Farming*, edited by V C Nielsen, J H Voorburg and P L'Hermite. Elsevier Applied Science, London, 188-193.

McGrath, D., Poole, D.B.R., Fleming, G.A. and Sinnot, J. (1983) Soil ingestion by grazing sheep. *Ir. J. Agric. Res.* **21**, 135-145.

McWilliams, L. (1984) A bumper crop yields growing problems. *Environment* **26**(4), 25-34.

Middlebrooks, E.J. (1972) Water quality and agricultural practices. *Public Works, New York* **103**(9), 144.

Ministry of Agriculture, Fisheries and Food (1984b) Silage - avoiding pollution. Booklet 2429, 23pp.

Ministry of Agriculture, Fisheries and Food (1985a) Equipment for handling farmyard manure and slurry. Booklet 2126, 50pp.

Ministry of Agriculture, Fisheries and Food (1985b) Advice on avoiding pollution from manures and other slurry wastes. Booklet 2200, 22pp.

Ministry of Agriculture, Fisheries and Food (1986a) Profitable use of farm manures. Booklet 2081, 22pp.

Ministry of Agriculture, Fisheries and Food (1986b) Water pollution from farm waste 1986, England and Wales. Water Authorities Association.

Ministry of Agriculture, Fisheries and Food (1987) Storage of farm manures and slurries: earth banked compounds for slurry storage. Advisory leaflet P3044, 2pp.

Ministry of Agriculture, Fisheries and Food (1989a) Storage of farm manures and slurries: choosing a storage system. Advisory leaflet P3042, 3pp.

Ministry of Agriculture, Fisheries and Food (1989b) Storage of farm manures and slurries: stores for traditional farmyard manure. Advisory leaflet P3046, 4pp.

Ministry of Agriculture, Fisheries and Food (1989c) Storage of farm manures and slurries: effluent tanks. Advisory leaflet P3047, 2pp.

Ministry of Agriculture, Fisheries and Food (1989d) Storage of farm manures and slurries: weeping-wall slurry stores. Advisory leaflet P3045, 2pp.

Ministry of Agriculture, Fisheries and Food (1989e) Storage of farm manures and slurries: above-ground circular slurry stores. Advisory leaflet P3043, 4pp.

Ministry of Agriculture, Fisheries and Food (1989f) Farm pollution: dirty water - sources and volumes. Advisory leaflet P3122, 2pp.

Ministry of Agriculture, Fisheries and Food (1989g) Farm pollution: dirty water - systems for disposal. Advisory leaflet P3123, 4pp.

Ministry of Agriculture, Fisheries and Food (1989h) Farm pollution: dirty water - low-rate irrigation systems. Advisory leaflet P3124, 2pp.

Ministry of Agriculture, Fisheries and Food (1990) Pesticides: Code of practice for the safe use of pesticides on farms and holdings. HMSO.

Ministry of Agriculture, Fisheries and Food (1991) Code of Good Agricultural Practice for the protection of water: a consultation document.

Nature Conservancy Council (1991) Nature conservation and pollution from farm wastes. NCC, Peterborough

Neeteson, J.J. (1989) Slurry as a fertiliser. In: *Hygienic Aspects of the Treatment and Use of Organic Sludge and Liquid Agricultural Wastes*, edited by D Strauch D, H Over and P L'Hermite. Commission of the European Communities, 191-192.

Noren, O. (1986) Design and use of biofilters for livestock buildings. In: *Odour Prevention and Control of Organic Sludge and Livestock Farming*, edited by V C Nielsen, J H Voorburg and P L'Hermite. Elsevier Applied Science, London, 234-237.

NRA/MAFF (1989) Water pollution from farm waste in England and Wales. NRA, London.

NRA/MAFF (1998) Water pollution from farm wastes in England and Wales, 1989. NRA South West Region, Exeter.

Osteen, C., Seitz, W.D. and Stall, J.B. (1981) Managing land to meet water quality goals. *Journal of Soil and Water Conservation* **36**(3), 138-141.

Paris Commission (1989) Convention for the prevention of marine pollution from land-based sources. Fourth meeting of the Working Group on Nutrients. Oslo, 26-29 September 1989. Paris Commission, London.

Payne, M.R. (1989) Farm waste and nitrate pollution. Proceedings of IWEM Annual Symposium 1989 - Agriculture and the Environment, Lavenham Press, Suffolk, 27-33.

Peltola, I. (1986) Use of peat as litter for milking cows. In: *Odour Prevention and Control of Organic Sludge and Livestock Farming,* edited by V C Nielsen, J H Voorburg and P L'Hermite. Elsevier Applied Science, London, 181-187.

Petersen, R.C. (in press) A building block model for stream restoration. In: *The conservation and management of rivers* edited by P Boon, G Petts and P Calow. John Wiley and Sons.

Phillips, J.D. (1989) Nonpoint source pollution control effectiveness of riparian forests along a coastal plain river. *Journal of Hydrology* **110**(3/4), 221-237.

Placido, R. and Soldatini, G.F. (1988) Evaluation of water quality of the Cornia river. *Inquinamento* **30**(4), 56-59.

Porter, K.S. (1975) Nitrogen and phosphorus: Food production, waste and the environment. Ann Arbor Science Publishers Inc, 378 pp.

Prins, W.H. and Snijders, P.J.M. (1987) Negative effects of animal manure on grassland due to surface spreading and injection. In: *Animal manure on grassland and fodder crops* edited by H G v d Meer *et al*. Martinus Nijhoff, Dordrecht.

Riley, C.T. (1988) A review of poultry waste disposal possibilities. *J. Inst Wat. Pollut. Control* **2**, 113.

Ritter, W.F. (1988) Reducing Impacts of Nonpoint Source Pollution from Agriculture. A Review. *Journal of Environmental Science and Health,* **A23**(7), 645-667.

S.C.S. Biotechnology (1989) Farm gas - anaerobic digester systems. Catalogue, 10pp.

Sadler, B.S. and Cox, W.E. (1987) Water resources management: the socio-political context. *Water Resources Journal* **6**, 14-22.

Schofield, K. and Bascombe, A.D. (1990) Sources of farm pollution and their impact on river quality - progress on the Eastern Cleddau catchment study. WRc Report PRS 2347-M/1.

Schua, L. (1970) Discharges from fermentation silos: A serious threat to the water quality in water resources management. *Gas- u. WASSFACH* **111**, 388-392.

Sherwood, M. (1986) Impact of agriculture on surface water in Ireland. Part II; prospects for the future. *Environmental Geology and Water Science* **1**, 11-14.

Shoemaker, L.L., Magette W.L, and Shirmohammadi, A. (1990) modelling management practice effects on pesticide movement to ground water. *Ground Water Monitoring Review* **10**(1), 109-115.

Smith, C.M. (1989) Riparian pasture retirement effects on sediment, phosphorus and nitrogen in channellised surface run-off from pastures. *New Zealand Journal of Marine and Freshwater Research*, **23**, 139-146.

Strauch, D. (1989) Newer strategies of dealing with environmental problems caused by animal slurries in the Federal Republic of Germany. In: *Hygienic aspects of the treatment and use of organic sludge and liquid agricultural wastes* edited by D Strauch, H Over and P L L'Hermite. Commission of the European Communities, 51-57.

Suss, A. (1989a) Investigations on the influences of nutrient composition of slurry. In: *Safe and Efficient Slurry Utilisation*, edited by H Vetter, G Steffens and P L'Hermite. Commission of the European Communities, 103-107.

15.3 Rapid biological assessment

Hill, M.O. (1979) TWINSPAN - a FORTRAN programme for arranging multivariate data in an ordered two-way table by classification of the individuals and attributes. Ecology and systematics, Ithaca, New York.

Jaag, O. and Ambuhl, H. (1964) The effect of the current on the composition of biocoenoses in flowing water streams. International Conference of Water Pollution Research, London. Pergamon Press, Oxford pp 31-49, 8, 163-165.

Metcalfe, J.L. (1989) Biological water quality assessment of running waters based on macroinvertebrate communities: history and present status in Europe. *Environmental Pollution* **60**, 101-139.

Reynolds, N. (1989a) The effects of agricultural pollution on the biological quality of headwater streams in West Wales - rapid assessment of agricultural pollution by the use of an indicator key. NRA Welsh Region Internal report Nº PL/EAW/89/3.

Reynolds, N. (1989b) Application of an indicator key to detect agricultural pollution in West Wales streams in August/September 1990. NRA Welsh Region Internal report No. PL/EAW/89/4

Richardson, L. (1990) The impact of chronic agricultural pollution upon biological quality and the salmonid fishery status of the Taf catchment in Southwest Wales. NRA Welsh Region Internal report Nº PL/EAW/90/15.

Strange, C.D., Aprahamian, M.W. and Winstone, A.J. (1989) The assessment of a semi-quantitative electric fishing technique for juvenile Atlantic Salmon (*Salmo salar* L.) and trout (*S. trutta* L.) in small streams and its application to the Regional Juvenile Salmonid Monitoring Programme. Regional Rivers of the Welsh Water Authority. Internal Report Nº HQ FC 89/1.

Wade, K.R., Ormerod, S.J. and Weatherley, N.S. (1989) Classification and ordination of macroinvertebrate assemblages to predict stream acidity in upland Wales. *Hydrobiologia* **171**, 59-78.

Wightman, R.P. (1989) The effects of agricultural pollution on headwater streams in west Wales. Environmental Appraisal Unit South West, NRA (Welsh Region). Internal Report Nº EAW/89/1.

Wright, J.F., Moss, D., Armitage, P.D. and Furse, M.T. (1984) A preliminary classification of running water sites in Great Britain based on macroinvertebrate species and the prediction of community type using environmental data. *Freshwater Biology* **14**, 221-256.

15.4 Detailed site investigations

Alabaster, J.S. and Lloyd, R. (1982) Water Quality Criteria for Freshwater Fish. Butterworth Scientific.

Curtis, E.J.C. (1969) Sewage Fungus: Its Nature and Effects. *Water Research* **3**, 289-311.

Milner, N.J., Hemsworth, R.J., and Jones, B.E. (1985) habitat evaluation as a fisheries management tool. *Journal of Fisheries Biology* **27** (Supplement A), 85-108.

Quinn, J.M. and McFarlane, P.N. (1988) Control of sewage fungus to enhance recreational use of the Manatau River, New Zealand. Verh Internat Verein. *Limnol*. **23**, 1572-1577.

Schofield, K. and Bascombe, A.D. (1990) Sources of farm pollution and their impact on River Quality - Progress report on the E Cleddau Catchment Study. WRc Report PRS 2347-M.

Turner, C. (1989) PhD Progress Report: Episodic Pollution and Recovery in Streams. University of Wales College of Cardiff.

WPRL (1969) Notes on Water Pollution No 47. Water Pollution Research Laboratory.

Water Research Centre (1988) Proposed Environmental Quality Standards for List Two Substances in Water: Ammonia ESSL TR 260.

15.5 Salmonid recovery studies

Bagenal, T. (1978) Methods for assessment of fish production in fresh waters. Blackwell Scientific Publications, Oxford.

Elliott, J.M. (1990) Mechanisms responsible for population regulation in young migratory trout (*Salmo trutta*). III. The role of territorial behaviour. *Journal of Animal Ecology* **59**, 803-818.

NRA (1989) Regional Juvenile Salmonid Monitoring Programme Annual Report 1988. NRA Welsh Region Internal Report Nº HQ FC 89/2.

Rutt, G.P., Pickering, T.P., and Mainstone, C.P. (1990) Sources of farm pollution and impact on river quality-interim report. WRc report Nº NR 2603.

Schofield, K. and Bascombe, A.D. (1990) Sources of farm pollution and their impact on river quality - progress on the Eastern Cleddau catchment study. WRc Report Nº PRS 2347-M.

Strange, C.D., Aprahamian, M.W. and Winstone, A.J. (1989) The assessment of a semi-quantitative electric fish sampling technique for juvenile Atlantic salmon (*Salmo salar* L.) and trout (*Salmo trutta* L.) in small streams and its application to the Regional Juvenile Salmonid Monitoring Programme. Welsh Water (Regional Rivers Division) report HQ FC 89/1 (June 1989).

Wightman, R.P. (1989) The results of fisheries and biological surveys to assess the impact of agricultural pollution in five catchments in west Wales. NRA Welsh Region Internal Report.

15.6 Slurry transport studies

Cole, J.A., Montgomery, H.A.C. and Slade, S. (1990) Progress report on pollutant surveys and developments of a farm management model. WRc Report Nº PRS 2343-M.

APPENDIX A

FARM POLLUTION QUESTIONNAIRE USED IN THE NATIONAL ASSESSMENT EXERCISE

THE ASSESSMENT AND CONTROL OF FARM POLLUTION

A QUESTIONNAIRE FOR POLLUTION CONTROL OFFICERS

1. What geographical area are you responsible for?

REGIONAL FARMING PRACTICES

2. How important is livestock farming in your area?

3. Please describe the geographical distribution of livestock farming in your area, using quantitative data where possible and indicating livestock type (eg pigs, beef cattle, dairy cattle, sheep, poultry) and management practice (eg intensive livestock units, extensive).

4. What sheepdip formulations are used in your area? (Use quantitative data on usage if available, otherwise indicate relative usage of each formulation).

5. How frequently are contractors used by farmers to undertake sheepdipping operations?

REGIONAL POLLUTION PROBLEMS

6. Please describe the geographical distribution of pollution problems from livestock farming in your area, indicating:

    a) the farming practices (eg intensive beef cattle farming, intensive pig farming) responsible; and

    b) the critical sources of pollution (eg slurry, silage, sheepdip, yard washings, etc).

POLLUTION RISK ASSESSMENT

7. What factors are considered in assessing pollution risk at the following stages:

   a) Storage (eg slurry, silage, sheepdip, farm chemicals)?

   b) Treatment (if any)?

   c) Disposal (eg slurry, yard washings, sheepdip)?

8. What techniques are used for quantifying pollution risk on farm premises?

9. How is information on pollution risk reported and acted upon?

RIVER QUALITY MONITORING

10. How is chemical river quality usually monitored in problem areas?

11. Is biological monitoring used?

    If so, how?

12. What action is taken to monitor water quality after notification of a pollution incident?

POLLUTION INCIDENTS

13. Is there a documented strategy for immediate remedial action following a pollution incident?

14. How is a 'pollution incident' defined in your area?

15. Are incidents graded in terms of severity?

    If so, how?

16. Is there a defined protocol for the reporting of pollution incidents?

17. Is information on pollution incidents stored in a computer archive?

If so, is the archive system used for the purpose of pollution control?

POLLUTION CONTROL

18. Is current pollution control legislation adequate?

If not, how is it deficient?

If it is adequate, are continuing farm pollution problems caused by:

i) interpretation of the legislation?

ii) difficulties in gathering conclusive scientific evidence?

iii) other reasons? (please specify)

19. Do successful prosecutions generally result in improved water quality?

20. How effective do you think educational campaigns, or educational visits targeted at problem farms, are in reducing farm pollution?

21. Which waste control technologies do you think offer most potential for pollution abatement?

22. What aspects of catchment management, such as the the establishment of protection zones, do you think offer most potential?

23. How useful do you think catchment management models currently under development will be to pollution control staff?

Sheepdipping controls

24. What constraints on sheepdipping methods are imposed on farmers/contractors by your NRA region?

25. Is the location of sheepdipping sites specified or recommended by your region?

    If so, on what basis?

26. What rules for the safe disposal of spent sheepdip chemicals by farmers/contractors are laid down by your region?

APPENDIX B

EXPLANATORY NOTES ON THE FORM OF POLLUTION INCIDENT DATA REQUESTED FOR THE NATIONAL ASSESSMENT EXERCISE

B.1 INCIDENT TYPE

Pollution incident data was requested for 1988 and 1989, indicating the National Grid Reference of each incident, incident type and incident severity. For incident type, it was requested that the categories below, based in the annual Farm Wastes Report (FWR) (NRA/MAFF 1989), were followed.

STUDY CODE	FWR CODE	DESCRIPTION
01	1(a)	CATTLE - Slurry stores/waste collection tanks
02	(b)	CATTLE - Solids stores
03	(c)	CATTLE - Yard washings
04	(d)	CATTLE - Dairy/parlour washings
05	(e)	CATTLE - Land run-off
06	(f)	CATTLE - Treatment system failure
07	(g)	CATTLE - Silage
08	2(a)	PIGS - Slurry stores
09	(b)	PIGS - Yard washings
10	(c)	PIGS - Land run-off
11	(d)	PIGS - Treatment system failure
12	3	Poultry
13	4	Sheepdips
14		Other
15	5 or 10	Where it is unclear from the records whether the incident was due to cattle or pig slurry.
16	1 or 8	Where it is unclear from the records whether the incident was due to a cattle or pig slurry store.

B.2 INCIDENT SEVERITY

It was requested that either the new national incident categories were followed, ie:

Major
Significant
Minor

or alternatively the FWR categories of:

Serious
Minor

It was assumed that the FWR grade of severity roughly equates with national incident categories 'Major' and 'Significant' combined, and that the 'Minor' categories are roughly comparable.

The criteria for these grades are given below (an incident only has to satisfy one of the criteria to be included in a category):

National incident categories

Major (1)

a) Potential or actual persistent effect on water quality or aquatic life.
b) Closure of potable water, industrial or agricultural abstraction necessary.
c) Extensive fish kill (>50).
d) Excessive or repeated breaches of consent conditions.
e) Extensive remedial actions necessary.
f) Major effect on amenity value.

Significant (2)

a) Notification to abstractors necessary.
b) Fish kill (<50).
c) Measurable effect on invertebrate life.
d) Water unfit for stock.
e) Bed of watercourse contaminated.
f) Amenity value reduced by odour or appearance.
g) Breach of consent conditions.

Minor (3)

Suspected or probable pollution which on investigation proves unlikely to be capable of substantiation or to have no noticeable effect.

FWR categories

Serious

a) Downgrading of the class of any watercourse classified in the River Quality Survey by more than 10% over 0.5 km.
b) Interference with water abstraction through quantity or quality.
c) Fish mortality.
d) Significant interference with legitimate use of water, including stock watering.
e) Adverse effect on any SSSI, nature reserve or area of high conservation interest.

Minor

Any incident attributed to a discharge arising from farming activities that does not satisfy any of the above criteria.

B.3 REFERENCES

NRA/MAFF (1989) Water pollution from farm waste 1989 - England and Wales. NRA, London.

APPENDIX C

ESTIMATION OF WASTE LOADINGS AND POLLUTION RISK FROM LIVESTOCK

C1. LIVESTOCK DATA

The categories of livestock and land use used in the MAFF/DAFS/DANI agricultural census summaries were combined to produce the following simplified categories:

		MAFF code	DAFS code
	Dairy cattle		
1.	>= 2 years and all heifers in calf	70+72+74+75+(82/2)	100+102+104+106+111
2.	6 months to 2 years	85+88	115+119
3.	<6 months	91	121
	Beef cattle		
4.	>= 2 years and all heifers in calf	71+73+76+77	101+103+105+107
5.	1 to 2 years	80+(82/2)+83+86	110+112+114+116
6.	< 1 year	87+89+90	118+120
	Pigs		
7.	Fattening pigs	111-(100+101+102)	157-(146+147+148)
8.	Dry sow	102	148
9.	Sow + litter	100+101	146+147
	Poultry		
10.	Broilers	127	164
11.	Laying hens, ducks, geese	(137-127)+129+130	170-164
	Available land		
12.	Total crops and fallow, pasture	4+5+6+7	46+47
	Sheep		
13.	All sheep except lambs <6 months	119-118	145-144

C2. ORGANIC WASTE OUTPUT

Volumetric waste output of fresh excreta (faeces + urine):

The volumetric outputs, in terms of fresh undiluted slurry, were estimated for categories 1 to 11 above from interpolations of tabulated data in ADAS Advisory booklet 2081 (ADAS 1986). This booklet gives estimates of waste output for different livestock types at given weights (for cattle) and different breeding status (for pigs). To extract volumetric outputs from the above categories of cattle, the average weight of animals in each category had to be estimated. The average weights and estimated volumetric outputs are given below:

CATEGORY	AVERAGE WEIGHT (kg)	AVERAGE OUTPUT ($l\ day^{-1}$)
[1]	520	42
[2]	250	20
[3]	150	12
[4]	540	44
[5]	375	25
[6]	175	12
[7]	-	9 *
[8]	-	4.5 *
[9]	-	15 *
[10]	-	59 (per 1000)
[11]	-	114 (per 1000)

* These values vary considerably depending upon feeding method.

Volumetric waste loading:

The following calculations, based on the above waste outputs, provide estimates of the volumetric loading on land potentially available for slurry spreading in any one catchment.

DAIRY - (D)

$$\frac{([1]x42)+([2]x20)+([3]x12)}{1000x[12]}$$

in m^3 fresh undiluted excreta day^{-1} ha^{-1} available land

BEEF - (B)

$$\frac{([4]x44)+([5]x25)+([6]x12)}{1000x[12]}$$

"

PIGS - (Pi)

$$\frac{([7]x9)+([8]x4.5)+([9]x15)}{1000x[12]}$$ in m^3 fresh undiluted excreta day^{-1} ha^{-1} available land

POULTRY - (Po)

$$\frac{([10]x59)+([11]x114)}{1,000,000x[12]}$$ "

Biological Oxygen Demand (BOD) loading:

From estimates of BOD levels in slurries given in ADAS advice booklet 2200 (ADAS 1985), total BOD loading was calculated as follows:

(Dx20,000)+(Bx20,000)+(Pix30,000)+(Pox35,000) in mg BOD day^{-1} ha^{-1} available land

and

$$(Dx20,000)+(Bx20,000)+(Pix30,000)+(Pox35,000) \times \frac{\text{available land}}{\text{catchment area}}$$

in mg BOD day^{-1} ha^{-1} catchment

A range of BOD levels is given in the booklet for typical slurries from different livestock types, but since the estimates in this analysis are based on undiluted slurry the upper limit of each range was taken.

Nutrient loading:

ADAS booklet 2081 gives typical nutrient contents of fresh and undiluted slurries from different livestock types. These were used to calculate nitrogen and phosphorus loads on each catchment as follows:

i) Nitrogen loading:

(Dx5)+(Bx5)+(Pix5)+(Pox14) in kg N day^{-1} ha^{-1} available land

ii) Phosphate loading:

(Dx2)+(Bx2)+(Pix2)+(Poxll) in kg P2O5 day^{-1} ha^{-1} available land

C3. SHEEPDIP LOADING

As outlined in the main text (see section 5.2.2), certain assumptions made by Littlejohn and Melvin (1989) were used in the following estimations. These are that: a dipper volume of 2700 litres (2.7m3) is used, and 300 sheep are dipped in one day; replenishments of 15% of the dipper volume are made twice a day (every 100 sheep); and completely fresh dip solution is made each day. This gives a total daily usage of sheepdip of 3.57m3 for every 300 sheep. Assuming that the manufacturer's recommended dilutions are used, this is equivalent to a daily usage of 1.25 kg propetamphos for every 300 sheep. This allows the following estimates to be made:

$$\frac{([13]\times(3.57/300))}{\text{catchment area (ha)}}$$ in m^3 sheepdip solution per dipping period per ha catchment

$$\frac{([13]\times(1.25/300))}{\text{catchment area (ha)}}$$ in m^3 'propetamphos equivalent' per dipping period per ha catchment

The amount of waste phenolic compounds, which are used in conjunction with propetamphos, can be estimated by multiplying propetamphos usage by 2.5.

C4. POLLUTION RISK

ORGANIC POLLUTION RISK

The following weighting factors (W) were used in order to combine individual factors to produce an index of overall risk.

FACTOR	W
BOD loading on available land	0.33
BOD catchment loading	0.43
Slope	0.08
Rainfall	0.08
Winter Rainfall Acceptance Potential (6 - class)	0.08

SHEEPDIP POLLUTION RISK

The following weighting factors were used to produce an overall index of pollution risk from spent sheepdip.

FACTOR	W
Volumetric waste loading over whole catchment area	0.76
Slope	0.08
Rainfall	0.08
Winter Rainfall Acceptance Potential (6 - class)	0.08

C5. REFERENCES

ADAS (1985) Advice on avoiding pollution from manures and other slurry wastes. Advice booklet 2200. MAFF Publications.

ADAS (1986) Profitable uses of farm manures. Advice booklet 2081. MAFF Publications.

Littlejohn, J.W. and Melvin, M.A.L. (1989) A theoretical evaluation of the pollution potential of sheep dip preparations. *Environmental Technology Letters* **10**, 1051-1056.

APPENDIX D

RECENT NWC DOWNGRADINGS DUE WHOLLY OR PARTIALLY TO FARM POLLUTION

A list of river stretches, by region, is given below where NWC class is, or has been in the recent past (1988 or 1989), downgraded due wholly or partially to livestock farming. Only whole class downgradings are considered due to the uncertainties of class designation.

River	Length affected (km)	NWC class of affected stretch	NWC class upstream	Cause of downgrading
NRA ANGLIAN REGION				
Tove	4	3	U	agriculture (general)
Padbury Brook	3	3	1B	cattle + sewage
	4	2	U	
Sabiston	8	3	2	sewage + pigs + bacon factory
Stowlangtoff Brook	8	3	1B	sewage + pigs
Dove/Waveney	8	3	U	pigs
	2	3	U	pigs ?
	3	3	U	pigs
N Kelsey Beck	6	3	1B	ducks
Tud	10	3	U	pigs/cattle
TOTAL	**56**			
NRA NORTHUMBRIAN REGION				
None known				
NRA YORKSHIRE REGION			*	
Wiske (1988)	24.1	2	1B	Intermittent but regular farm incidents
The Stell (1988)	6.4	2	1B	As above
Willow Beck (1988)	4.8	2	1B	As above
Crimble Brook (1988)	2.9	2	1B	Silage
Weeton Beck	4.5	2	1B	General farm pollution
Mires Beck	7.9	2	1B	Agricultural drainage
TOTAL	**50.6**			

* where the upstream reach is unclassified, or, adjacent stretches where the river is unaffected by farm pollution

Appendix D continued/2

NRA SEVERN TRENT REGION

Sarnwen Brook	0.8	3
	4.7	3
Tetchill Brook	4.5	3
Newness Brook	2.0	3
Rea Brook	3.0	2
River Roden	6.0	2
Soulton Brook	2.7	2
Leigh Brook	2.5	2
Battlefield Brook	5.0	2
Horsebere Brook	6.0	3
Red Brook	5.3	2
Ley Brook	5.0	2
Wem Brook	2.5	3
Carr Brook	2.0	2
Heath End Brook	1.8	2
Burton Brook	4.6	2
Countesthorpe Brook	0.5	2
Dalby Brook	7.5	2
River Whipling	3.2	2
Car Dyke	9.0	2
Broad Bridge Dyke	1.5	2
River Arrow	6.0	2
River Wreake/Eye	19.2	2
River Blythe	26.7	2
TOTAL	**132.0**	

U	Farm drainage/septic tanks
3	Farm drainage/septic tanks
U	Farm drainage
U	Farm drainage
U	Farm drainage and STW
U	Farm drainage
U	Farm drainage
1B	Farm and STW
U	Farm and storm overflows
U	Farm and industrial
U	Agricultural problems
U	Agricultural problems
U	Farm pollutions
U	Farm effluents
U	Farm effluents
U	Farm waste and sewer dyke
1B	Farm drainage, STW and storm overflows
U	Agricultural run-off
2	Agricultural run-off
2	Farm drainage and STW
U	Agricultural problems
U	Suspected farm source
U	Suspected farm source
U	Suspected farm source

Appendix D continued/3

NRA WELSH REGION

Afon Bach (R Clwyd)	0.6	2
Aldford Brook (R Dee)	3.7	3
Worthenbury Brook (R Dee)	2.7	4
	3.9	2
River Dulas	6.0	2
Olway Brook (Usk)	8.0	2
Trothy (Wye)	12.9	2
Worm Brook (Wye)	9.4	2
	6.8	3
Jury Brook (Wye)	5.8	2
Garren Brook (Wye)	13.8	2
Rudlace Brook (Wye)	4.0	2
How Caple Brook (Wye)	5.8	2
River Lodon (Wye)	18.0	2
Hackley Brook (Wye)	5.0	2
Withington Lakes (Wye)	3.8	2-4
	1.4	3
Withington Marsh (Wye)	6.8	3
Moreton Brook (Wye)	8.8	2
Wellington Brook (Wye)	4.8	2
Bodenham Brook (Wye)	6.1	2
Main Ditch (Wye)	13.0	2
Ridgemoor Brook (Wye)	5.6	2
River Enig (Wye)	6.9	2
W Cleddau	3.2	2
E Cleddau	3.5	2
Syfynwy	11.1	2
Anghof	2.9	2
Aeron	3.2	2
Mydyr	3.2	3
TOTAL	**190.7**	

U	Dairy effluents/slurry
2	Dairy effluents/slurry
3	Dairy effluents/slurry & silage
3	Dairy effluents/slurry & silage
U	Dairy effluents/slurry
U	Cattle
1B	Cattle
1B	Cattle
1B	Cattle
1B	Cattle
1B	Cattle
1B	Cattle
1B	Cattle
1B	Cattle
1B	Cattle/pigs
2	Cattle
2	Cattle
1B	Cattle
1B	Cattle
1B	Cattle
1A	Cattle
1B	Cattle
1B	Cattle
1A	Livestock
1B	Probably slurry
1B	Probably slurry
U	Probably slurry
U	Probably slurry
U	Probably slurry
U	Probably slurry

APPENDIX E

LIST OF PARTICIPANTS IN THE NATIONAL ASSESSMENT EXERCISE

REGION	CONSULTATION	DATA COLLATION
NRA Anglian	Alan Barnden	Geoff Taylor
NRA North West	David Griffiths	David Griffiths
NRA Northumbrian	Bob Pailor Jim Lancaster	Jim Lancaster
NRA Severn Trent	Bob Harvey	
NRA South West	Clem Davies Geoff Bateman	Neil Pallister
NRA Southern	Keith Loy	
NRA Thames	John Haines	Tania Woodward
NRA Welsh	Bob Merriman	Frank Jones
NRA Wessex	David Palmer	Brian Frankling
NRA Yorkshire	Brian Ogden	Gerard Morris
Clyde RPB		
Forth RPB	William Halcrow Rod Wallace	
Highland RPB	Duncan Buchanan	
North East RPB	David Mackay	
Solway RPB	W T Welsh	
Tay RPB	Ron Allcock	
Tweed RPB	Ian Currie	
DoE N Ireland	E Hagan	

APPENDIX F

SYNOPSIS OF A THESIS ON THE BIOLOGICAL RECOVERY OF STREAMS USING SIMULATED POLLUTION EPISODES

CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF FIGURES continued

LIST OF FIGURES continued

F1. INTRODUCTION

F1.1 Background

Pollution control measures taken in recent years have decreased pollution loads from chronic discharges to receiving waters. However, sporadic pollution from farm wastes, storm sewage overflows and chemical spills is now being recorded more commonly, posing significant problems of water quality management. The number of episodic pollution incidents recorded in England and Wales has almost doubled, from 12 500 in 1981 to 24 153 in 1988 (NRA, 1989). In 1988, industrial incidents, including the release of oil and a large variety of chemicals accounted for 34% of these events. Discharge of sewage from storm overflows etc and the release of farm wastes were also major problems, contributing 20% and 17% of total discharges respectively.

Pollution episodes involve a toxicant input of short duration and high concentration, which passes downstream as a wave of increasing length and reducing amplitude (Edwards 1987, Pascoe 1988). The physico-chemical processes in aquatic systems (eg dispersion, sorption) cause attenuation (weakening) of pollutant activity, and there is also evidence that dispersion in the stream bed is related to depth of substrate penetrated by the pollutant (Bencala 1984, Edwards *et al* in press). After an episode it is difficult to establish the time-concentration profile of exposure and the previous ecological status of downstream reaches unless, of course, an incident can be anticipated or arranged. After the event, recovery of populations and communities occurs through the processes of recolonisation and succession. This is in contrast to the classical descriptions of spatial recovery (eg Kolkwitz and Marsson 1909, Streeter and Phelps 1925, Hynes 1960) characteristic of continuous discharges, which involve selective processes based on species sensitivity and physiological and genetic adaptation to a quasi-steady-state.

F1.2 Objectives

Since there is rarely an opportunity to record the impact of, and recovery from, these episodes, their effects on stream biology are difficult to interpret. In view of this, a programme of field experiments, simulating pollution incidents, was undertaken to provide a fuller understanding of episodic pollution and the processes of recovery. Whilst, experiments of this type are subject to statistical strictures described by Hurlbert (1984) the effects are frequently dramatic and unequivocal in nature and conclusions drawn from them may be supported by other evidence (Edwards *et al* in press).

Farm waste was used as a model pollutant type for the investigation. Agricultural pollution incidents are of increasing concern, particularly those resulting from accidental or deliberate discharges of animal slurry and silage. These effluents are highly polluting with a typical biological oxygen demand (BOD) for undiluted slurry of 20 000 mg l^{-1} and for silage liquor of 80 000 mg l^{-1}. Total ammonia concentrations are approximately 1200 mg l^{-1} and 200 mg l^{-1} for slurry and silage respectively. Concentrations recorded in small watercourses following incidents are highly variable, with concentrations of total ammonia up to 700 mg l^{-1}, DO down to 0.7 mg l^{-1} and pH as low as four (in association with discharges of silage). Cattle slurries also contain significant concentrations of sulphides.

The objectives of the research programme were:

(i) To provide a fuller understanding of organic pollution episodes through field-simulations. This was achieved by dosing streams to produce low DO, increased ammonia and increased sulphide concentrations relevant to farm wastes.

(ii) Investigate the recovery of streams following these disturbances.

(iii) Identify some of the processes involved in the changes detected above.

The emphasis of the study was on the response of macroinvertebrates, however some data were gathered on the impact upon fish. The results of the three year research programme will be reported fully in a thesis to be submitted in candidature for the higher degree of Philosophiae Doctor. This report summarises the main findings.

F1.3 Research programme

Seven experiments simulating pollution episodes were undertaken between July 1988 and June 1990 (Table F1) consisting of: reduced dissolved oxygen (four); increased ammonia (two); increased sulphide (one). A further field experiment, using sodium chloride as a tracer, was carried out to study dispersion. In addition, laboratory experiments examining migration responses of macroinvertebrates (drift and vertical movements) were undertaken in 1989, using a small-scale artificial stream.

F2. METHODS

F2.1 Field experiments

F2.1.1 Site selection

Sites offered by the Welsh NRA were chosen on the following criteria:

(i) Streams were of low order (1st - 3rd, Strahler, 1957) and of good quality (equivalent to NWC class 1A or 1B), supporting diverse fish and invertebrate faunas.

(ii) The impact of field experiments was spatially limited by dilution from downstream sources.

(iii) Access was relatively easy, in view of the large volume of equipment and chemicals transported to the sites.

(iv) Landowners were sympathetic.

Figure F1 refers to the locations of field sites (see also Table F1). National grid references are: Mounton Brook, ST485945; Nant Dowlais with tributary, ST074840 and Yazor Brook, SO455427.

F2.1.2 Pollution episode simulation

Although the experiments were designed to investigate the biological effects of low DO, increased ammonia and increased sulphide episodes relevant to farm wastes, the results have wider application to other forms of organic episodic discharge (eg storm-sewer overflows), since the component effects could originate from a wide range of sources of organic waste.

The details of each experimental episode are described in Table F1. In each case the downstream effects of the pollutant release were compared to an untreated reference zone upstream of the dosing point.

a) Reduced dissolved oxygen

Episode 1, on Mounton Brook (July 1988), was designed to investigate the impact of a short episode (6 hr) of very low (1 mg l^{-1}) DO.

Episode 3, on Yazor Brook (May 1989), examined the effect of a brief episode (6 hr) of intermediate dissolved oxygen concentration (3-4 mg l^{-1}). The number of dead animals in the drift was determined.

Episode 4, on Mounton Brook (July 1989), sought to determine the DO concentration of at which invertebrate drift increased during short exposure (1 hr). This was achieved by progressively reducing the concentration in a stepwise fashion, with intervening periods of recovery (1 hr), when the oxygen concentrations were returned to normal.

Episode 6, on Mounton Brook (November 1989), examined the influence of season by comparing responses with those in July (Episode 4).

b) Ammonia

Episode 2, on Nant Dowlais (September 1988), examined the impact of a short episode (6 hr) of increased unionised ammonia (5 mg l^{-1}, pH 8.5) mimicking the shape of an attenuated pulse (sinusoidal).

Episode 5, on a tributary of Nant Dowlais (September 1989), was designed to study the impact of prolonged (24 hr) high concentrations of unionised ammonia (6 mg l^{-1}, pH 9.0). The ability of semi-natural substrate to protect *G. pulex* from the full effect of the toxicant was also investigated. In an additional downstream zone where unionised ammonia concentrations had decreased to ~3 mg l^{-1}, the DO concentration was artificially lowered to 5 mg l^{-1} for 12 hours.

c) Sulphide

Episode 8, again on a tributary of Nant Dowlais (May 1990), investigated the impact of a prolonged episode (24 hr) of increased sulphide (nominal 6 mg l^{-1} as total sulphide. The influence of water velocity upon the toxicity of sulphide to *G. pulex* (mortality) was also examined.

F2.1.3 Dosing of streams

Dissolved oxygen concentrations were reduced by the injection into the stream of sodium sulphite (Na_2SO_3 solution) the rapid oxidation of which was catalysed by cobalt maintained in the stream at trace concentrations (0.2-1.0 mg l^{-1}). Stream concentrations of sulphate (from oxidation of sulphite) and cobalt occurring during dosing were non-toxic.

Ammonia concentrations were raised by the addition of ammonium chloride (NH_4Cl) solution (150-200 g l^{-1}). Ammonia is most toxic in the unionised state (Wurhmann and Woker 1948, Alabaster and Lloyd 1980, Williams *et al* 1986) and therefore at high pH. In designing experiments with ammonia, a compromise is required to ensure the increased pH is not directly damaging (Edwards *et al* in press) and was increased to between 8.5 and 9.0 using sodium hydroxide (NaOH) solution.

During Episode 7 (tracer experiment), sodium concentrations were increased using a 75 g l^{-1} solution of sodium chloride (NaCl). During Episode 8 sulphide concentrations were increased using sodium sulphide (Na_2S) solution (150 g l^{-1}). Chemicals were delivered into the stream using peristaltic pumps or by gravity feed. Dosing rates were dependent upon stream discharge, estimated before the period of dosing from the mean flow velocity (ms^{-1}) multiplied by the cross-sectional area (m^2) (BS 3680: Part 3: 1964). Mixing zones and travel times were gauged using fluoroscene dye.

F2.1.4 Water quality monitoring

Dissolved oxygen, pH and temperature were monitored using pHOX 100 DPM multiparameter instruments and surface water samples were taken for metals analysis by ICP. Ammonia samples were preserved with sulphuric acid to <pH 2. Sulphide samples were preserved with zinc acetate (2N) after settling of solids. Total ammonia and sulphides were determined colorimetrically (APHA 1985, parts 417 and 427) and the undissociated species (NH_3 and H2S) determined from pH and temperature readings (Seager, Wolff and Cooper 1988, Mance, O'Donnell and Campbell 1988).

F2.1.5 Attenuation studies

During Episodes 3, 5, 7 and 8 interstitial water from the sediment was sampled using stainless steel stand-pipes (1 cm x 1 m) at 10-15 cm and 30-35 cm depth in the stream bed, to assess the 'within-sediment' attenuation of pollutant episodes. In Episodes 5, 7 and 8 samples were withdrawn using 50 ml plastic syringes and preserved in plastic universal bottles (30 ml). Dissolved oxygen was measured *in situ* during Episode 3 using a micro-medical oxygen electrode inserted into the stand-pipes.

F2.1.6 Biological studies

The following were investigated during toxicant episodes.

(i) Invertebrate drift - this was measured using 0.5 mm mesh nets held inside 0.3 m diameter, 1 m long steel tubes in which the flow of water was measured. Drift was expressed as animals/m^3 (after Elliott 1970) and the total drift could be estimated using stream flow data.

(ii) Benthic invertebrates - kick samples (Hynes 1961) were taken before and after the treatments in riffles (1 min) and margins (1 min) to assess impact and recovery. Quantitative cylinder sampling (Niell 1938) was used at the Yazor Brook (Episode 3).

(iii) *In situ* toxicity tests - opportunities were taken by colleagues to use the simulated episodes for toxicological studies. They conducted *in situ* tests with a range of caged invertebrates and fish. Lethal and sub-lethal responses were measured (McCahon *et al* in press). The influences of semi-natural substrates (sand and stones) and water velocity upon the toxicity of ammonia (Thomas *et al* in press) and sulphide to *G. pulex* were also investigated.

F2.1.7 Recovery mechanisms

In 1976, Williams and Hynes described four principal pathways or mechanisms by which stream benthos colonise small areas of implanted substrate: downstream, upstream, aerial and within-substrate movements (see also Townsend and Hildrew 1977, Williams 1977). However, these earlier studies did not address the relative importance of each pathway following a pollution episode because only small patches of substrate were initially cleared of invertebrates and migration from adjacent areas could occur.

A study of recovery mechanisms was undertaken following deoxygenation of the Mounton Brook in July 1989 (Episode 4). Four traps were designed, each to limit the recolonisation to a single route into the stream substrate, and a fifth trap was included which allowed colonisation by all pathways. Four replicates of each trap type, containing a semi-natural substrate of limestone chips, were used. All twenty traps were constructed to the specifications of Williams and Hynes (1976).

F2.2 Laboratory investigations

Episodic pollution has been shown to have an impact upon various facets of invertebrate behaviour, particularly drift (Edwards *et al* in press) and precopular disruption in *G. pulex* (McCahon *et al* in press). The vertical migrational behaviour of invertebrates within stream beds has been observed during spate conditions (Williams and Hynes 1974). However, field observations made during simulated episodes of reduced pH were equivocal (Ormerod *et al* 1987). In the current study, a small scale laboratory stream (1 m length) was designed to examine vertical migration (Figure F19). An artificial substrate of glass beads, bounded by sheets of perspex, simulated a section of gravel bed 20 cm deep and 4 cm thick. This allowed animals to be observed and counted so that migration into and out of the substrate could be assessed. A small drift net at the downstream end was used to monitor downstream migration. In a series of experiments of reduced dissolved oxygen and increased ammonia, the stream was seeded with animals (*E. venosus* or *G. pulex*) and dosed in a similar manner to the field experiments described earlier. The substrate was covered by opaque screens between observations of the number of animals within the glass beads before, during and after dosing.

F3. RESULTS AND DISCUSSION

F3.1 Field investigations

Biological responses in the field were determined from invertebrate drift densities, *in situ* toxicity tests and comparisons of the benthic macroinvertebrate fauna before and after the experiments.

F3.1.1 Dissolved oxygen

a) Invertebrate drift and *in situ* toxicity tests

The drift density at the Mounton Brook was normally very low during the day (<0.5 animals m^{-3}). This increased in response to the reduced DO during Episode 1 (Figures F2a and b) to a peak of 43 animals m^{-3}, consisting mainly of *Ephemerella ignita*, *Ecdyonurus venosus*, *Rhithrogena semicolorata*, *Baetis rhodani* and *Isoperla grammatica*. Another peak occurred later associated with *Gammarus pulex*, *Ephemera danica*, *Limmius volckmari*, *Simuliidae* and *Chironomidae*. Densities in the upstream reference zone remained low during daylight and there was the normal night-time peak; this night-time peak did not occur in the treatment zone. There were also substantial mortalities in caged fish and invertebrates and a range of sensitivities was observed (Table F2). Studies with *G. pulex* demonstrated that the low-oxygen regime disrupted precopular behaviour and that the presence of a parasite (*Pomphorynchus laevis, Ancanthocephala*) increased mortality.

During Episode 3, dissolved oxygen concentrations of 3-4 mg l^{-1} (Episode 3) also caused substantial increases in drift over a 6 hour period. The proportions of dead *Baetis* and *Gammarus* in the drift were normally very low during daylight (<1%), but the proportion of dead *Baetis* increased during the night to between 5 and 10%. At the end of the 6 h exposure to 3-4 mg l^{-1} DO the proportions of dead *Baetis* and *Gammarus* were 52% and 43% of the total number caught for each taxa, respectively. During Episode 4, the DO concentration was lowered in a stepwise fashion to determine the concentration at which invertebrate drift increased. Normal drift densities were low in both the treatment and reference zones (<3 and <1 animals m^{-3}). The first significant increase in total drift occurred at 4 mg l^{-1} dissolved oxygen (Figures F3a, 4a) and recovered to background levels when the DO returned to normal. Exposure to 2 mg l^{-1} DO also increased drift densities (>10 fold); however, the density remained above background in the recovery period following this treatment (Figures F3a, F4a).

b) Natural benthic macroinvertebrate communities

Low dissolved oxygen episodes simulated in the Mounton Brook in July of 1988 (Episode 1) and 1989 (Episode 4) resulted in severe disturbances to the benthic fauna. However, recovery was rapid and pre-treatment conditions were recorded within two months (Figures F5a-c). A similar pattern was also recorded by quantitative sampling following Episode 3.

Recolonisation of benthic invertebrates following Episode 4 (DO depletion) was principally by downstream movement (44.9%). Within substrate migration, upstream movements and aerial sources contributed 31.5%, 15.6% and 7.9%, respectively. Differences between pathways were also found for major groups of invertebrates (Table F3, Figure F6), however, all four sources were equally significant for the Chironomidae.

c) Seasonal differences in impact

A comparison of benthic invertebrate responses recorded during Episodes 4 and 6 (July and November) in the same stream (Mounton Brook), showed clear seasonal differences. Invertebrate drift was normally extremely low in November (<0.3 animals m^{-3}) compared with July (3 animals m^{-3}). Drift at this time increased above background when the DO, was reduced to 6 mg l^{-1}; however the density was approximately 2% of the July figure at 4 mg l^{-1} DO (Figure F4b). The high drift density at 4 mg l^{-1} DO, which occurred in July, was not achieved in the November experiment even after 3 hours exposure to 1 mg l^{-1} DO despite comparable invertebrate abundances at both times of year. Consequently, the impact on the benthos in November was minimal.

F3.1.2 Ammonia

a) Invertebrate drift and *in situ* toxicity tests

The drift response of macroinvertebrates to an attenuated pulse of ammonia (Episode 2, Figure F7a) was similar in scale to the nocturnal peak (Figure

F7b). Caged fish were killed rapidly and, as expected, salmonids were the most sensitive (Table F2). There were no mortalities in caged invertebrates, but behavioural changes were observed in: *Polycelis tenuis* (contraction), *Physa fontinalis* (vertical migration from water) and *G. pulex* (precopula disruption). There were no perceptible changes in the benthos (Figures F8a-c).

As expected, a prolonged pulse of ammonia (Episode 5), in the form of a square wave (Figures F9a and b), had a greater impact on the drift (Figures F10a and b), also causing precopular disruption and mortality in *G. pulex*. The presence of semi-natural substrate (sand and stones) in the tanks holding *G. pulex* significantly reduced mortality ($p<0.05$, ANCOVA, Sokal and Rohlf 1981). This was later shown to be affected by water velocity in laboratory experiments (Thomas *et al* in press). In a second treatment zone (100 m downstream), attenuation of pH and unionised ammonia concentrations occurred (Figures F9a and b). Here, the dissolved oxygen concentration was artificially lowered to 5 mg l^{-1} for 12 hours (Figure F9c). Invertebrate drift in this zone also increased (Figure F10c) but was significantly lower than in the first treatment zone. Disruption of precopula in *G. pulex* was also observed to be significantly less than in the first treatment zone ($p<0.05$ Litchfield 1949).

b) Natural benthic macroinvertebrate communities

Although increases in drift and some mortalities were recorded, the ammonia episodes had a relatively low impact on benthic invertebrates. Reductions in taxonomic diversity and biotic score (B.M.W.P.) were not observed (Figures F8 a,c) however, a decrease in relative abundance was apparent (Figure F8b) following Episode 5.

F3.1.3 Sulphide

In Episode 8 the total sulphide concentration was raised to 5 mg^{-1} (Figure F11) and drift increased to an order of magnitude above background (Figure F12). Disruption of precopula in *G. pulex* occurred and males were observed guarding dead females. In a downstream zone (50 m) in which total sulphide concentrations had reduced to 2 mg^{-1} groups of *G. pulex* were exposed to different water velocities, in standardised cages containing substrate (sand and stones). A significant relationship between ambient water velocity and mortality due to sulphide toxicity was found (Figure F13). No mortality was recorded in *G. pulex* held under similar flow conditions in the reference zone.

F3.1.4 Interactions of pollutant episodes with the stream bed

Physico-chemical processes (dispersion, sorption) in aquatic systems may cause attenuation (weakening) of pollutant activity. The longitudinal dispersion of tracers and pollutants has been extensively studied (McBride and Rutherford 1984, Whithead *et al* 1986). Mass transfer of solutes between surface and interstitial water in sediments has been studied in the laboratory (Thidbodeaux and Boyle 1987, Nagaoka and Ohgaki 1990) and in the field (Bencala 1983, Bencala *et al* 1984, Bencala 1984 a,b). However, few studies have described the distribution of a pollutant or solute in relation to depth and duration within the substrate (eg Munn and Meyer 1988, Edwards *et al* in press).

In the current study the attenuation of pollutant episodes and the penetration of a solute tracer (sodium chloride) into the bed of a small stream were investigated. Observations of the penetration of the tracer were related to interstitial seepage rates.

The locations of sampling sites for surface and interstitial water (10 and 30 cm) at the Tributary Nant Dowlais are indicated in Figure F14. During the solute tracer experiment only Site 1 (riffle) showed significant penetration of sodium into the bed to a depth of 10 cm (Sites 1-6, Figure F15). Site 2 was in the margin, one metre from Site 1; however, there was only a slight increase in concentration in the substrate at 10 cm. The solute did not penetrate to 30 cm at any of the sites investigated. Sediments in the stream are sandy and very compacted, and as expected the seepage rates (Carling and Boole 1986) were extremely low at all the sampling points. Notably, Site 1 showed the highest seepage velocity at 10 cm (Figure F15).

The stream bed at the Tributary Nant Dowlais also attenuated unionised ammonia concentrations (Figure F14, Site A, Figure F16 a-c) and total sulphides (Figure F14, Site B; Figure F17). Apparent anomalies between sodium and ammonia penetration at Site 3/A were probably due to dramatic changes in sediment and flow patterns (riffle -> 'glide') at this point, brought about by flooding in the winter of 1989. During Episode 3 (Yazor Brook) dissolved oxygen concentrations at 10 cm and 30 cm in the substrate (riffle) closely followed the surface profile (Figure F18).

F3.2 Laboratory investigations

The laboratory stream confirmed downstream movement as a response to reduced dissolved oxygen and increased ammonia. Migration of animals into the substrate was observed soon after the onset of dosing. Figure F20 shows the migration pattern for *G. pulex* during an ammonia episode. There was clearly an increase in the total number of *G. pulex* in the substrate in response to increased ammonia. Similar patterns occurred with *G. pulex* and *E. venosus* with dissolved oxygen reductions.

F4. CONCLUSIONS

Field simulations of pollution episodes were a useful tool to provide data on the biological effects of intermittent low DO, ammonia and sulphide, which are major components of most organic wastes such as those emanating from farms. 'Real' slurry or silage pollution events often result in fish mortalities and cases have been recorded where angling clubs have suspended fishing following serious pollution (Howells and Merriman, 1986). As expected, caged fish were highly sensitive to reduced DO and elevated ammonia concentrations during brief exposure.

Studies with caged invertebrates and natural populations demonstrated a wide spectrum of responses, with reduced DO causing the most severe disturbances even when compared with prolonged episodes of sulphide or ammonia. Brief exposures at or below 4 mg l^{-1} DO in the summer caused partial denudation of benthic invertebrates in contrast with the winter study when the response was considerably reduced. However, recovery occurred rapidly (<2 months) and followed a clear 'exponential' pattern despite differences in sites, sampling techniques and year of study (1988, 1989). The pattern is consistent with the MacArthur - Wilson model (1963) for island fauna and similar curves have been found for aquatic animals colonising implanted substrates (Dickson and Cairns 1972, Sheldon 1977). Clearly, recovery following short-term disturbances can be rapid providing there are sources of organisms available to recolonise. In the current study, downstream movement was the principal pathway for recovery, a similar result to that described in previous studies (eg Williams and Hynes 1976); however, other pathways were important, particularly for certain groups such as the Chironomidae, and should not be ignored.

Sources of animals from within the substrate also played a major role in the recolonisation process, furthermore, the penetration of pollutants into stream beds demonstrated extensive spatial patchiness. Large areas of the stream bed could provide a refuge from episodes, especially since some animals demonstrate an ability to move deeper in response to events. These animals could survive to recolonise surface layers of the stream bed. However, care should be taken when extrapolating the laboratory observation of vertical migration to real streams and further work is needed to satisfactorily investigate this phenomenon of invertebrate behaviour under field conditions.

Pollution incidents, particularly those due to farm wastes and storm-sewer overflows, rarely occur in isolation and repeated events may not allow complete recovery of the system. The impoverished nature of water courses subject to repeated episodes has been confirmed by field studies (WRc unpublished data) but as yet the mechanisms have not been examined.

Further work is required to increase our understanding of how animals, in terms of both populations and species assemblages, respond to repeated challenges by short-term episodes.

F5. ACKNOWLEDGEMENTS

My sincere thanks are due to:

Professor Ron Edwards for supervision of the project, for advice, guidance and for reviewing this manuscript.

My friends and colleagues of the old Roof Laboratory (ex UWIST) for moral and material support.

The UWCC Catchment Research Group especially Mr Stewart Thomas.

The staff of the Welsh NRA and Water Authority for laboratory support and equipment loans.

M. John Fletcher and family, The Forestry Commission and RAF Hereford.

WRc for funding.

Thank you to Alison Richards for typing this manuscript.

I am deeply indebted to Barbara for her support.

Craig Turner.

REFERENCES

APHA (1985) Standard methods for the examination of water and waste water. 16th edition, edited by M A H Franson.

Alabaster, J.S. and Lloyd, R. (1980) Water quality criteria for freshwater fishes. Butterworths, London, England pp 297.

BS 3680: Part 3: (1964) Flow measurements in open channels.

Bencala, K.E. (1983) Simulation of solute transport in a Mountain Pool and riffle stream with kinetic mass transfer model for sorption. *Water Resources Research* **19**, 3, 732-738.

Bencala, K.E. and Walters, R.A. (1983) Simulation of solute transport in a Mountain Pool and riffle stream: a transient storage model. *Water Resources Research* **19**, 3, 718-724.

Bencala, K.E. (1984) Interactions of solutes and streambed sediments. *Water Resources Research* **20**, 12, 1797-1814.

Bencala, K.E., Kennedy, V.C., Zellweger, G.W., Jackman, A.P. and Avarzine, R.J. (1984) Interactions of solutes and streambed sediments. *Water Resources Research* **20**, 12, 1804-1814.

Cairns, J.Jr., Crossman, J.S., Dickson, K.L. and Herricks, E.F. (1971) The effect of major industrial spills upon stream organisms. Proceedings of the 26th Industrial Waste Conference. *Eng Bull Purdue University Ser* **140**, 156-170.

Carling, P.A. and Boole, P. (1986) An improved conductiometric standpipe technique for measuring interstitial seepage. *Hydrobiologia* **135**, 3-8.

Caulcutt, R. and Boddy, (1983) Statistics for analytical chemists pp 201-205, Chapman, Hall Ltd, London.

Dickson, K.L. and Cairns, J. Jr. (1972) The relationship of freshwater macroinvertebrate communities collected by floating artificial substrates to the MacArthur - Wilson equilibrium model. *American Midland Naturalist* **88**, 1, 68-75.

Edwards, R.W. (1987) Ecological assessment of the degradation and recovery of rivers from pollution. In: *Ecological Assessment of environmental Degradation, Pollution and Recover,* edited by O Ravera pp 159-194. Elsevier Science, Amsterdam.

Edwards, R.W., Ormerod, S.J. and Turner, C. (in press) Field experiments to assess the biological effects of pollution episodes in streams. *Vehr. Internat. Verein. Limnol.*

Elliott, J.M. (1970) Methods for sampling of invertebrate drift in running water. *Annales de Limnologie* **6**, 2, 133-159.

Howells, W.R. and Merrimann, R. (1986) Pollution from Agriculture in the area of the Welsh Water Authority. In: *Effects of land use on freshwater* edited by J F de L G Solbé) pp 267-282. Ellis Horwood Ltd, Chichester.

Hurlbert, S.H. (1984) Pseudoreplication and the design of ecological field experiments. *Ecological Monographs* **54**, 187-211.

Hynes, H.B.N. (1961) The invertebrate fauna of a Welsh mountain stream. *Archiv für Hydrobiologie* **57**, 344-388.

Hynes, H.B.N. (1960) The Biology of polluted waters. Liverpool Univ press.

Litchfield, J.T. (1949) A method for rapid graphic solution of time-percent effect curves. *Journal of Pharm. Exp. Ther.* **97**, 399-408.

Kolkwitz, R. and Marsson, M. (1909) Oekologie der tierschen Saprobien. *Internat. Rev. Hydrobiol.* **11**, 126-52.

MacArthur, R. and Wilson, E.O. (1963) An equilibrium theory of insular zoogeography. *Evolution* **17**, 373-387.

Mance, G., O'Donnell, A.R.O. and Campbell, J.C. (1988) Proposed Environmental quality standards for list II substances in water: sulphide. WRc Report ESSL TR257. WRc Medmenham, UK.

McBride, G.B. and Rutherford, J.C. (1984) Accurate modelling of River Pollutant Transport. Journal of Environmental Engineering. 110, 4, 808-827.

McCahon, C.P., Poulton, M.J., Thomas, P.C., Xu, Q., Pascoe, D. and Turner, C. (in press) Lethal and sub-lethal toxicity of field simulated farm waste episodes to several freshwater invertebrate species. *Water Research*.

Munn, N.L. and Meyer, J.L. (1988) Rapid flow through the sediments of a headwater stream in the southern Appalachians. *Freshwater Biology* **20**, 235-240.

National Rivers Authority (1989) Water pollution from farm waste. Joint report by the national Rivers Authority and Ministry of Agriculture, Fisheries and Food. NRA, South West Region, Exeter.

National Water Council (1981) River quality: the 1980 survey and future outlook London. *National Water Council* pp 39.

Nagaoka, H. and Ohgaki, S. (1990) Mass transfer mechanism in a porous riverbed. *Water Research* **24**, 4, 417-425.

Niell, R.M. (1938) The food and feeding of Brown Trout (*Salmo trutta* L.) in relation to the organic environment. *Transactions of the Royal Society, Edinburgh* **59**, 481-570.

Ormerod, S.J., Boole, P., McCahon, C.P., Weatherley, N.S., Pascoe, D. and Edwards, R.W. (1987) Short-term experimental acidification of a Welsh Stream: comparing the biological effects of hydrogen ions and aluminium. *Freshwater Biology* **17**, 341-356.

Pascoe, D. (1988) Episodic pollution incidents: experimental studies in field and laboratory. In: *Biomonitoring of Environmental Pollution* edited by M Yasuno and B A Whitton. pp 145-156 Proceedings of the 4th Symposium on Biomonitoring of the state of the Environment, 1987. Tokai Univ press, Tokyo.

Seager, J., Wolfe, E.W. and Cooper, V.A. (1988) Proposed environmental quality standards for List II Substances in water: ammonia. WRc report ESSL TR 260. WRc Medmenham, UK.

Sheldon, A.L. (1977) Colonisation curves: application to stream insects on semi-natural substrates. *Oikos* **28**, 256-261.

Sokal, R.R. and Rohlf, F.J. (1981) Biometry, 2nd edition. Freeman and Company, New York. pp 859.

Strahler, A.N. (1957) Quantitative analysis of watershed geomorphology. *Transactions of the American Geophysical Union* **38**, 913-920.

Streeter, H.W. and Phelps, E.B. (1925) A study of the pollution and natural purification of the Ohio River. *Bulletin of the US Public Health Service* Nº **146**.

Surber, E.W. and Bessey, W.E. (1974) minimum oxygen levels survived by stream invertebrates. *Bull. Virginia Water Resources Research Centre* Nº **81**.

Thidbodeaux, L.J. and Boyle, J.D. (1987) Bedform generated convective transport in bottom sediment. *Nature* **325**, 6102, 341-343.

Thomas, P.C., Turner, C. and Pascoe, D. (in press) An assessment of field and laboratory methods for evaluating the toxicity of ammonia to *Gammarus Pulex* (L.) - effects of water velocity. In: *Proceedings of the 6th IUBS Symposium on Biomonitoring of the state of the Environment*, edited by M Yasuno and B A Whitton.

Townsend, C.R. and Hildrew, A.G. (1976) Field experiments on the drifting, colonisation and continuous redistribution of stream benthos. *Journal of Animal Ecology* **45**, 759-773.

Whitehead, P.G., Williams, R.J. and Hornberger, G.M. (1986) On the identification of pollutant or tracer sources using dispersion theory. *Journal of Hydrology* **84**, 273-286.

Williams, D.D. (1977) Movements of benthos during the recolonisation of temporary streams. *Oikos* **29**, 306-312.

Williams, D.D. and Hynes, H.B.N. (1974) The occurrence of benthos deep in the substratum of a stream. *Freshwater Biology* **4**, 233-256.

Williams, D.D. and Hynes, H.B.N. (1976) Recolonisation mechanisms of stream benthos. *Oikos* **27**, 265-276.

Williams, K.A., Green, D.W.J. and Pascoe, D. (1986) Studies on the acute toxicity of pollutants to freshwater macroinvertebrates. 3. *Ammonia Archiv fur Hydrobiologie* **106**, 1, 61-70.

Wurhmann, K. and Woker, H. (1948) Experimentelle Untersuchunger Uber die Amoniak-und Blaudurevergiftung. *Schweitzerische Zeitschrift fur Hydrologie* **11**, 210-244.

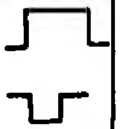
TABLES AND FIGURES

KEY.

▬ Night.

▲ ▲ } Duration of episode.
△ △

Table F1. Summary of simulated episodes.

EPISODE	TYPE	LOCATION	DURATION (hr)	NOMINAL Concentrations (mgl^{-1})	SHAPE	DATE	INVESTIGATIONS	
							Chemistry	Biological
1	Reduced Dissolved Oxygen	Mounton Brook	6	1		July 1988	Surface	Macroinvertebrate drift, Precopula Gammarus pulex, Mortality of fish and macroinvertebrates. Impact and recovery of Macrobenthos.
2	Increased Ammonia*	Nant Dowlais	6	5		September 1988	Surface	Macroinvertebrate drift, Precopula G.pulex, Invertebrate behaviour, Mortality of Fish and Invertebrates. Impact on Macrobenthos.
3	Reduced Dissolved Oxygen	Yazor Brook	6	2		May 1989	Surface and interstitial	Macroinverterate drift, impact and recovery of Macrobenthos.
4	Reduced Dissolved Oxygen	Mounton Brook	12	12-1		July 1989	Surface	Drift vs. Oxygen concentration, Precopula G.pulex, impact and recovery of Macrobenthos, recovery pathways.
5	Increased Ammonia* with Reduced Dissolved Oxygen	Tributary Nant Dowlais	24	*Ammonia 6 D.O. 5		September 1989	Surface and interstitial	Macroinvertebrate Drift, Precopula G.pulex Mortality G.pulex, Impact and recovery of Macrobenthos.
6	Reduced Dissolved Oxygen	Mounton Brook	12	12-1		November 1989	Surface	Time of year comparison with July (No. 4). Drift vs. oxygen concentration, Impact and recovery of Macrobenthos.
7	Sodium Chloride	Tributary Nant Dowlais	4	65		April 1990	Surface and interstitial	None.
8	Increased Sulphide	Tributary Nant Dowlais	24	5		May 1990	Surface and interstitial	Macroinvertebrate drift, Precopula G.pulex, Mortality G.pulex, Impact on Macrobenthos.

* Unionised

Table F2 - Spectrum of sensitivities of caged fish and invertebrates exposed during episodes 1 and 2.

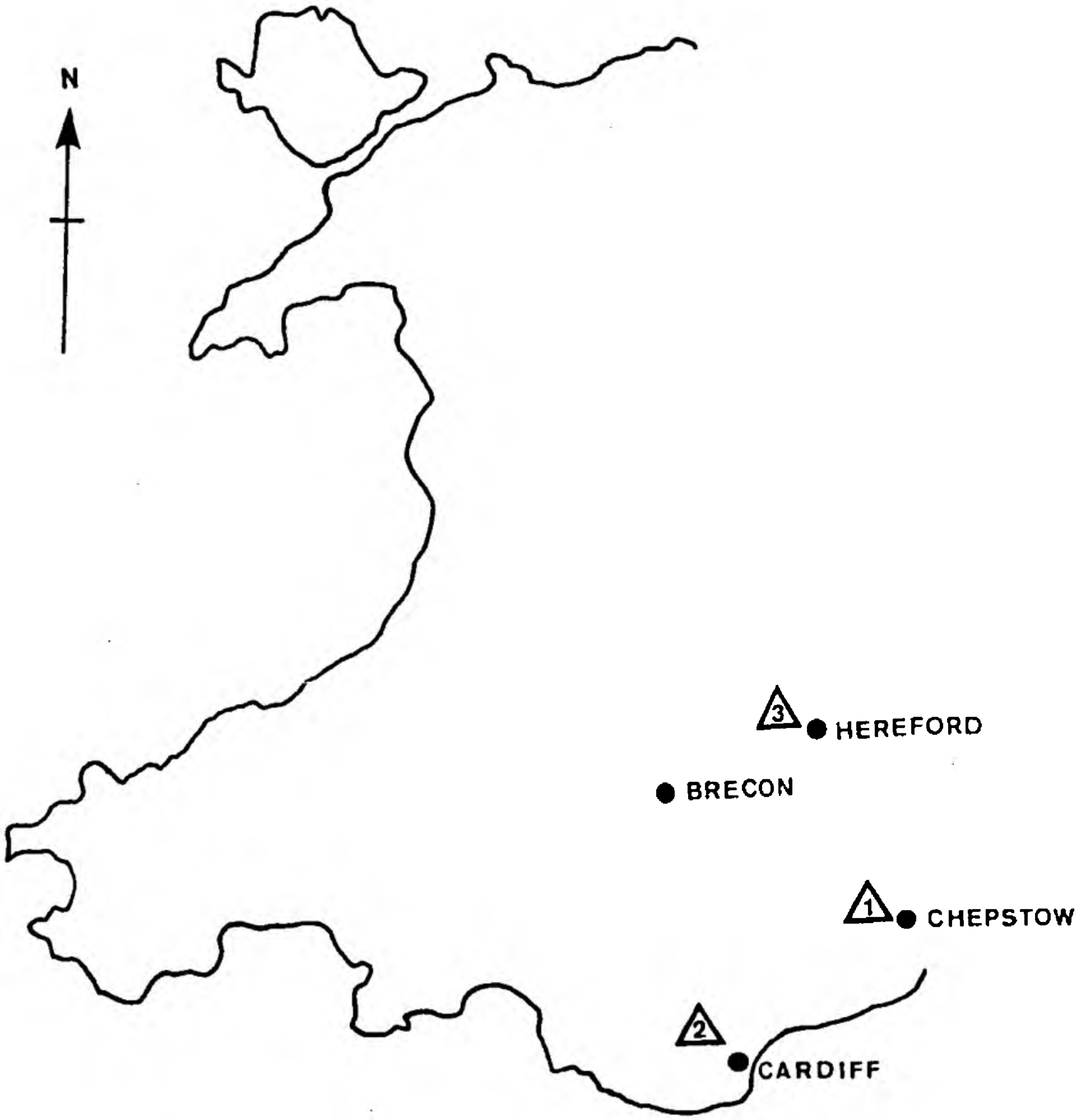
Episode 1: Oxygen		Episode 2: Ammonia	
Fish			
0+ *Salmo trutta*	**I** ^	0+ *Salmo trutta*	
1+ *Salmo salar*	**N**	0+ *Salmo salar*	
Cottus gobio	**C**	*Neomacheilus barbatulus*	
Neomacheilus barbatulus	**R**	*Cottus gobio*	
	E	*Gasterosteus aculeatus* (parasitised with *Hydrodactylus* sp.)	
	A		
	S	*Gasterosteus aculeatus* (unparasited)	
	I	*Cyprinus carpio*	
	N		
	G		
Invertebrates			
	S		
Dinocras cephalotes	**E**	*Polycelis tenuis*	**
Gammarus pulex	**N**	*Gammarus pulex*	**
(parasitised with	**S**		
Pomphorhnychus laevis)	**I**	*Physa fontinalis*	**
*Chironomus riparius***	**T**	*Ephemera danica*	**
Rhyacophila dorsalis	**I**	*Dinocras cephalotes*	**
*Gammarus pulex**	**V**	*Chironomus riparius*	**
(unparasitised)	**I**		
*Asellus aquaticus**	**T**	*Hydropsyche angustipennis*	**
*Chironomus riparius***	**Y**	*Asellus aquaticus*	**

* no difference in sensitivity
** no mortalities

Table F3 - Relative importance of biological recovery mechanisms.

GROUP	NUMERICAL ORDER OF PATHWAYS
G. pulex	DS > S > U
Ephemeroptera	DS > S > U > Ae
Plecoptera	DS > S > U > Ae
Chironomidae	DS // S // U // Ae
Simuliidae	DS > S*
All groups	DS > S > U > Ae

* = No other mechanisms involved
DS = downstream
S = within substrate
U = upstream
Ae = aerial
// = not significant
\> = significantly greater than ($p < 0.05$), two sample t test



1. Mounton Brook.

2. Nant Dowlais.

3. Yazor Brook.

Figure F1. Site locations.

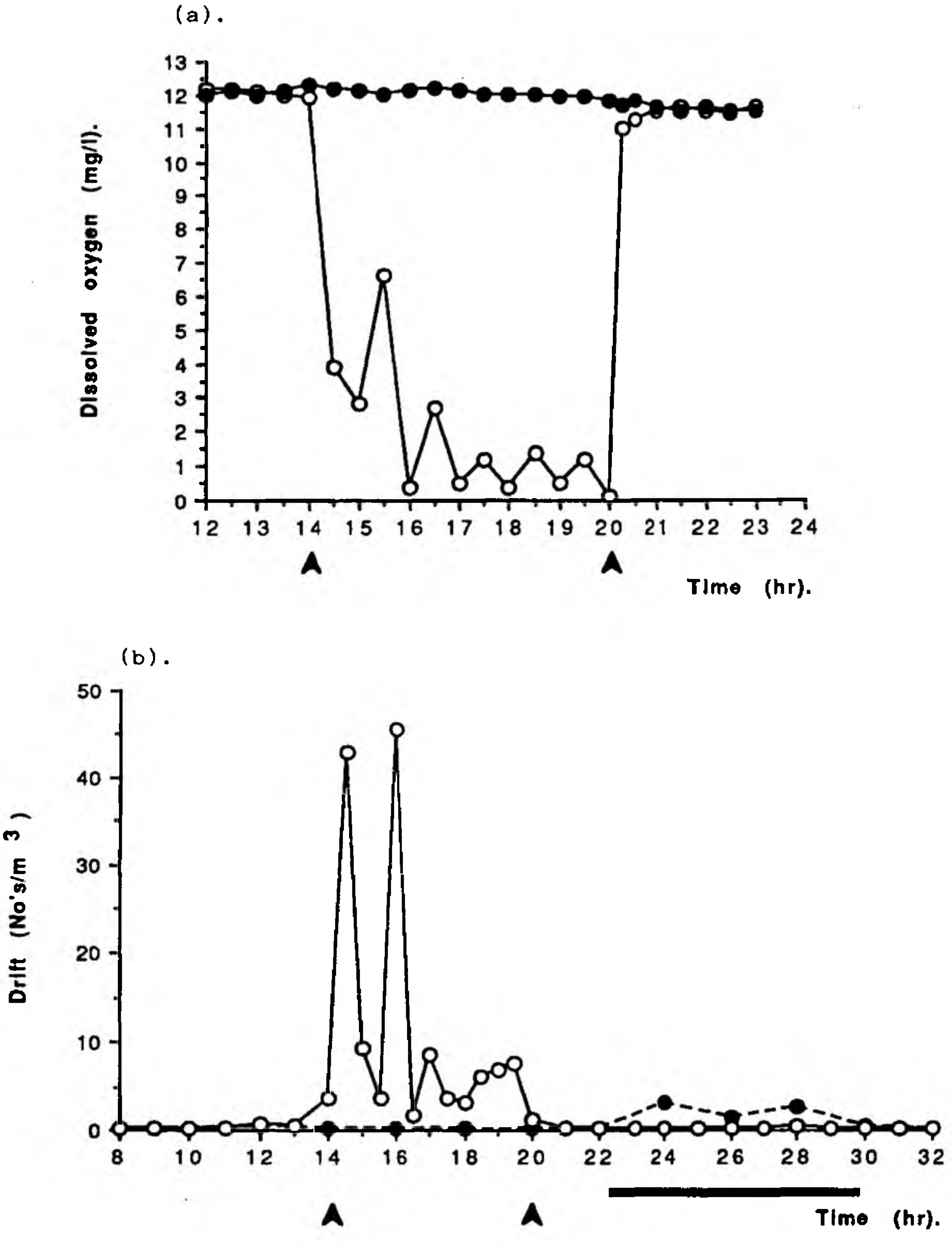


Figure F2. Dissolved oxygen regimes during episode 1 (a) and drift response (b) in reference (●) and treatment (O) zones.

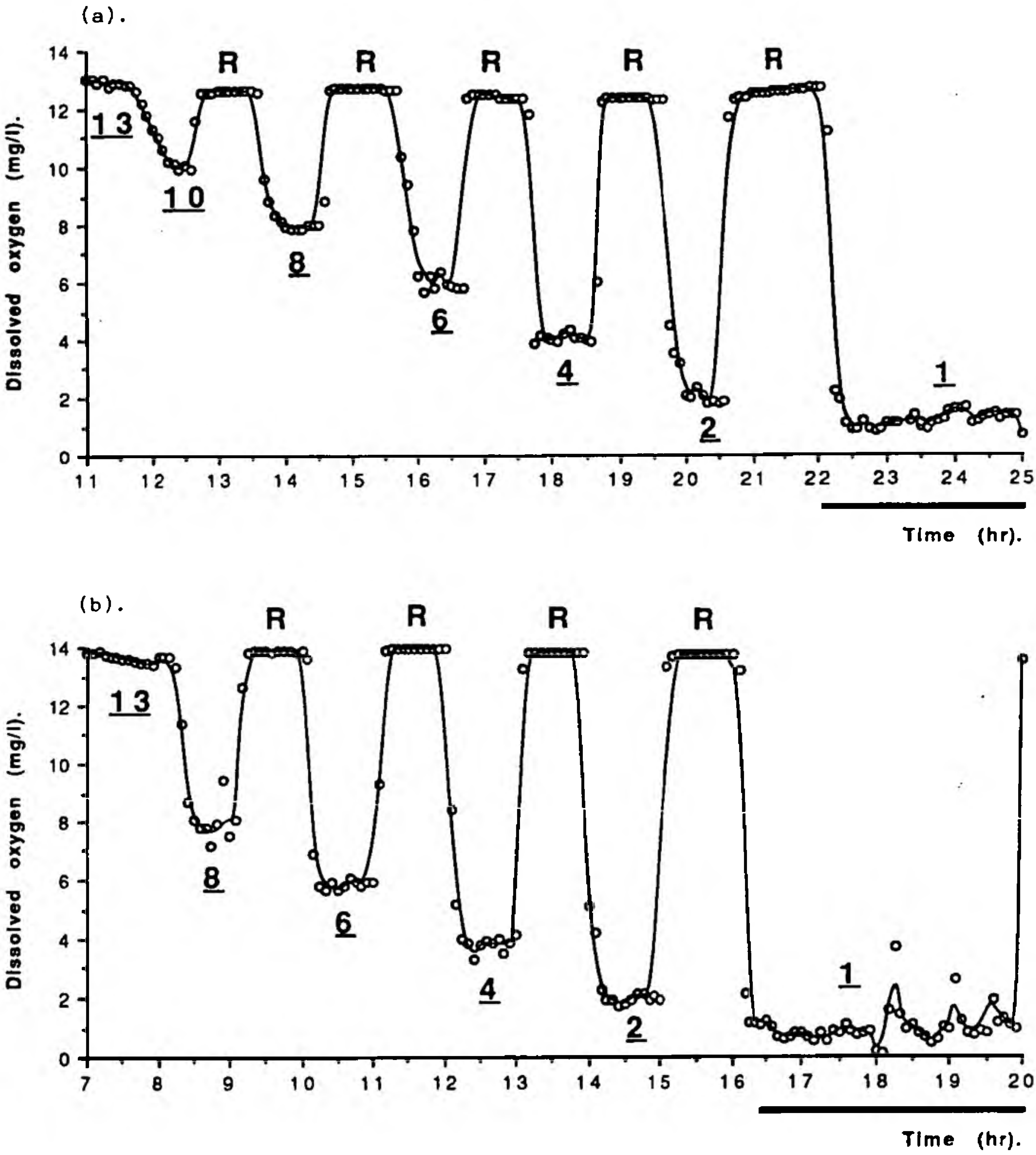


Figure F3. Dissolved oxygen regimes during episode 4 (a; July) and episode 6 (b; November). Underlined figures refer to nominal oxygen concentrations and R=recovery period.

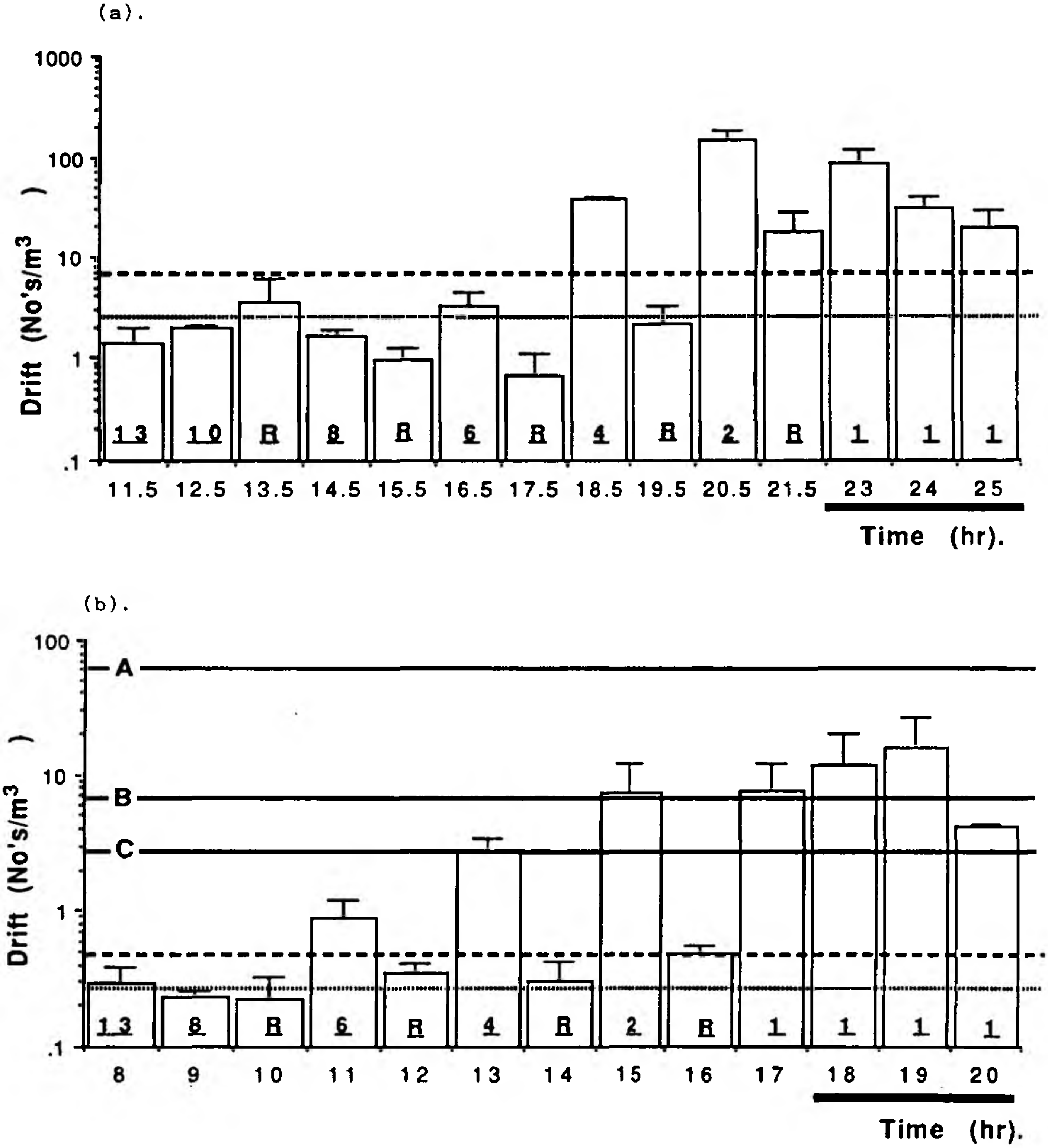


Figure F4. Invertebrate drift response to stepwise reductions in dissolved oxygen in July (a) and November (b) showing mean background drift (......) and mean + 3sd*(— —). Fig.4b also gives the July drift density at 4mg/l.D.O. (—A—) and the July mean background density with mean + 3sd (—C— and —B—).

*Note: 3sd= three standard deviations (equivalent to probabilty of 0.001 that deviation from background is by chance).

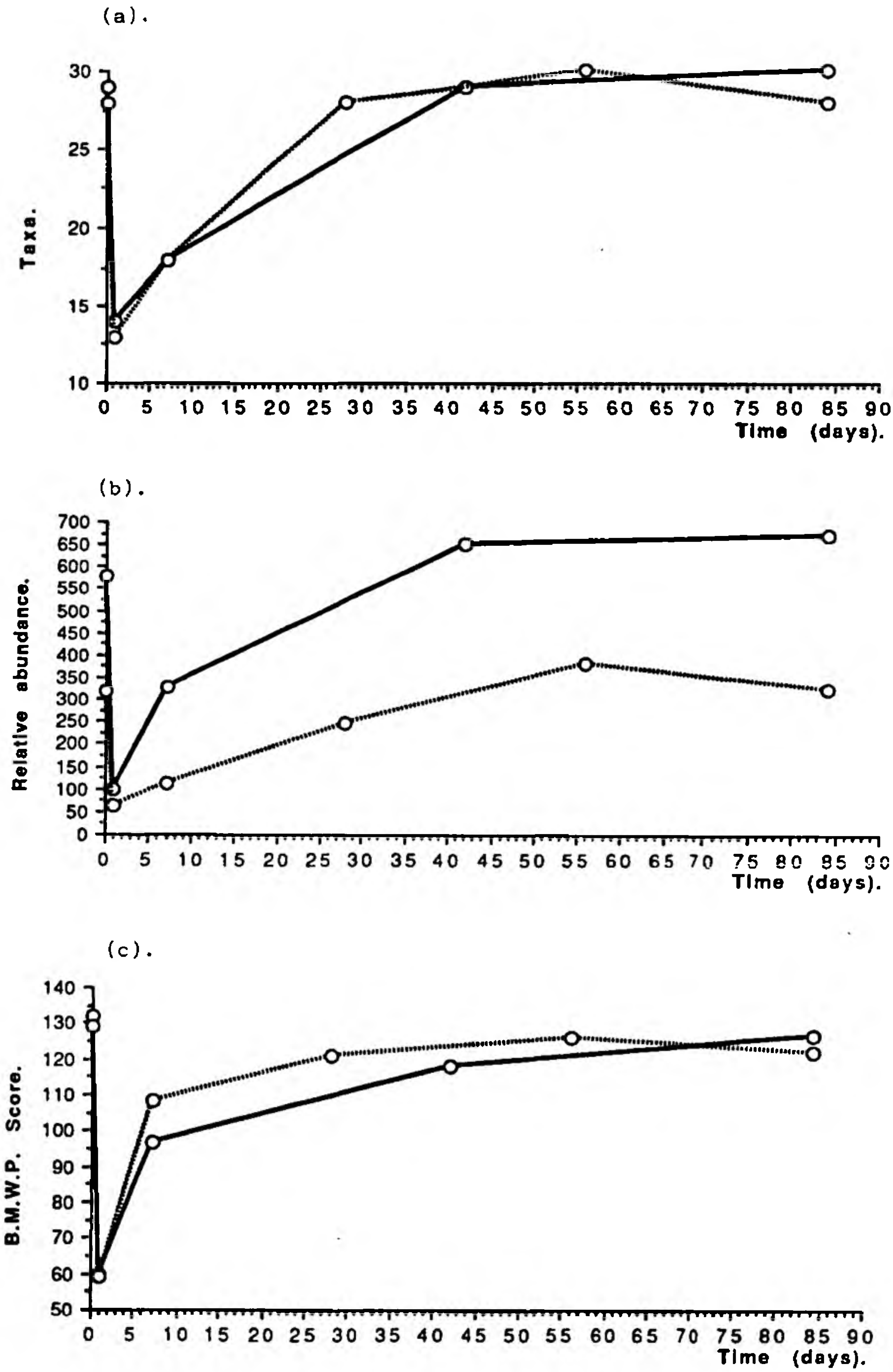


Figure F5. Recovery of taxa (a), abundance (b) and biotic score (c) at the Mounton Brook, July 1988 (—O—) and 1989 (··O··) Episodes 1 and 4, respectively.

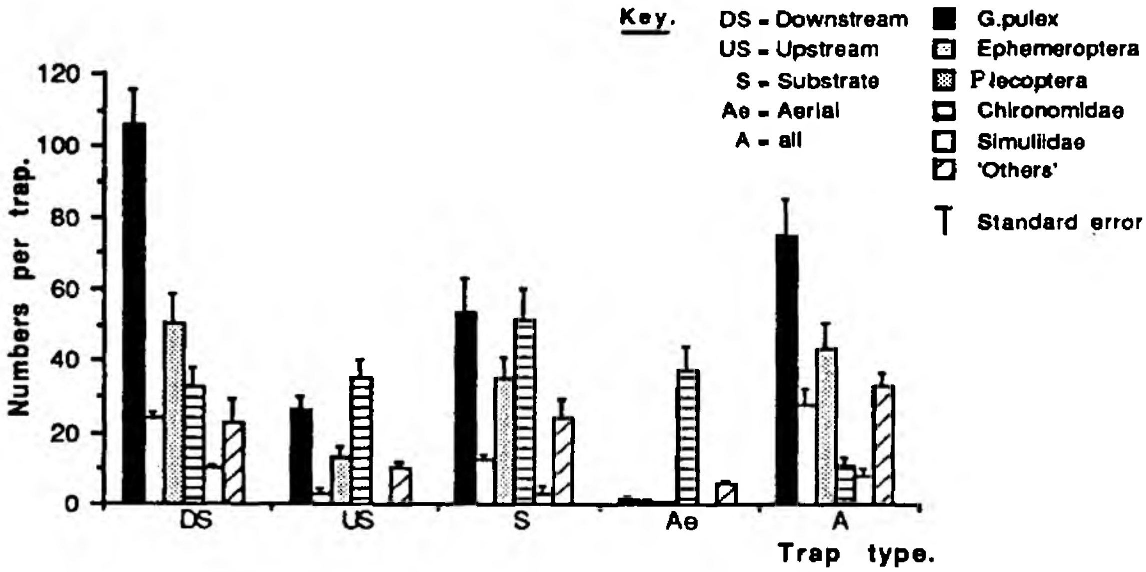


Figure F6. Relative importance of recovery mechanisms/pathways for major groups of invertebrates.

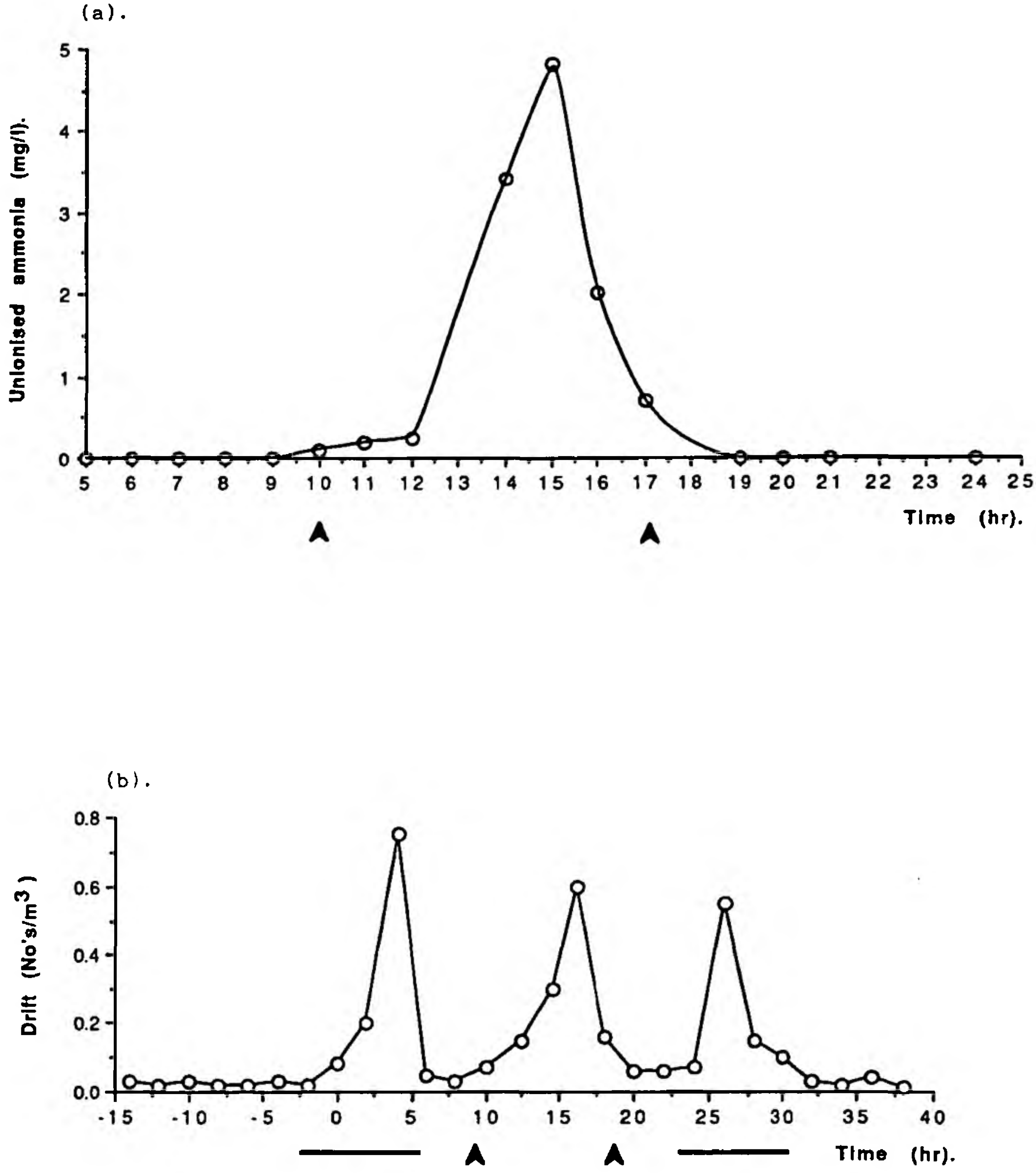


Figure F7. Simulation of an attenuated pulse of unionised ammonia (a) and drift response (b).

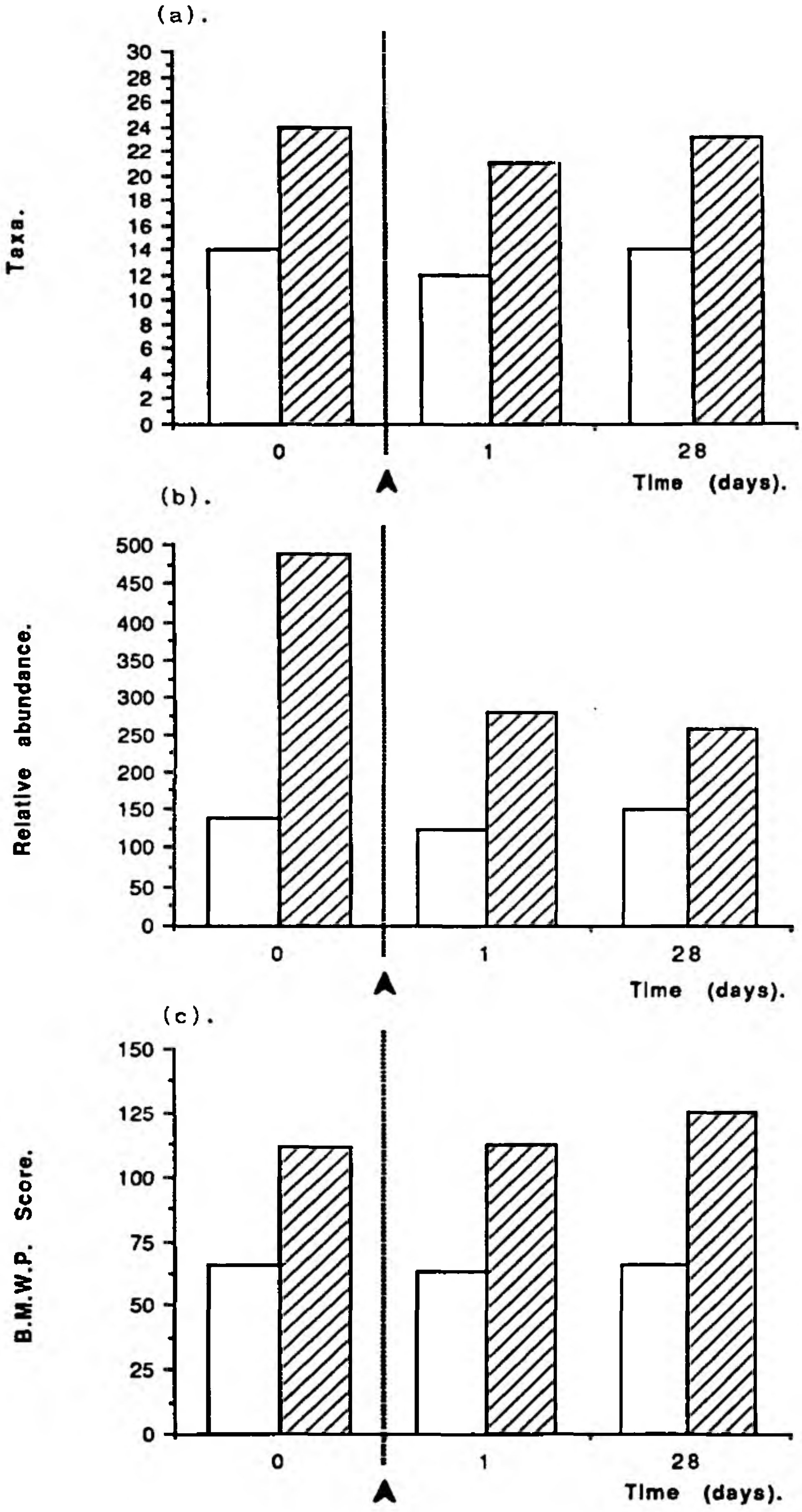


Figure F8. Impact of ammonia episodes upon benthic invertebrates, Nant Dowlais 1988 (□) and 1989 (▨). ▲ denotes the episode.

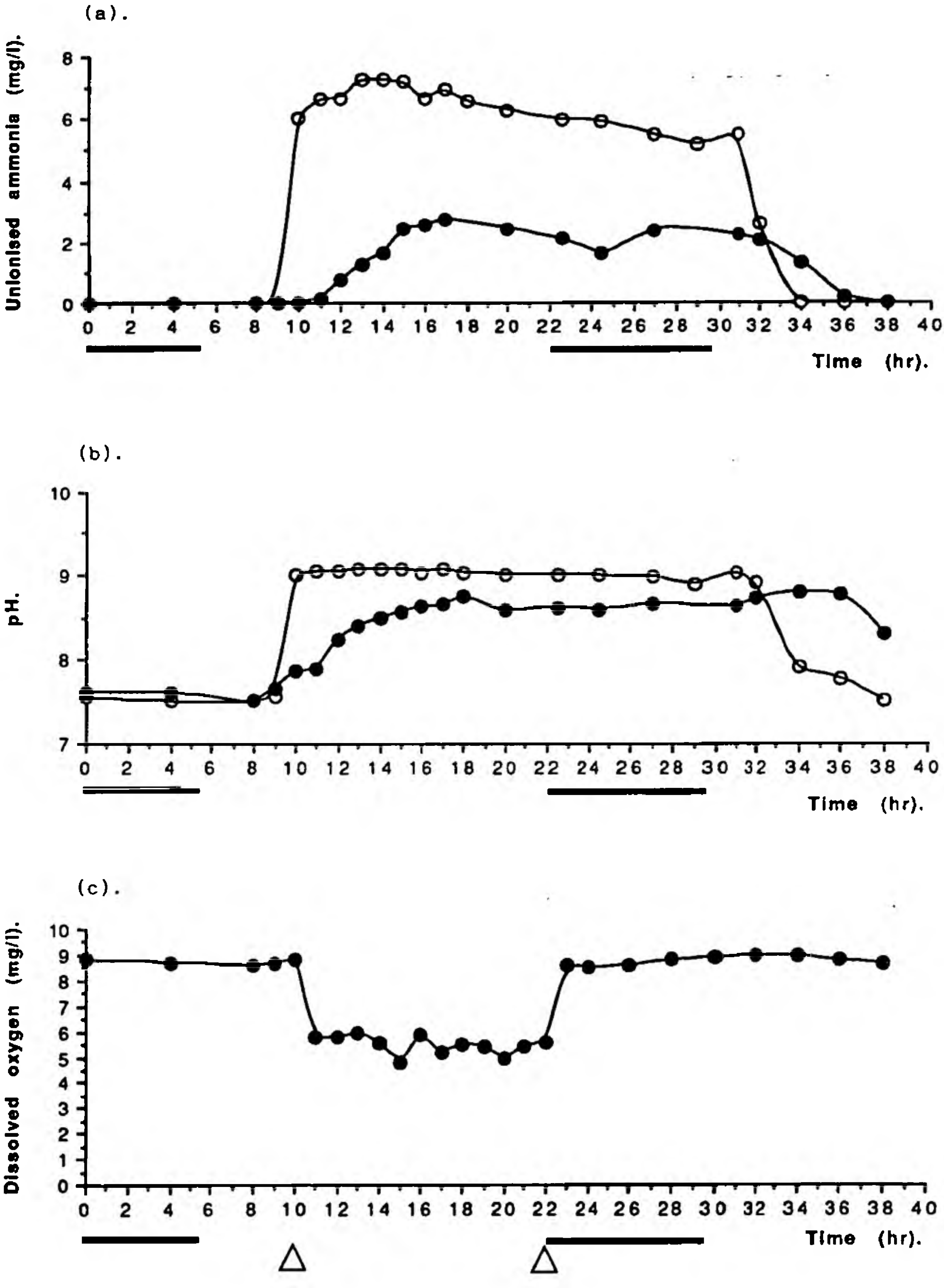


Figure F9. Unionised ammonia (a), pH (b) and dissolved oxygen (c) in the first treatment zone (O) and second treatment zone (●).

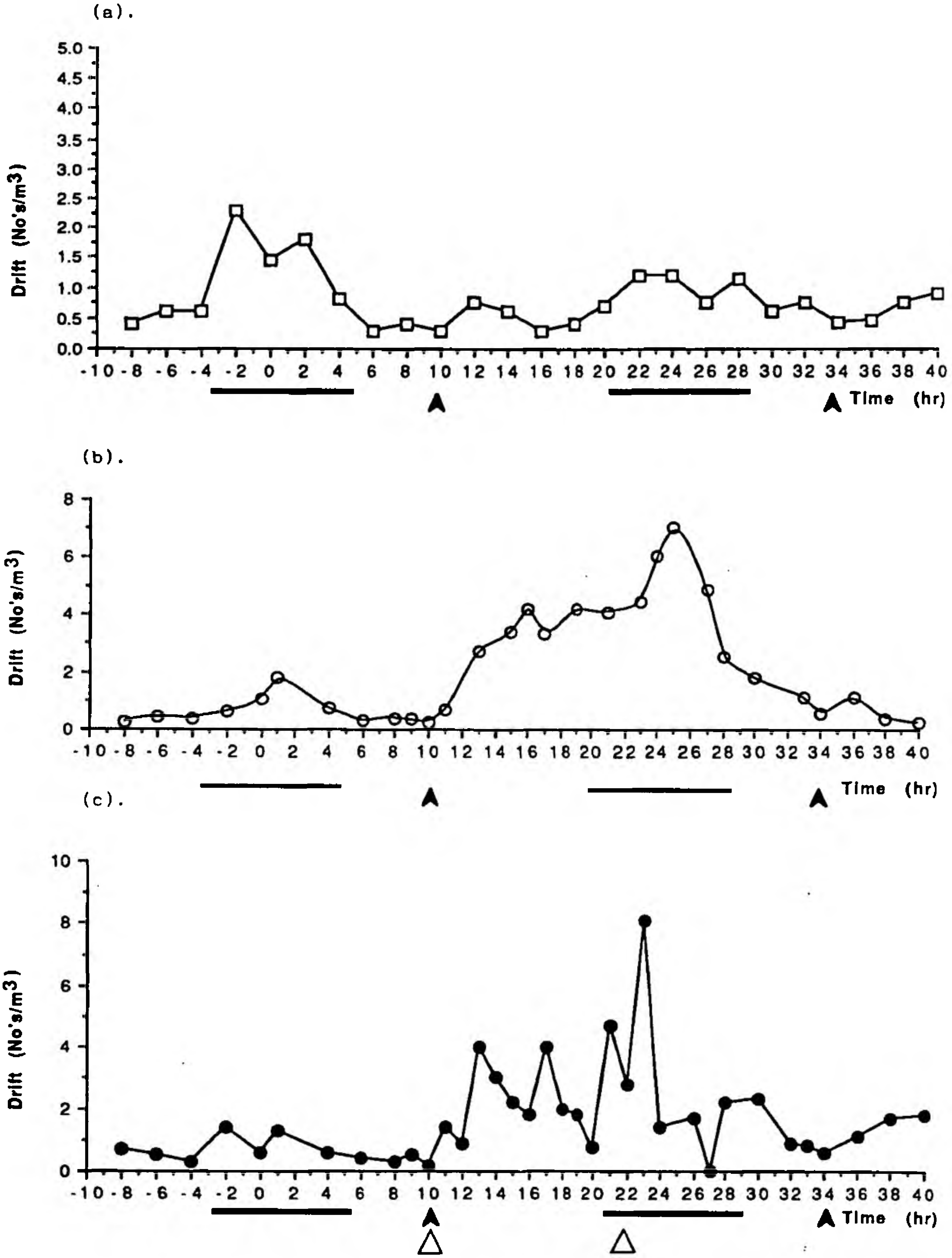


Figure F10. Invertebrate drift response during episode 5 in the reference (□) 1st treatment (O) and second treatment (●) zones. △ △ denotes duration of reduced D.O.

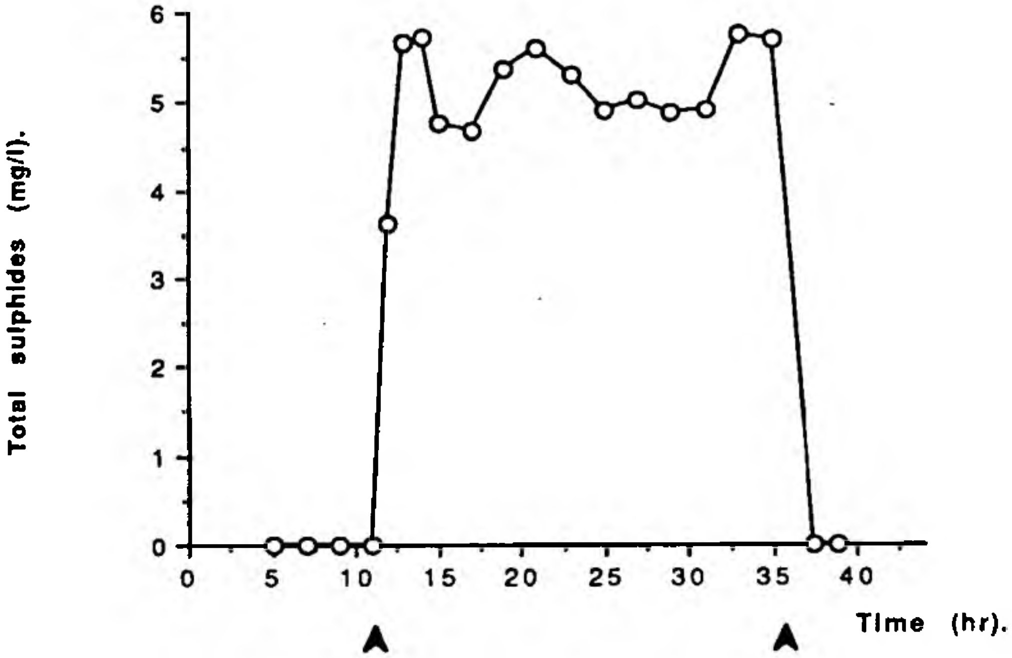


Figure F11. Surface water concentrations of total sulphides in the 1st treatment zone, episode 8, Tributary Nant Dowlais.

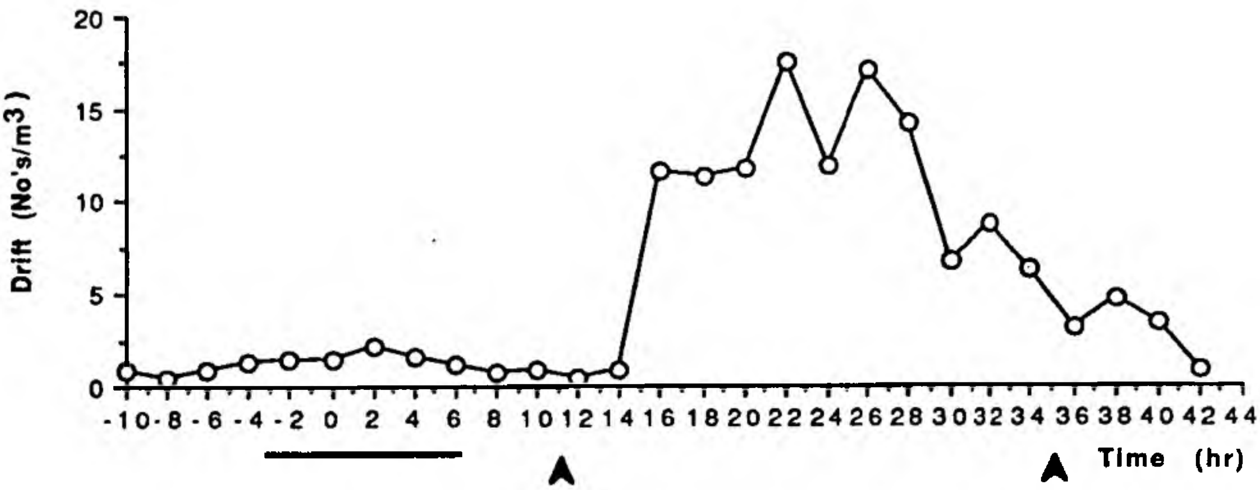


Figure F12. Drift response to increased sulphides.

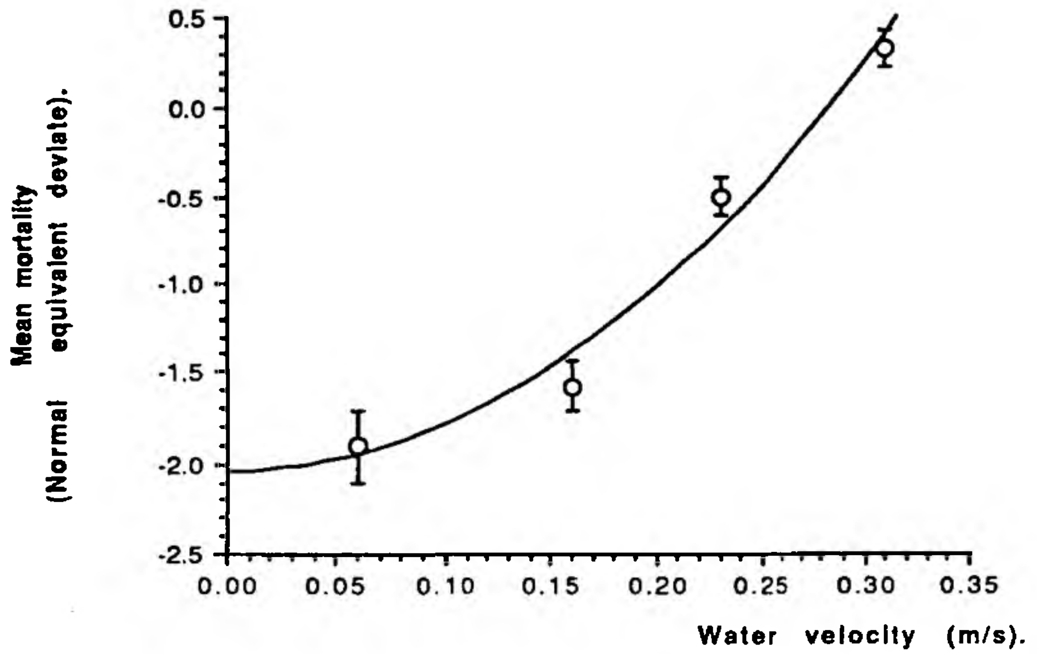


Figure F13. . Mortality response of G.pulex to sulphides in relation to water velocity ($r^2 = 0.974$; $p<0.001$). I = least significant differences between means of transformed (normal equivalent deviate) mortality curves (ANCOVA, Sokal and Rholf, 1981).

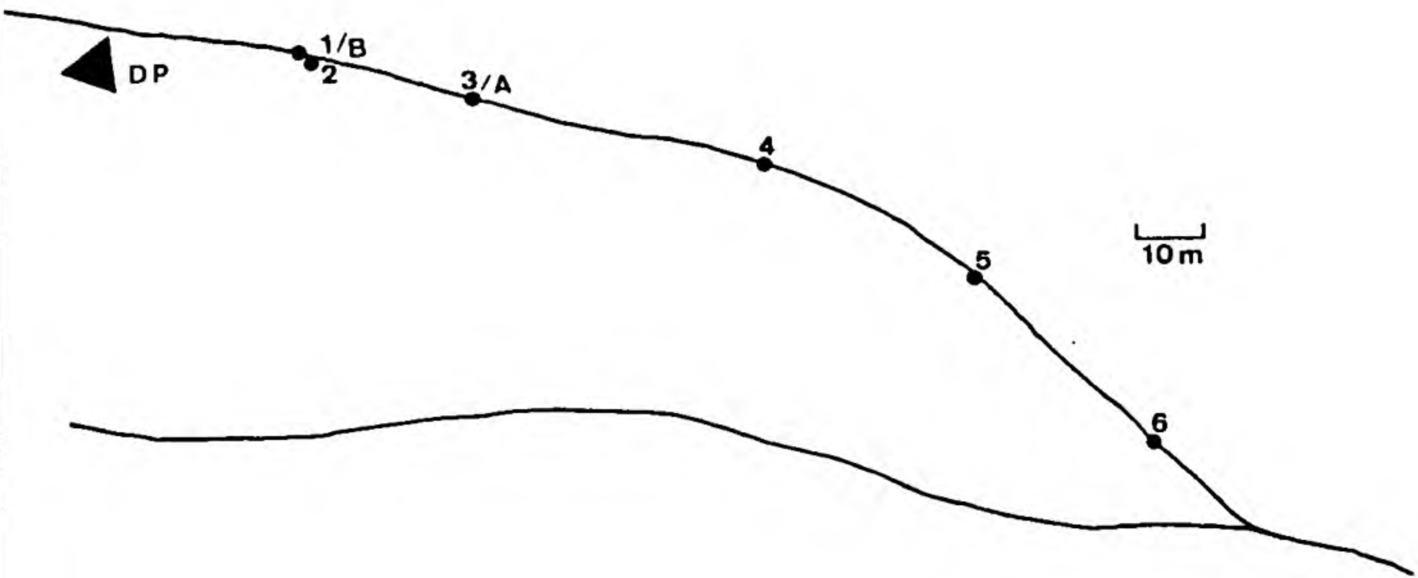
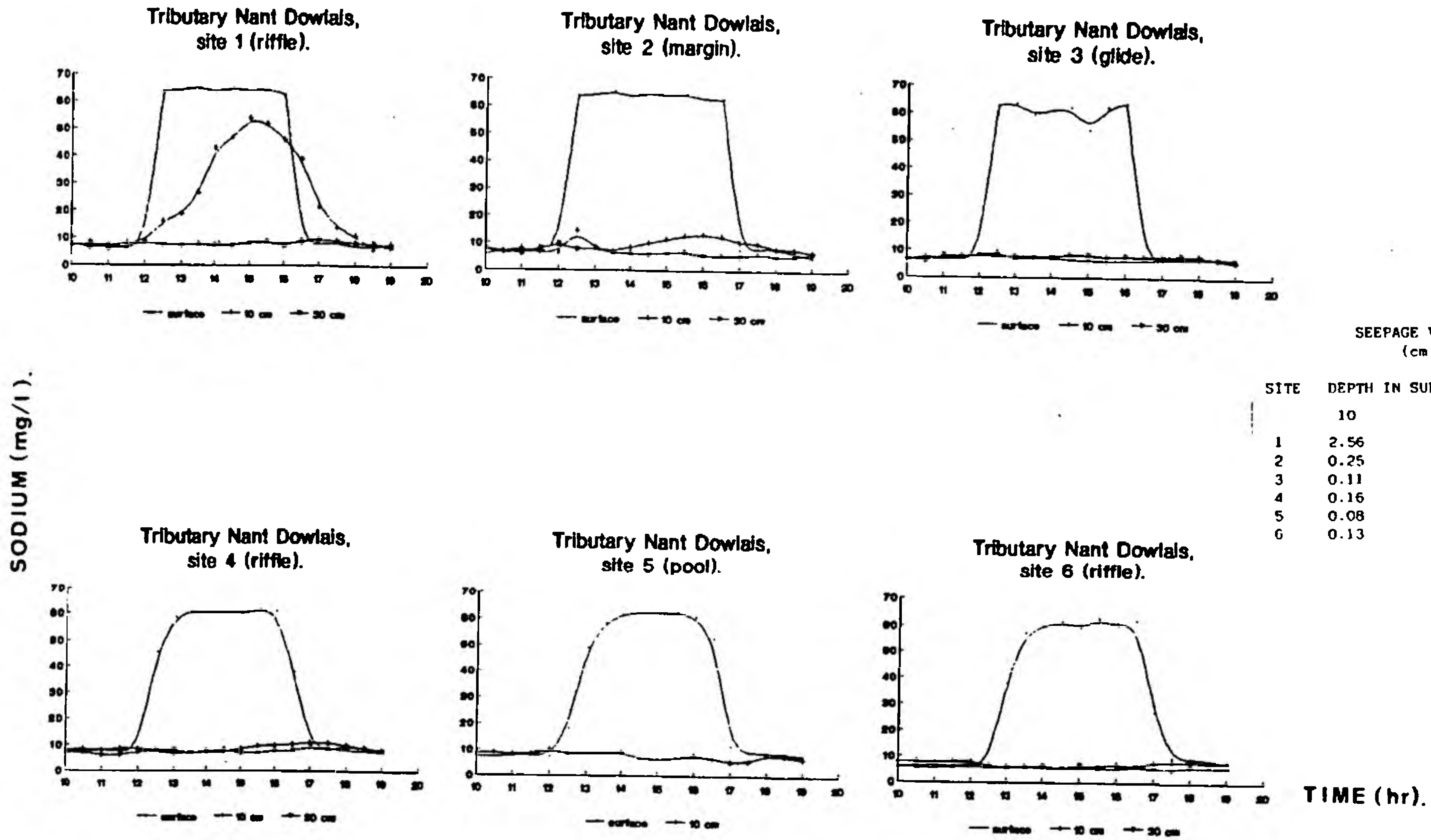


Figure F14. Locations of sampling points for attenuation studies, Tributary Nant Dowlais. Sites 1-6 refer to sodium tracer experiment, A to episode 5 (ammonia) and B to episode 8 (sulphide). DP= dosing point.



SEEPAGE VELOCITIES ($cm.hr^{-1}$).

SITE	DEPTH IN SUBSTRATE (cm). 10	30
1	2.56	0.22
2	0.25	0.11
3	0.11	0.07
4	0.16	0.04
5	0.08	0.001
6	0.13	0.09

Figure F15. Sodium time-concentration profiles during the sodium chloride tracer experiment.

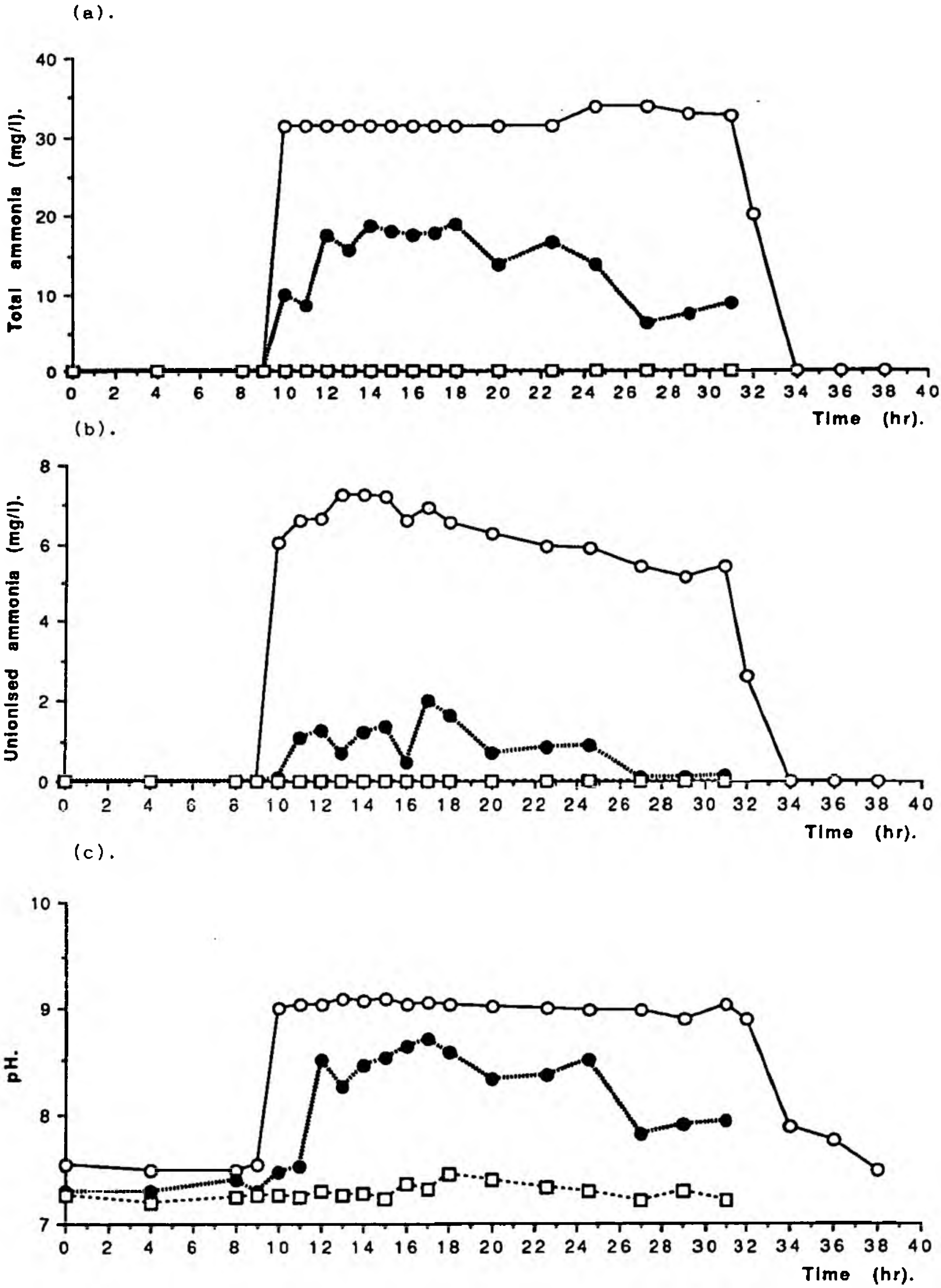


Figure F16. Total ammonia (a), unionised ammonia (b) and pH (c) in surface (○) and interstitial water; 10cm= ● ,30cm= □ .

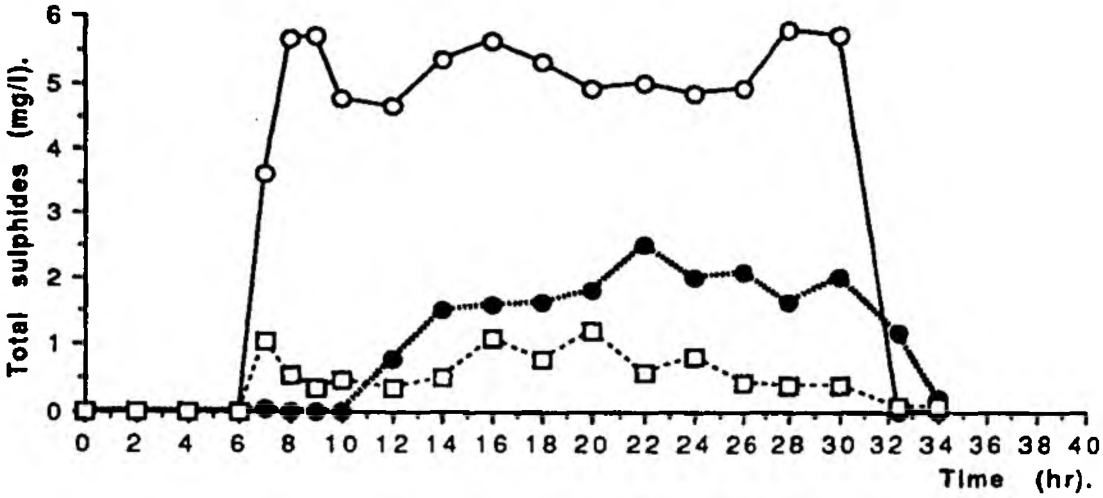


Figure F17. Attenuation of total sulphides during episode 8; surface water (O), 10cm= ● ,30cm= □ .

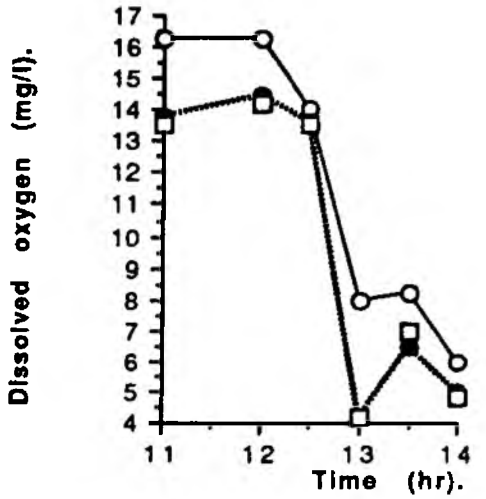


Figure F18 Penetration of reduced dissolved oxygen into the bed of the Yazor Brook (episode 3). Surface water (–O–) ; 10 and 30cm (●·······□).

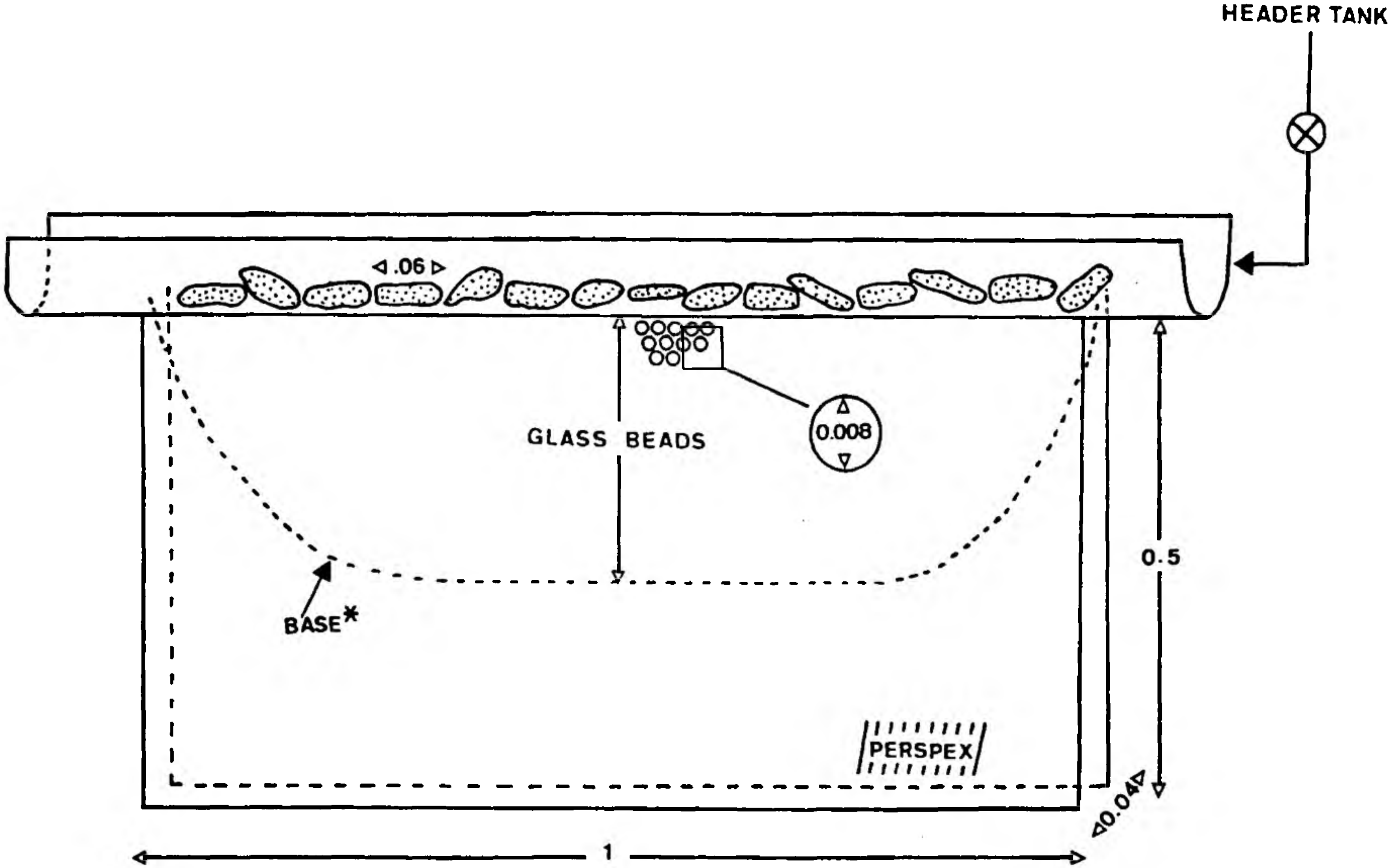
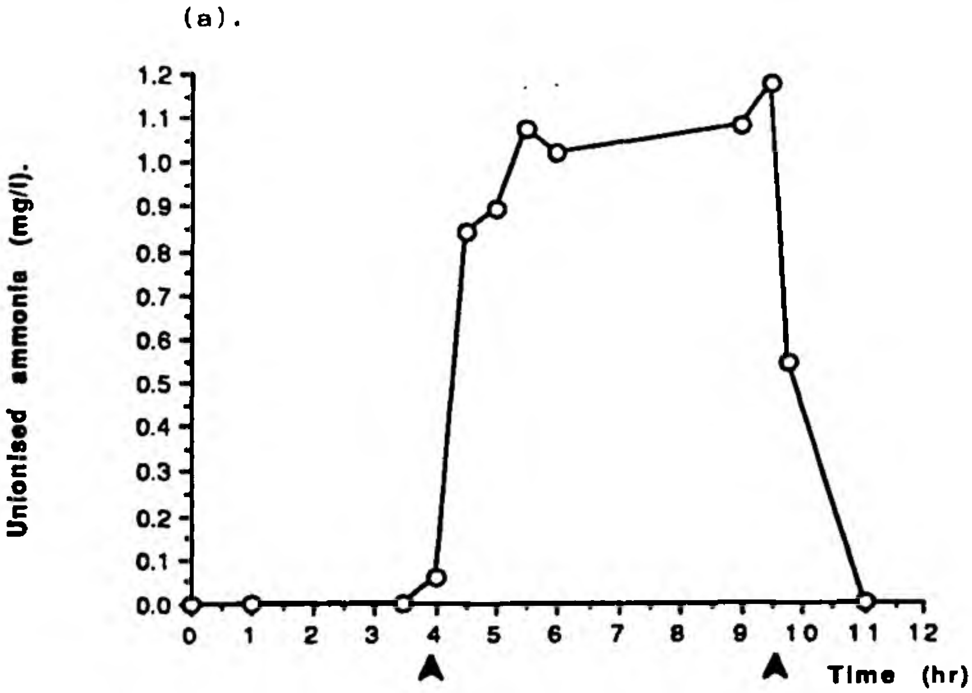


Figure F19. Artificial stream section for investigating vertical migration. Dimensions are indicated in metres. *Base is a plastic divider which supports beads and separates perspex sheets. The whole structure is suppprted in a steel frame.



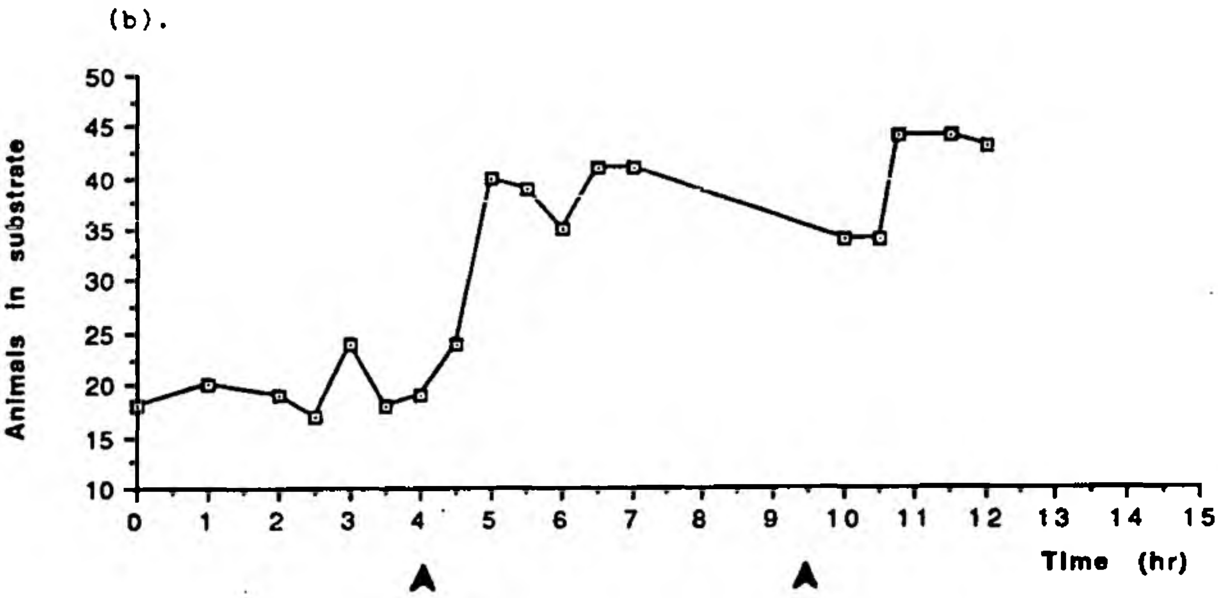


Figure F20. Simulated episode of ammonia (a) and downward vertical migrational response of G.pulex (b).