Development of a Design Manual for Agricultural Pesticide Handling and Washdown Areas

R&D Technical Report P2-200/TR/2

S. Rose, B. Basford and A. Carter

Research Contractors:
ADAS Consulting Ltd

Publishing Organisation
Environment Agency, Rio House, Waterside Drive, Aztec West, Almondsbury,
BRISTOL, BS32 4UD
Tel: 01454 624400 Fax: 01454 624409
Website: www.environment-agency.gov.uk

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This report will ensure that Agency staff, external organisations and farmers are better informed about the potential point source pollution risk of pesticide handling and washdown areas and the options for their design, including the use of biobeds. The report provides underpinning information for Policy and Process staff involved in developing water quality, land quality and pesticides policies and guidance. Operational staff will benefit from an improved understanding of the issues of pesticide handling/washdown, the risks to surface and groundwater and the ways that farmers can improve their practice. Due to scientific and regulatory uncertainties this project has not produced a design manual for pesticide handling/washdown areas. Design concepts are provided in the Project Record (P2-200/PR) and it is anticipated that the pesticide industry will utilise this information to produce guidance for farmers in the future.

Keywords:
Point source pollution, pesticides, pesticide handling and washdown areas, bioremediation systems, biobeds.

Research Contractor:
Steve Rose, Bill Basford & Andrée Carter, ADAS Consulting Ltd
Contact: Andrée Carter, ADAS Gleadthorpe, Meden Vale, Mansfield, Notts NG20 9PF
Tel: 01623 844331, Fax: 01623 847424, Email: andree.carter@adas.co.uk

Environment Agency's Project Manager:
The Environment Agency's Project Managers for R&D Project P2-200 were:
Alan Barnden and Alison Frogley, Kingfisher House, Goldhay Way, Orton Goldhay, Peterborough, PE2 5ZR

SNIFFER's Project Manager:
SNIFFER's Project Manager for R&D Project SR(02)34 was:
Rob Morris, SEPA Corporate Office, Erskine Court, Stirling, FK9 4TR

Further copies of this report can be obtained from the Environment Agency's National Customer Contact Centre by emailing enquiries@environment-agency.gov.uk or by telephoning 08708 506506.

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EXECUTIVE SUMMARY

Water resources in the UK are at risk of both point and diffuse source contamination from agricultural pesticides. Point source contamination of surface water by pesticides within agricultural catchments can be significant and has been shown to account for up to about 70% of the pesticide load leaving a catchment. As part of their pollution prevention activities, the Environment Agency for England and Wales, Scottish Environment Protection Agency and Environment and Heritage Service in Northern Ireland and the Department for Environment, Food and Rural Affairs, are seeking to reduce the risk of pesticide pollution from point sources. One major source of potential contamination is the farmyard where activities involved in handling pesticides, filling sprayer equipment and washing down the sprayer equipment after applications take place. A number of UK and European studies have determined that the characteristics of the farmyard surface and its drainage can significantly influence the rate at which any spilt pesticide or sprayer washings reaches surface or groundwater.

There is a wide range of relevant EU and national legislation, codes of practice and advisory information currently available to spray operators concerning pesticide handling, mixing, washdown and waste disposal operations. However, the desk review undertaken within this project identified that the information given is often found to be confusing and open to interpretation, which could prove problematic to the regulatory agencies.

There are still many spray operators who are not fully aware of the environmental consequences of spillages and inappropriate disposal and washdown activities in the farmyard. The Voluntary Initiative (VI) led by the crop protection industry is helping to educate spray operators in the application of good practice principles in all aspects of their work to minimise the risk of environmental pollution. Further research was needed to investigate whether improvements could be made to the design, operation and management of pesticide handling and washdown areas.

The primary objective of this project was to develop practical and low-cost design criteria for pesticide handling and washdown areas in order to reduce pesticide pollution from point sources, based on an improved understanding of the risk from waste pesticides arising from agricultural activities.

Experimental tank studies were undertaken to ascertain pesticide losses in runoff and throughflow from eight different surfaces subjected to simulated pesticide point source pollution arising from farmyard pesticide handling and washdown activities. The simulated contamination sources were: dropped foil seals from pesticide packaging, leaky hoses/nozzles, sprayer sump rinsate and sprayer washdown liquid. A mixture of six pesticides with a range of physico-chemical properties was artificially applied, in appropriate concentrations and volumes, to represent each contamination source. The surfaces investigated were concrete, asphalt, hardcore, porous paving, soil/grass, biobed (comprising straw, loamy topsoil and peat-free compost), biobed with a carbonaceous additive (replacing peat-free compost component) and hardcore with a carbonaceous additive. The aim of these experiments was to gain some simple results which could be used for comparative purposes, and that a high degree of statistical confidence was therefore not required.

All the surfaces provided a substantial improvement on the pesticide losses measured from the concrete surface, which is still in widespread use on many farms. The biobed surface (without the carbonaceous additive) gave the best overall performance during these experiments, with a >99% reduction in total loss of pesticides when compared to the concrete surface, which concurs with other UK studies. For the soil/grass surface this reduction was slightly lower at 97%. These two bioremediation systems provided enhanced conditions for pesticide retention and/or degradation (especially microbial degradation) to take place. The addition of a carbonaceous material to the biobed and hardcore surfaces did not significantly change their level of performance.

The findings from the experimental tank work were used to develop the design specification for the construction of three full-scale pesticide handling and washdown areas with associated bioremediation systems on a large arable farming enterprise in Lincolnshire which ran spraying operations from three existing farmyards that were suitable for modifications and monitoring purposes. The three design options constructed were: a) concrete intercept area draining to a biobed; b) drive-over biobed; and c) concrete intercept draining to a biologically active soil and grass area. Point source pesticide contamination sources were artificially applied to each system, as in the experimental tank studies, to simulate multiple severe pollution incidents in the farmyard on one spray day.

Pesticide concentrations in excess of 100,000μg/l were measured in the liquid entering the bioremediation systems. All the bioremediation systems performed very effectively on-farm to retain and/or degrade the pesticides prior to discharge to the environment, via an authorised land disposal area. Pesticide concentrations in the discharge liquid from the systems were generally below 0.5μg/l and often below 0.1μg/l. 87% of over 1100 individual analytical determinations from the leachate discharged from the bioremediation systems had a pesticide concentration <0.5μg/l. There were some pesticide detections above 0.5μg/l but these should be viewed in the context of the input concentrations and the considerable opportunities for further dilution, retention and degradation that exist in the soil within the disposal area.

This project has provided good evidence that redesigned agricultural pesticide handling and washdown areas, linked to bioremediation systems, can minimise point source pollution of surface waters. Interception and bioremediation of spillages and contaminated water would also minimise the risk of infiltration and discharge to groundwaters compared to existing practices where no systems are in place.

All the information and data collected and obtained during each stage of this project were considered in preparing a document for the design of agricultural pesticide handling and washdown areas. However there are a number of scientific and regulatory uncertainties that are beyond the scope of this project and which are of sufficient importance to preclude the production of a design manual as an output from this project. The scientific issues are concerned with the residual risks to groundwater posed by bioremediation systems and to their long-term management and performance. The regulatory issues relate to new regulations including Agricultural Waste, Hazardous Waste and on Landfill that are likely to impact on the disposal of pesticide washings. These new legal provisions could have significant impacts on the costs associated with bioremediation systems and on how they may be controlled. The collated findings from the project on the design concepts for pesticide handling and washdown areas have been produced as an Appendix to the Project Record.

Despite the scientific and regulatory uncertainties, the Agencies recognise the potential of biobeds to reduce pesticide pollution of surface waters from pesticide handling areas. The Agencies will not be actively promoting the uptake of bioremediation systems on-farm but where there is a commitment to improve pesticide handling practices then proposals for biobeds will be considered on a case-by-case basis. The Agencies have produced interim guidance in order to advise their staff on the position regarding the use of biobeds on-farm. It is anticipated that the results of this project and the design concepts, whilst recognising the scientific and regulatory uncertainties, will be taken forward by the crop protection industry via the Voluntary Initiative.

CONTENTS

LIST OF TABLES

LIST OF FIGURES

1. INTRODUCTION

Groundwater and surface water is at risk of contamination from agricultural pesticides. In some cases this contamination is more likely to result from point sources than as a result of pesticide application to crops in the field (Carter, 2000). Such point sources include areas on farms where pesticides are handled, filled into sprayers, or where sprayers are washed down. As part of their pollution prevention activities, the Environment Agency for England and Wales, Scottish Environment Protection Agency (SEPA) and Environment and Heritage Service in Northern Ireland (EHSNI), (referred to jointly as the Agency or Agencies) and the Department for Environment, Food and Rural Affairs (Defra), are seeking to reduce the risk of pesticide pollution from point sources.

1.1 Aims and Objectives

The primary objective of this R&D project was "to develop practical and low-cost design criteria for pesticide handling and washdown areas in order to reduce pesticide pollution from point sources, based on an improved understanding of the risk from waste pesticides arising from agricultural activities."

The project was divided into five stages:
1) Initial desk studies – a review of the current practices and procedures of farmers in the UK, Europe, and other countries in handling pesticides, washing down equipment and subsequent handling of waste pesticide arising. This also included the identification and review of existing legislation and guidance.
2) Experimental surface studies – investigations were carried out on the fate of six pesticides (isoproturon, dimethoate, chlorothalonil, chlorpyrifos, pendimethalin and epoxiconazole), with a range of physico-chemical properties, following activities on different surfaces, including concrete, hard-core and a field surface. This identified the most suitable surfaces and provided a baseline against which the constructed design could be compared.
3) Design development – the results from the desk studies and on-farm assessments were used to develop designs for three full-scale pesticide handling and washdown area, linked to bioremediation systems. Two of these were based on a concrete handling area, as this is the most commonly found surface in the farmyard. The designs took into account pesticide disposal, cost effectiveness, practicality and health and safety.
4) Design trial - once the three full-scale designs were developed, each was constructed and investigations took place into their operation, management and pesticide reduction performance.
5) Design manual and report production – due to scientific and regulatory uncertainties a design manual for agricultural pesticide handling and washdown areas was not produced. Lessons learned throughout the project with respect to the design, construction, operation and management of these areas, linked to bioremediation systems, have been included as design concepts in an Appendix in the Project Record.

2. STAGE 1 – DESK STUDY REVIEW

2.1 Background

Stage 1 of the project reviewed existing UK farmer/spray operator practices on agricultural pesticide handling and washdown areas, relevant EU and UK regulations/ Codes of Practice, and associated research studies in the UK and abroad. This review has been published in the Environment Agency R&D Technical Report P2-200/TR/1.

2.2 Information available to pesticide users

There is a range of relevant EU and national legislation, codes of practice and advisory information currently available to farm managers and pesticide users concerning the pesticide handling, and disposal of associated washings and other materials.

The variety of requirements, information and advice provided was found to be confusing and is difficult to assimilate given the different and sometimes conflicting statements. There are a number of anomalies, and impractical or expensive solutions for which there is no guarantee of acceptance by the regulatory agencies.

2.3 Farm Practice

Surveys of typical farm practice concerning the handling, use and disposal of pesticides identified that current farmyard characteristics and practice vary considerably. Many spray operators are not aware of the environmental problems which might arise when pesticide is spilt or incorrectly disposed of in a farmyard, nor the potential consequences of washing down spray equipment. Spillages, overflows and yard washing are identified as typical sources of contamination in all of the studies. The potential for point source contamination of water is large and a number of survey responses suggest that there are common issues which are relevant to point sources of contamination; these include:

- there is restricted awareness of the environmental impact of point source losses and the need for individuals to address the problem;
- yard spray activities are mainly carried out on impermeable surfaces which are usually drained to a sump which then drains to surface water or a soakaway;
- few farmers have a spill contingency plan;
- few farmers have contracts with licensed disposal contractors;
- a number cite tank overfilling as a common source of spillage;
- many farmers washdown their spray vehicles in the farmyard;
- there is no clear advice for disposal of containers and packaging or spill clean up material; and
- concern that advice changes and is not proven, implementation may be expensive and there is no current justification or benefit to comply.

Recent campaigns, particularly the Voluntary Initiative, will help to educate spray operators on good practice so that the farmyard drainage poses less of a risk to the environment.

2.4 Catchment Monitoring

Reviews of monitoring projects in the UK and other countries have identified that point sources of pesticides can be responsible for a significant portion of the total amount of pesticide loading in water and can account for the peak concentrations detected. The ranges reported vary from at least 20% of the total load in a surface water catchment but could be as high as 70% depending on catchment characteristics (Mason *et al*, 1999; Bach, 1999; Kreuger, 1998). The farmyard characteristics, operating practices and local conditions vary but all researchers report similar reasons for the origin of the point source contamination (i.e. dropped foil seals when opening pesticide packaging, leaky sprayer nozzles/hoses, splashes/drips when filling sprayer with pesticide, disposal of sump rinsate, disposal of external sprayer washings).

2.5 Possible Solutions

A range of solutions and initiatives have been developed, or research is still taking place, to minimise point source pollution or treat waste which arises from the spraying operations. The systems investigated, such as the Sentinel and biobeds (Fogg *et al*, 2000), have been shown to significantly reduce pesticide concentrations but there does not appear to be clear advice on what is considered to be acceptable with regard to the concentrations of pesticide which can be discharged from these systems to the environment. The various relevant water or registration directives do not specify a *de minimis* and in the absence of data to prove no impact, the Drinking Water standard of 0.1μg/l is applied as a surrogate. None of the systems discussed can provide evidence for compliance and there is therefore concern from pesticide users that investment to reduce point source concentrations from washdown areas may still not be sufficient to obtain Agency approval.

Some of the technologies which have been developed elsewhere, such as sustainable urban drainage and porous pavements may have the potential to be applicable to the farmyard situation, but their pesticide removal performance requires further investigation. The concept of on-farm integrated waste management is attractive and would appeal to farmers who face a multitude of requirements concerning the different wastes which are generated by their activities.

2.6 Conclusions

The review emphasised the need for clear, pragmatic advice to spray operators concerning the handling and disposal of pesticides and the associated wastes. The desk review identified that there was insufficient information available in the literature on the losses of pesticides from different surfaces. There is no doubt that point source contamination of surface or ground waters can be important and any measures to reduce losses could make a significant difference. Awareness of the importance of point sources and training in good practice are clearly a priority area. Pending the results of the experimental components of the project the review made recommendations for interim improvements to current yard practice, namely:

- only tank mix in an area where spills are contained such that they cannot enter a water course or groundwater;

- wash down spray equipment in the field;
- apply internal tank washings to the treated crop in accordance with label recommendations;
- be prepared for accidental spillages and the actions required to prevent pollution;
- take care not to create minor spills through glugging or dropping of seals;
- rinse empty containers thoroughly, adding rinsate to the tank mix and store upright;
- incinerate containers and packaging as soon as possible after use (legal position being reviewed);
- sweep the yard if contaminated mud is deposited and return to the treated field; and
- store the sprayer under cover when not in use.

3. STAGE 2 – EXPERIMENTAL SURFACE STUDIES

3.1 Background

In Stage 2 experimental assessments were conducted on the fate of pesticides, with varying physico-chemical properties, following simulated pesticide handling and washdown operations on eight different test surfaces, namely:

- concrete;
- asphalt;
- hardcore;
- porous paving;
- soil/grass;
- biobed (mixture of straw, loamy topsoil and peat-free compost);
- biobed with a carbonaceous additive (replacing peat-free compost); and
- hardcore with a carbonaceous additive.

The objective of this stage of the project was to compare how much of the pesticide was lost via runoff and throughflow from the different test surfaces studied. This enabled the suitability of different surfaces for pesticide handling and washdown areas to be determined.

The aim of these experiments was to obtain data which could be used for comparative purposes, and that a high degree of statistical confidence was therefore not required.

3.2 Methodology

During summer 2000 eight fibreglass tanks, 1.92m long by 0.91m wide by 0.61m deep were installed below ground level at HRI Wellesbourne (Figure 3.1). The tanks were laid onto a bed of sand and tilted to give a slope of 1.5% towards the front end. Along the front edge of the tanks a 10m long by 1.5m wide x 1.5m deep instrument pit was dug and lined with wood. The floor of the instrument pit was covered with gravel. Once all the tanks and the wooden liner for the pit were in place soil was backfilled in around the tanks to ensure that a good contact was made between the tanks and surrounding soil. Each tank had a perforated drainage pipe installed running diagonally across its bottom. A hole was cut at the bottom front end of the tank to allow the pipe to carry water from the bottom of the tanks into a removable glass leachate collector. This container was housed in a much larger plastic tank to enable the collection of any overflow. For each tank a thin layer of pea shingle was laid in the bottom of the tank to cover the drainage pipe. This permitted all the water that infiltrated through the overlying layers to drain out of the tanks and become available for sampling. A layer of geotextile covered the pea shingle to prevent the in-wash of fine particles. The two surfaces likely to produce surface runoff (i.e. concrete and asphalt) also had the facility to monitor the rate of runoff and sample the runoff water.

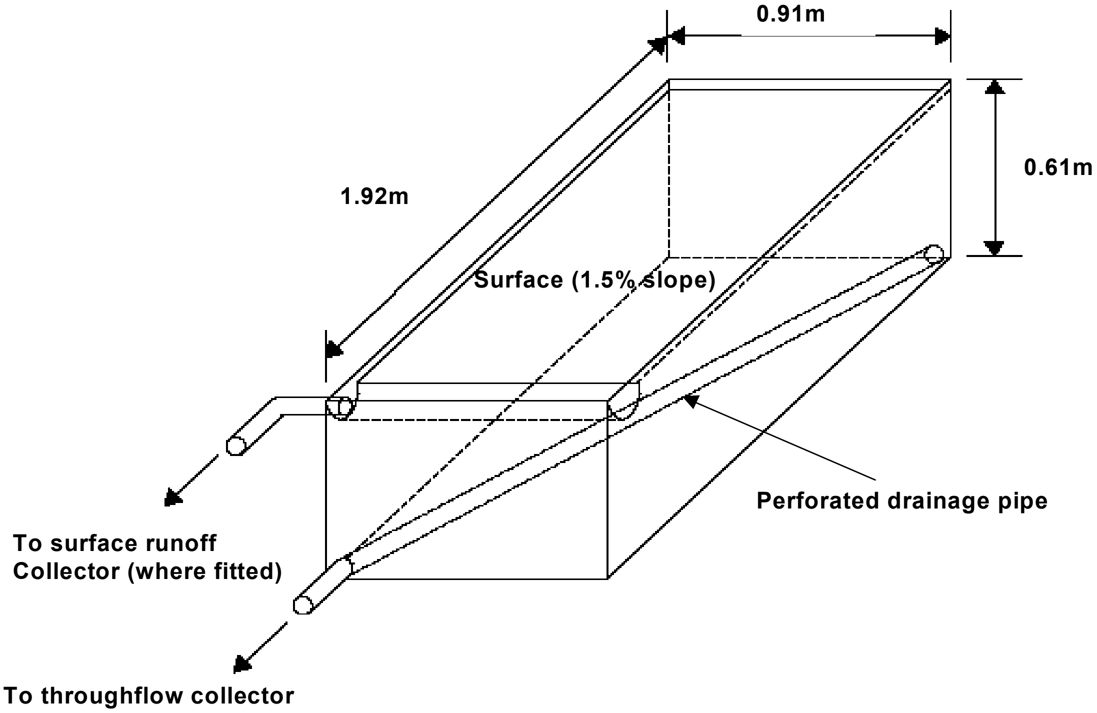

Figure 3.1: Schematic of experimental tank design

In order to eliminate the variability of contamination arising from spray operator activities each area was 'artificially' contaminated by simulating pesticide losses based on the data for isoproturon obtained from the Cherwell project (Mason *et al*., 1999). A grid was imposed on each surface and representative surface spots, spills, leaks and vehicle washing waste were applied in a standard manner to specific grid squares. Rainfall was then simulated (when necessary) to achieve a worst case event (e.g. 25mm in 24 hours) within 48 hours of an artificial pesticide application by adding irrigation water. Subsequent natural rainfall was allowed to fall on the test areas.

Six pesticides, with a range of physico-chemical properties, were artificially applied to the test surfaces, namely: isoproturon (herbicide), pendimethalin (herbicide), chlorothalonil (fungicide), epoxiconazole (fungicide), dimethoate (insecticide) and chlorpyrifos (insecticide).

The first application of pesticides took place to the test surfaces in June 2000. Only the three normally spring applied chemicals were used (chlorothalonil, dimethoate and epoxiconazole). The application rates represented the scaled-down Cherwell project findings on spills, drips, dilute sump liquid and sprayer washings when applied to the much smaller test surfaces. For the second application (in October 2000) all six pesticides were applied at the same scaled down applications rates. The third application (in December 2000), of all six pesticides, represented a worst case scenario. All the Cherwell pesticide losses onto the full-scale farmyard were applied but they were not scaled down to the size of the test surface. One litre samples were collected from the drainage water (surface runoff and/or throughflow) discharging from the test surface tanks immediately following the artificial application of the pesticides and then subsequently after rainfall/drainage events. All the samples were kept in a cold store (2-6^{o}C) prior to laboratory analysis.

3.3 Results

In order to rank the performance of the test surfaces in a way that eliminated the complications of the different amounts of drainage water (i.e. throughflow and surface runoff, where collected) it was decided to calculate the total amount of all pesticides measured as a proportion of that applied to the surface per mm of rainfall (natural or artificial) falling on the surfaces. The results are given in Table 3.1.

Table 3.1: Test surfaces performance - first application: three spring pesticides only applied; second and third applications: all six pesticides applied together

Surface	Total loss of pesticide (% applied per mm of rainfall)		
	1st application	2nd application	3rd application
Biobed	<0.001	0.001	<0.001
Soil/grass	<0.001	0.001	0.024
Biobed + additive	Not constructed	0.002	0.005
Hardcore + additive	Not constructed	0.009	0.044
Hardcore	0.003	0.011	0.058
Asphalt	0.130	0.013	0.097
Porous paving	0.162	0.158	0.498
Concrete	0.355	0.725	0.938

The results demonstrated that:

- all the surfaces provided a significant improvement in the retention and degradation of the test pesticides when compared to the concrete surface;
- both the biobed and the soil/grass surfaces reduced the total pesticide loss generally by a factor of over 100 when compared to the concrete surface;
- pesticide losses from these two surfaces were very low even with the worst case scenario of very high pesticide contamination during the third application, with the soil/grass area providing a 97.4% reduction when compared to concrete and the biobed providing 99.95% reduction;
- the addition of a carbonaceous material into a biobed or hardcore surface did not substantially alter their level of performance to retain and/or degrade pesticides; and
- the porous paving, designed to eliminate surface runoff and provide the capacity for immediate infiltration into the substrate, allowed the rapid transport of pesticides through the test tank and into the drainage water.

The maximum concentration of any pesticide lost from the biobed in any single sample collected during all three application periods was 0.2μg/l; for soil/grass it was 290μg/l. Taking isoproturon as a typical soluble and hence very mobile herbicide as an example, all samples of drainage water from the biobed were below 0.1μg/l. In comparison, the maximum concentration of isoproturon in the drainage water from the concrete surface was in excess of 420,000μg/l during the worst case scenario third application (Table 3.2). For porous paving and soil/grass it was 9570μg/l and 230μg/l respectively.

Table 3.2: Maximum pesticide concentrations (μg/l) in drainage water – third application (worst case scenario)

Pesticide	Concrete	Asphalt	Porous Paving	Hardcore	Hardcore + additive	Biobed + additive	Soil/ grass	Biobed
Dimethoate	46,000	730	980	210	111	24	70	<0.1
Chlorothalonil	200,600	2500	1970	180	443	67	50	<0.1
Isoproturon	421,300	1810	9570	2170	3144	184	230	<0.1
Chlorpyrifos	157,600	1800	4980	160	206	74	70	<0.1
Epoxiconazole	18,100	500	530	30	3977	102	<0.1	<0.1
Pendimethalin	371,900	6180	14,140	250	36	<0.1	290	0.2

3.4 Discussion

The performance of the biobed in retaining and degrading pesticides agrees well with the results from other studies in the UK and Europe. Fogg *et al* (2000) in the UK, Torstensson (2000) in Sweden and Henriksen *et al.* (1999) in Denmark, all found that the biobed matrix provided numerous opportunities for the pesticides to be adsorbed onto organic matter where microbial populations (bacteria and fungi) could then degrade the pesticides *in situ.* Other physical and chemical degradation processes could also take place within the biobed matrix that contained areas of both aerobic and anaerobic conditions. In a similar way the microbial population resident in the soil system, together with organic matter and clay adsorption sites, produced good opportunities for pesticide retention and degradation. Careful management of the water entering these systems was seen as critical to their longer term effectiveness in treating these pesticides, as sustained periods of water saturation and anaerobic conditions would be detrimental to the well-being of the microbial populations. The results also showed that a period of 3-6 months maturing of the biobed matrix, in terms of its microbial composition and activity, contributed to its improved performance even with greatly increased pesticide contamination episodes.

Even though the other surfaces provided a significant improvement in the retention and degradation of the test pesticides over concrete they did permit concentrations of pesticides in the drainage water to frequently exceed the 0.1μg/l Drinking Water Standard. The potential environmental impact of these higher concentrations would need to be considered with respect to Environmental Quality Standards (EQS) and the use of the water body into which the water was discharged.

Whilst the results from this work relate to the conditions at the experimental site, the characteristics of the materials used in the experimental surfaces/substrate (especially the soil and biomix components) and the pesticide suite considered, the principal findings of the work are considered to be relevant to other sites. Due consideration should always be given to individual environmental conditions, site characteristics and pesticide usage, however.

The results did reiterate the current advice on good agricultural practice to spray operators to, wherever possible, move all the pesticide handling and washdown operations away from concrete surfaces. This is particularly the case where there is a direct connection of farm yard drainage to a nearby watercourse. Such discharges have the potential to cause pollution, have an adverse impact on aquatic ecosystems and downstream water users.

3.5 Recommendation

The recommendation from this experimental work was to develop and test designs for full-scale pesticide handling and washdown areas on farms based on biobed and soil/grass bioremediation systems. Both a bunded concrete intercept area draining to a biobed and a drive-on biobed should be investigated over a number of representative pesticide applications periods.

4. STAGE 3 – SPECIFICATION FOR FULL-SCALE FACILITIES

4.1 Background

The objective of Stage 3 was to take the findings from the Stage 2 experimental tank studies and investigate the design options for scaling up for on-farm pesticide handling and washdown areas. Detailed design specifications were developed for three options to be considered under Stage 4 of the project.

When the surfaces investigated in Stage 2 were ranked in terms of their ability to retain and/or degrade pesticides then the use of a biobed system was considered to require further examination. This was also the case for the soil based bioremediation system.

The performance of these surfaces to retain and/or degrade pesticides suggested that designs for on-farm pesticide handling and washdown areas should be developed for:

- a concrete intercept area draining to a biobed;
- a drive-over biobed; and
- a concrete intercept area draining to a soil/grass area.

4.2 Design Aspects

The findings from earlier stages in the project had identified that water management within any bioremediation system was extremely important to the overall pesticide reduction performance. This includes the surface area of both the handling and washdown area and the bioremediation system (if separate) that is subject to direct rainfall inputs. Previous work from the Cherwell Study (Rose *et al*, 2000) had also shown that following normal usage of a sprayer the majority of the residues left on the sprayer machinery surfaces after applications are located from the centre of the sprayer to the rear of the sprayer, including the booms.

A study of a range of common mounted, trailed and self-propelled sprayers on the market identified that for the majority of these sprayers a handling and washdown area of 7m x 5m was sufficient. This included an allowance for the operator to walk around the sprayer (0.5m allowance at the front and 1m at the rear and sides). For some of the largest sprayers this might entail that the very front of a vehicle is overhanging the intercept area, but previous work (Rose *et al*, 2000) has shown that this area on a sprayer contributes very little to any contamination issue.

Few projects concerned with a lined biobed-type operation have considered the option of a roof cover. Reports of unsuccessful operation of the biobed, i.e. through waterlogging of the biobed matrix, raised concerns as to whether a roof would be an appropriate consideration (Fogg *et al*, 2000). A roof would control the amount of non-washing water (i.e. “clean” rainwater) entering the area and affords protection to the sprayer. This further reduces the potential contamination of the surrounding area. Therefore simple roofed options were considered and costed, checking both practical relevance and economic justification to commercial operations. The roof options considered were: full portal frame, lean-to framed structure, polythene tunnel and polythene roof over straw bale walls.

Typical costs (excluding VAT) for the construction of these roofing options ranged from about £1,000-£4,500. This was considered to be a significant additional cost. It was therefore decided that careful bunding of the intercept area (to limit the ingress of unnecessary amounts of "clean" water) and water flow control through the bioremediation systems would be planned to manage the moisture content of the biobed matrix and maximise its pesticide removal potential.

In order to obtain data on the flow of water through the system and sample the leachate, it was necessary for the bioremediation systems to be fully lined. A typical impermeable butyl rubber liner (as used in certain types of slurry store or on-farm winter storage reservoirs) of the size required would cost about £1,000-£1,500.

In the drive-over biobed option a number of Health and Safety issues required consideration. The metal drive-over grid structure had to be designed to take the full weight of a fully loaded sprayer and provide a safe working environment for the operator. The grid therefore had to cover the entire surface area of the biobed. Due to the requirement for an impermeable liner this grid had to be designed to fully span the biobed, without any central supporting pillars. This increased the cost substantially. A proprietary steel grid would cost £3,000-£5,000 to construct, whereas a farmer home-build grid is more likely to cost about £1,000-£1,500.

All the designs required electrical power to be available to run pumps to transfer water around the systems and to operate drip irrigation systems. The power supplies needed to comply with all the relevant electrical regulations.

Drip irrigation was specified to distribute the runoff from the concrete intercept area (where present) over the entire surface area of the bioremediation systems, thereby maximising the potential treatment area available. Drip irrigation was also specified for the disposal of the treated water from to bioremediation to an approved area of land. The disposal area required a Groundwater Regulations Authorisation.

Schematic layouts of the three designs are shown in Figures 4.1, 4.2 and 4.3. Due to the experimental component of Stage 4 of the project all the designs were more complicated than if monitoring was not required. The monitoring capability could easily be excluded from on-farm designs.

Investigations into possible sites for the construction of the three full-scale pesticide handling and washdown areas identified a large farming enterprise in Lincolnshire with three yards that could be re-designed for experimental purposes. The maximum distance between any two sites was 5km.

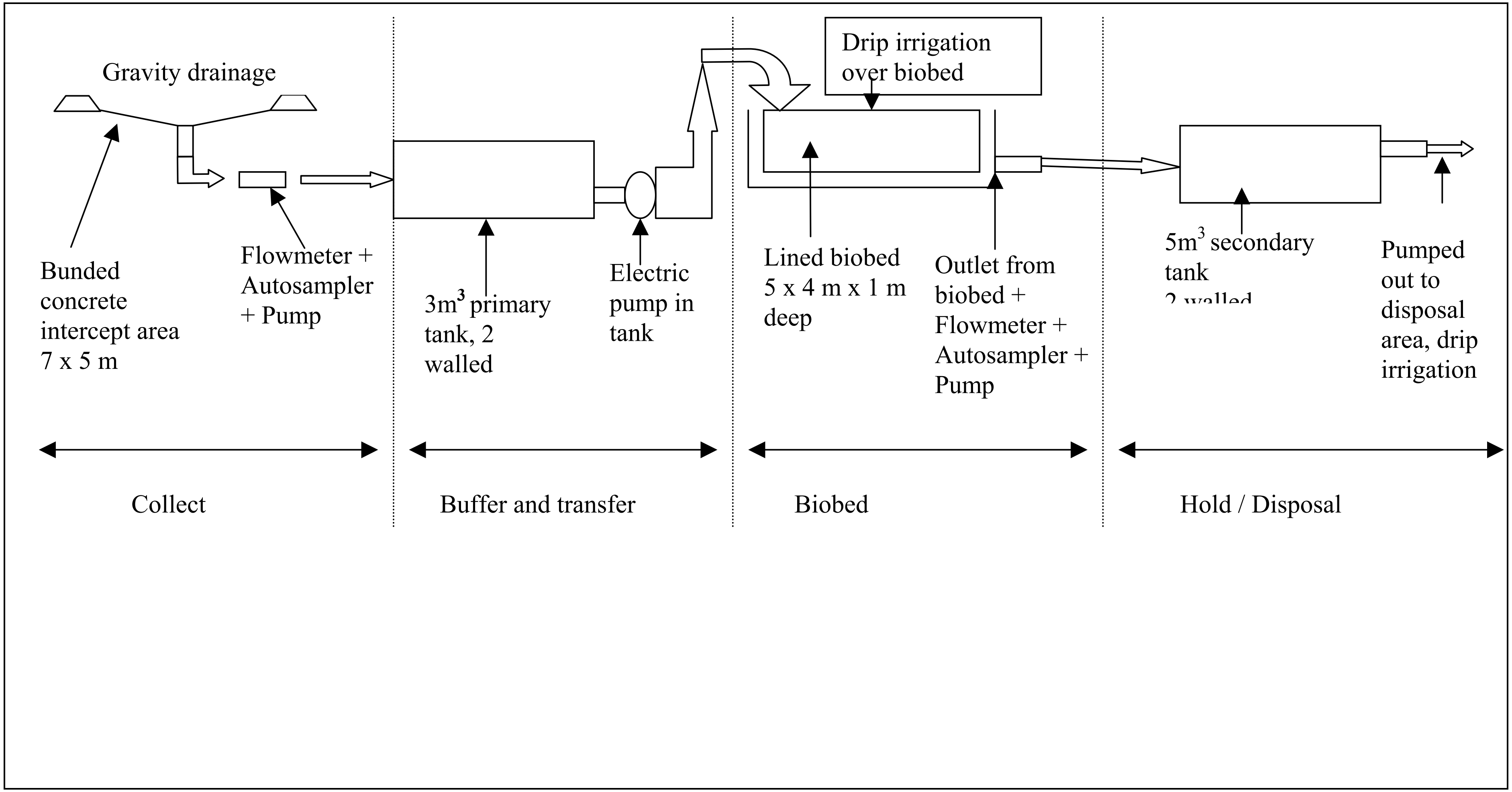

Figure 4.1: Schematic layout of concrete intercept to biobed

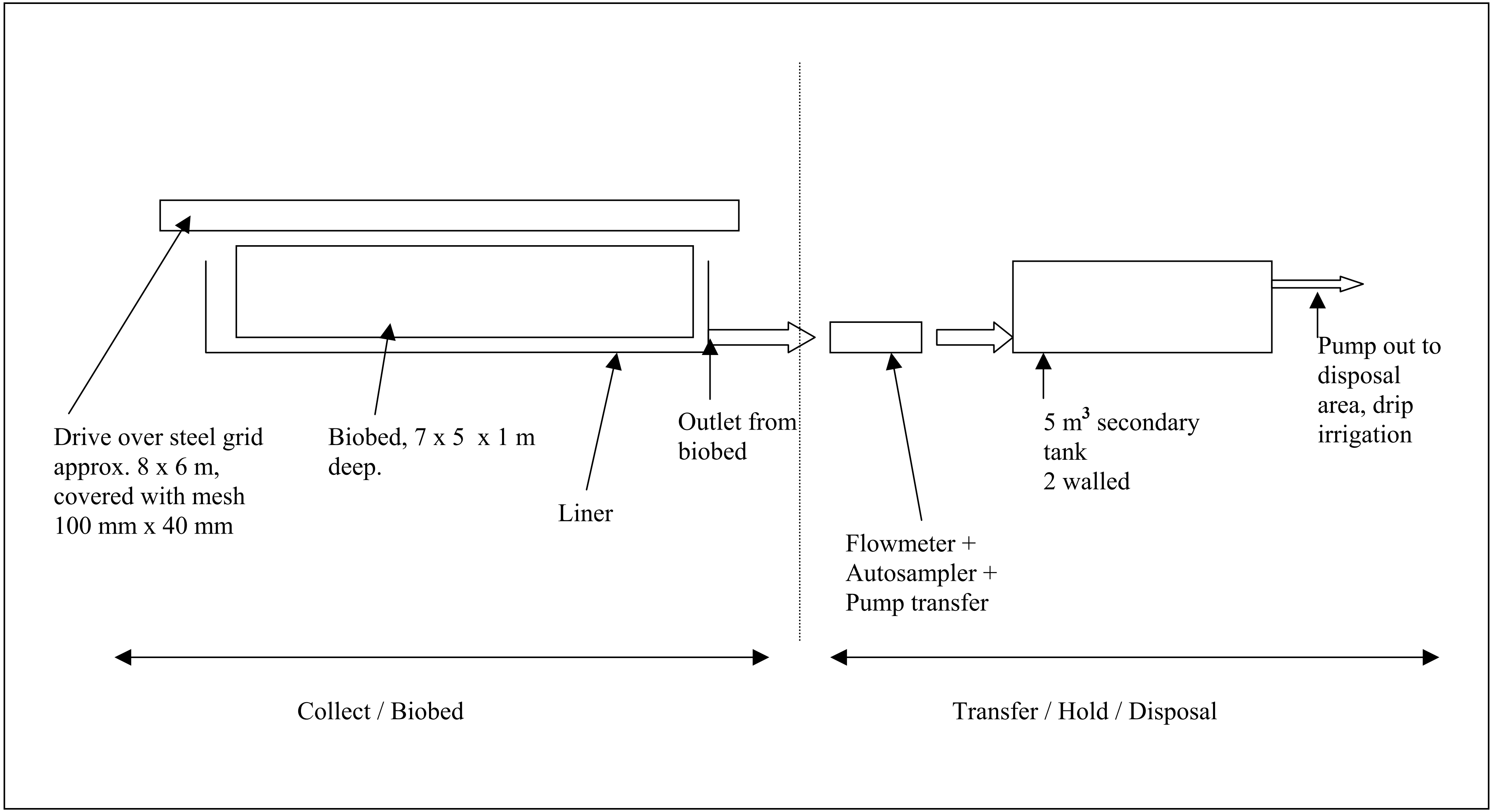

Figure 4.2: Schematic layout of drive-over biobed

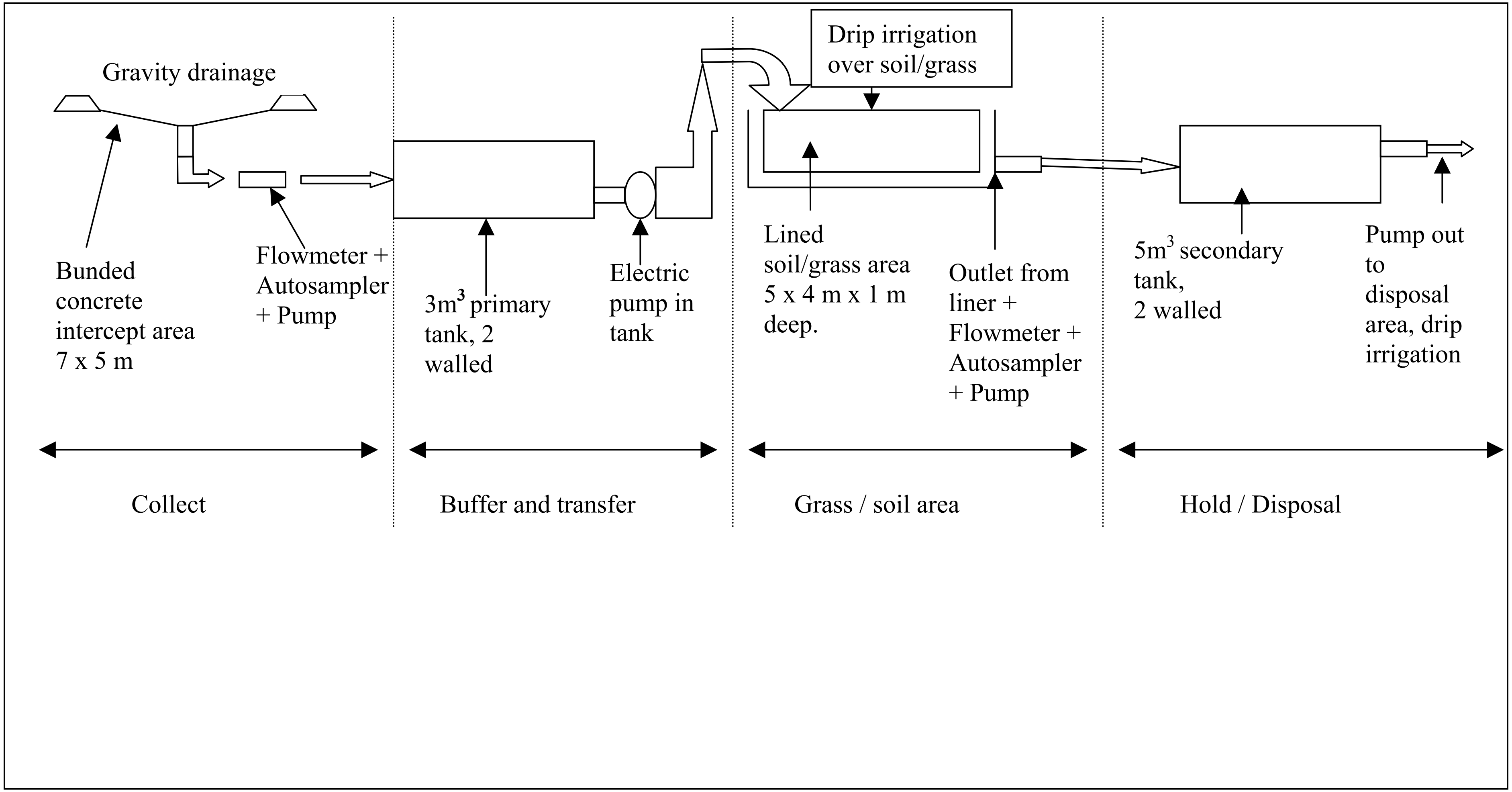

Figure 4.3: Schematic layout of concrete intercept to soil/grass area

5. STAGE 4 – FULL-SCALE PESTICIDE HANDLING AND WASHDOWN DESIGN TRIALS

5.1 Background

The objective of Stage 4 of the project was to take the design recommendations from Stage 3 and construct some new full-scale pesticide handling and washdown areas with integrated monitoring instrumentation. The investigations using experimental tanks in Stage 2 of the project had clearly shown that bioremediation systems based on a biobed (comprising peat-free compost, topsoil and straw) or a biological active loamy soil bed, both with a grass turf cover, were very effective at retaining and/or degrading a suite of pesticides with a range of physico-chemical properties. These treatment systems were thought to provide favourable conditions for the retention and degradation of the pesticides.

The three designs chosen for full-scale construction were:

- concrete intercept draining to a biobed;
- drive-over biobed; and
- concrete intercept draining to soil/grass area.

5.2 Construction and Instrumentation

Construction commenced in February 2002 and all the sites were commissioned for use in April 2002.

The biomix used in the two biobeds (each 1m deep) was created on one of the farm sites on 19 February 2002 by mixing straw (50% by volume), local topsoil - silty clay loam (25% by volume) and a peat-free compost (25% by volume). This was left to mature in the farmyard for 3-4 weeks prior to being loaded into the biobed liners. By the time the sites were commissioned for use by the farm in April 2002 the biomix was 9 weeks old. This was expected to slump naturally over time and would require an annual top-up of fresh biomix. The biomix in both biobeds was covered in grass turf derived from a long-term pasture field at ADAS Gleadthorpe. The soil that was loaded into the soil/grass liner (1m deep) was a silty clay loam topsoil derived locally from the farm. Like the biomix the soil was covered in grass turf derived from a long-term pasture field at ADAS Gleadthorpe.

At each site particular attention was given to the automation of the pumping systems for transporting the runoff/drainage water between treatment system components, whilst also allowing manual intervention and override whenever necessary. The pumps had both float switch and timer switch activation to make the most efficient use of the storage tanks within the systems prior to the application, via drip irrigation, to either the biobed/soil area or to the authorised disposal area. The use of drip irrigation over the surface of the biobed/soil area allowed the pesticide laden runoff water to be distributed evenly across the entire surface area of the treatment system, thereby maximising the potential for pesticide retention and/or degradation.

Water flow from the concrete intercept areas and leachate flow from the biobed/soil areas was measured by a tipping bucket flowmeter system linked to a dedicated data logger. Automatic water samplers were set up to sample all these waters. A logged tipping bucket raingauge was installed at the central concrete intercept to biobed site. All water samples were stored in the cold store at ADAS Gleadthorpe prior to despatch to the contract analytical laboratory for analysis.

In addition to the data collected from the ADAS instrumentation on-site, extra information was gathered from the farm. This included daily rainfall from a manually recorded raingauge, all pesticide applications to the farm areas serviced by the three new pesticide handling and washdown sites and any washdown operations. During the course of the monitoring periods it became apparent that all washdown operations (exterior surfaces of the sprayer), using a pressure washer, were actually only being undertaken at one of the new sites (concrete intercept to biobed). This placed this particular bioremediation system under considerably increased loading in terms of volumes handled.

5.3 Artificial Applications

The same suite of six test pesticides as used in Stage 2 of the project were artificially applied to the three pesticide handling and washdown areas on two occasions in June 2002 and September 2002. These pesticides were: isoproturon (herbicide), pendimethalin (herbicide), chlorothalonil (fungicide), epoxiconazole (fungicide), dimethoate (insecticide) and chlorpyrifos (insecticide). In addition, it was considered useful to include within the site investigations one pesticide that was confidently predicted to be used in normal agricultural practice on the farms during 2002. This pesticide was the fungicide, azoxystrobin. Azoxystrobin was not artificially applied with the other six pesticides, it was only included as a determinand in the sample analysis. For a two month period after each application the sites were intensively monitored.

It was decided that the most appropriate way to test the new bioremediation systems was to use a worst-case scenario (i.e. a very heavy load of pesticides in a short period of time), based on the results from Stage 2 of the project. The worst-case scenario represented the equivalent of the expected maximum possible pesticide contamination arising from 16 individual tank mixes on one day.

A set of four controlled mixtures were formulated with known pesticide concentrations and volumes to represent four possible contamination sources, namely:

i) dropped foil seals from pesticide packaging (spray concentrate);
ii) faulty valves/nozzles/hoses (spray suspension);
iii) sump rinsate; and
iv) washdown liquid.

For each of the contamination sources above a simulated 16 tank mixture containing the possible contamination from each of the six pesticides were formulated in three new glass bottles (one for each site). In reality, all four mixtures were applied to a site within a very short time period that only lasted approximately 30-45 minutes. This exercise therefore represents a very severe test of the ability of the bioremediation systems to remove pesticides from water. This level of contamination is extremely unlikely to happen during the normal agricultural usage of these systems, perhaps with the exception of a significant spillage of pesticide concentrate which can never be prescribed for.

Mixtures i), ii) and iii) were applied by hand from new glass bottles. These mixtures were applied to specific locations on the new pesticide handling and washdown areas where it would have been expected that the particular contamination source would fall. Mixture iv) was applied through a small portable petrol driven sprayer with a hand lance across the entire pesticide handling and washdown area to represent the washing down of the entire sprayer.

5.4 Farm Applications and Washdown

The farming enterprise on which all the test systems were located provided ADAS with all the pesticide application data for each of the three sites for the period from April 2002 until November 2002. These applications, in response to pest and disease problems on the farms, were undertaken at the three sites in addition to the artificial applications. The data provided included the dates of applications, the products applied, and any washdown operations. The farm records indicated that during 2002 the concrete intercept to biobed site was used more often for spray operations than the other two sites. This is due to the particular cropped fields that this site serviced and the pests and diseases identified in these fields during the 2002 growing season. This demonstrates how the extent of use of bioremediation systems will vary quite considerably from site-to-site and from year-to-year. During the period April 2002 to the end of the monitoring period in November 2002 the concrete intercept to biobed site had 17 individual spray days, whereas the drive-over biobed only had 9 spray dates and the concrete intercept to soil/grass area only had 5 spray days. In addition, 6 washdown operations took place at the concrete intercept to biobed site, whereas no washdown operations were undertaken at either of the other two sites. As each washdown operation utilised approximately 150-200 litres of water then this could have an impact on the results from this particular site.

Some of the test pesticides that were applied artificially to the sites were also applied during normal farm spraying operations in 2002. In addition, the extra test pesticide of interest, azoxystrobin, was used at two of the sites. However, the same pesticides were not used at all sites.

5.5 Results

Both the two month monitoring periods following the artificial applications were characterised by prolonged dry and then very wet spells. After the first application on 6 June 2002 a dry spell lasted for the rest of June before very heavy rains returned in July. August was slightly drier than average. Following the second application on 12 September 2002 the dry spell lasted throughout September, before wet weather returned in October and November. Over the whole May to November 2002 period the total rainfall was 119% of the long term average.

The occurrence of these dry and wet spells after the artificial applications would have had some impact on the potential for pesticide transport off the concrete intercept areas and/or through the bioremediation systems. In addition, other environmental factors prevalent at the sites, such as air temperature, humidity, sunshine hours, biomix/soil temperature, biomix/soil moisture content, biomix/soil organic matter content, evapotranspiration and biomass activity will have affected the rate of degradation of the pesticides and the potential for pesticide transport.

The flow record for runoff and/or throughflow from the sites showed substantial variability. Local conditions, including rainfall, site exposure to sun/wind, moisture status (of concrete and/or biobed/soil), grass growth, washdown activities or other on-site incidents will all have influenced these flow values by varying degrees. The total surface area (for direct rainfall entry) of the two sites with concrete intercept areas was 25% greater than that of the drive-over biobed. In addition, the water management at the sites, including temporary storage in tanks, by pumps (with float switches and automatic timer activation) will have greatly affected both the amount and the timing of when water was transferred from one component of the treatment system to another.

At all sites the loss of water, either via direct evaporation from the concrete and/or evapotranspiration from the grass turf, would have had a significant impact on the flow volumes. The grass growth at the concrete intercept to soil/grass site remained very good throughout the monitoring period, even after the input of pesticide laden water. The deep loamy topsoil present in this treatment system appeared to encourage good root development, which can then fully utilise the available soil water. The drip irrigation took place right at the base of the grass stems and so any herbicide residues in the water were not directly applied to the grass leaves. Grass growth at the two biobed sites was not as good. In addition, the grass growth at the biobed sites (especially the drive-over biobed) was more affected by the pesticide (i.e. herbicide) inputs, both on application day and subsequently during normal farm spraying activities. As a consequence, the amount of water lost by evapotranspiration from the two biobeds would have been less than that from the soil/grass area.

All three bioremediation systems were able to reduce the input pesticide concentration by a factor of the order 10,000-100,000 times. For the six pesticides artificially applied to the sites a total of 1134 individual analytical determinations were made of the leachate samples from all three bioremediation systems. Of these samples 87% had a pesticide concentration <0.5μg/l. A summary of maximum pesticide concentration detected at each site is shown in Table 5.1.

5.5.1 Concrete intercept to biobed

On the application day (6 June) pesticide concentrations in the runoff generated from the concrete intercept area exceeded 100,000μg/l. Three days after application (9 June) some detections in excess of 200μg/l were still being measured. During the rest of June and July the detections in the runoff from the concrete surface reduced to below 5μg/l, except for epoxiconazole, pendimethalin and azoxystrobin. Epoxiconazole and pendimethalin tends to bind quite strongly to most materials, including concrete and soil. It will therefore tend to remain on the concrete surface where degradation processes will ensue, unless rain or pressure washing causes it to be re-mobilised and transported off the pad.

The results for the second application followed a very similar pattern to the first application for both the runoff from the concrete and the leachate from the biobed. Numerous detections in excess of 1000μg/l were found in runoff from the concrete and this lasted for at least 1.5 weeks after the application. Detections in excess of 50μg/l were still present over one month after application. This may be related to the lack of significant rainfall throughout August and September, which did not permit any mobilisation and transport of the test pesticides off the concrete surface in runoff water.

Pesticide concentrations in the leachate from the biobed were generally very low (<0.5μg/l) throughout both monitoring periods. This represented a reduction in the concentration that was applied to the top of the biobed (via drip irrigation) of >10,000 times. However, some detections in excess of the limit of quantification were obtained.

Table 5.1: Summary of maximum pesticide concentrations (μg/l) detected in runoff and leachate samples following artificial applications

	Concrete intercept to biobed		Drive-over biobed	Concrete intercept to soil/grass	
First application					
	Runoff	Leachate	Leachate	Runoff	Leachate
Dimethoate	28,000	5.4	5.0	12,000	<0.5
Chlorothalonil	106,000	1.2	1.0	114,000	0.4
Isoproturon	190,000	68.8	6.9	91,000	3.3
Chlorpyrifos	106,000	0.4	3.9	79,000	3.4
Pendimethalin	228,000	3.4	13.7	109,000	2.6
Epoxiconazole	11,000	0.6	0.9	8,200	0.6
Azoxystrobin	4,100	5.4	6.9	1,700	0.6
	Concrete intercept to biobed		Drive-over biobed	Concrete intercept to soil/grass	
Second application					
	Runoff	Leachate	Leachate	Runoff	Leachate
Dimethoate	44,277	0.9	15.5	24,800	<0.5
Chlorothalonil	96,807	0.3	<0.1	94,600	<0.1
Isoproturon	140,850	<0.5	1.2	55,900	<0.5
Chlorpyrifos	77,646	0.7	0.4	56,300	0.8
Pendimethalin	205,550	2.3	0.5	107,900	0.8
Epoxiconazole	9,108	0.8	0.7	9,450	0.8
Azoxystrobin	2,960	5.8	1.9	6,4100	0.6

5.5.2 Drive-over biobed

During the artificial applications the pesticide mixtures were applied to specific locations on the pesticide handling and washdown areas to match where the particular contamination source would fall. In the drive-over biobed system this meant that the mixtures were applied directly to appropriate areas on the top surface of the biobed (grass turf), through the metal grid. This differs from the other two systems, which evenly distributed the pesticide laden runoff water across the complete surface of the biobed/soil area through the drip irrigation system. The drive-over biobed will therefore potentially develop pesticide "hotspots" over time for certain pesticide contamination sources (e.g. under hopper, under sump, under nozzles/valves), if the sprayer is always parked on the grid in the same orientation. This "hotspot" effect was very noticeable at this site with the grass turf being severely scorched in distinct areas. This scorching will also have affected the amount of evapotranspiration possible from the grass cover.

The drive-over biobed also differs from the other two treatment systems in that it contained a larger volume of biomix for the retention and degradation of pesticides and, because it did not have an associated concrete intercept area, it received less direct or indirect rainfall as the total surface area is approximately 25% smaller.

Throughout both monitoring periods pesticide detections in the leachate water were rarely in excess of 0.5μg/l. Some unexpected detections of azoxystrobin were found before the artificial application on 6 June. These could not be explained as azoxystrobin was not used at the site until after 6 June and its physico-chemical properties would suggest that it would be strongly sorbed to the organic material in the biobed and not available for transport.

5.5.3 Concrete intercept to soil/grass area

Like the concrete intercept area to biobed site the pesticide detections in the runoff water from the concrete on the application days were very high, often in excess of 50,000μg/l. Similarly, the detections were reduced more quickly in the few days after the first application than they were following the second application. The amount/rate of rainfall falling on the concrete surface after the application, together with the production of surface runoff, were thought to be the main reasons for this. Detections in excess of 100μg/l were still being measured on the runoff water a month after the second application.

Like the biobeds the soil/grass bioremediation system performed particularly well with few detections in excess of 0.5μg/l and many <0.1μg/l. This represented a reduction in the pesticide input concentration of >10,000 times.

The maintenance of a very good grass cover in the deep loamy soil system will have undoubtedly permitted large volumes of water to be lost to the atmosphere through evapotranspiration. This water and any associated pesticide residues would therefore not be available for rapid vertical percolation through the soil column and so the leaching risk would be reduced.

5.6 Discussion and Conclusions

The results from the three full-scale pesticide handling and washdown areas constructed in Lincolnshire have shown that biobeds and soil/grass plots are extremely effective bioremediation systems and have considerable potential to reduce point source pesticide pollution.
All three sites were subjected to the equivalent of the maximum potential point source pesticide contamination that might have arisen from 16 individual tank mixes on one spray day. This represented an extreme test of the treatment systems to retain and/or degrade pesticides. Individual pesticide concentrations in excess of 100,000μg/l were

measured in water that was applied to the bioremediation systems. In general, all three treatment systems were able to reduce these concentration to below 0.5μg/l and often below 0.1μg/l over the course of the whole 5 month monitoring period. Some detections in excess of 0.5μg/l were measured in the water leaching out of the biobed/soil area, but these should be put into the context of the overall pesticide reduction performance of these treatment systems and what is happening in practical, on-farm circumstances.

Like Stage 2, the results are specifically applicable to the experimental sites investigated. Environmental conditions, site characteristics and pesticide usage will vary from site to site. However, the principal findings are appropriate to other sites, provided that due consideration is given to these differences.

Work by other researchers (Torstensson, 2000, Fogg *et al*, 2000 and 2001) would suggest that following the maturing of the biomix over time, together with the adaptation of the biomass in all these treatment systems to selectively degrade pesticides, then the losses of contaminants out of the leachate water will be further reduced. At some point in the future, estimated as being five to seven years in the UK climate, the biomix and soil may need to be removed from the liners and recovered in an appropriate manner. Fresh biomix (ideally pre-mixed and stored for at least two months) or soil would then have to be reloaded into the liners prior to any subsequent pesticide handling and washdown operations. Due to the timespan of this project it has not been possible to investigate the possible options for the disposal, storage or "recovery" of used biomix/soil. This will become an important consideration as proposals for extending controls over agricultural wastes are advanced.

The widespread implementation of these on-farm bioremediation systems within the UK farming industry will require further research and practical evaluation in appropriate circumstances.

5.7 Recommendations

The work undertaken in this stage of the project has highlighted the need to undertake further research into:

- The long-term operation, management and performance of on-farm bioremediation systems to reduce point source pesticide contamination. This could be achieved by further monitoring of the three existing sites in Lincolnshire for a number of years.
- The ability of the biomix or soil to retain and degrade pesticides. Can the biomix/soil be modified even further to improve its potential to remove pesticides, especially those pesticides that are persistent or particularly mobile?
- Lifespan of bioremediation systems. How many years can these systems be operated before the biomix or soil needs to be replaced? Does a soil based system have a very different lifespan to a biobed?
- Disposal options for spent biomix/soil. How does the spent biomix/soil need to be handled, stored, treated etc. prior to disposal? What environmental risks does the spent biomix/soil pose?

6. STAGE 5 – DEVELOPMENT OF A DESIGN MANUAL

All the information and data collected and obtained during all the previous stages of this project were considered in the preparation of a draft design manual for agricultural pesticide handling and washdown areas. Critically, however there remain a number of scientific and regulatory issues which are beyond the scope of this project and which are of sufficient importance to preclude the production of a design manual for general use at this stage.

The scientific issues primarily relate to the residual risks to groundwater posed by bioremediation systems and to their long-term management and performance. Further research is currently in hand on biobeds and it is likely that this will answer some of these questions. This project has identified a number of recommendations for additional research which, if taken forward, would address the longer-term uncertainties.

The regulatory issues relate to new regulations likely to impact on the disposal of pesticide washings. In particular regulations are known to be in preparation on Agricultural Waste and Hazardous Waste. The future of the Groundwater Regulations and their relationship to the Landfill Regulations is unclear, as is the issue of Groundwater Regulations charges. These regulatory matters could potentially have significant impacts on the costs associated with bioremediation systems and on their legal status.

In light of these unanswered questions it is considered inappropriate to publish a design manual as an output from this project, even in draft form, since its publication would imply the acceptability of the bioremediation systems whereas there is actually significant uncertainty. The collated findings from the project on the design concepts for pesticide handling and washdown areas have been produced as an Appendix to the Project Record.

Despite the scientific and regulatory uncertainties, the Agencies recognise the potential of biobeds to reduce pesticide pollution of surface waters from pesticide handling areas. The Agencies will not be actively promoting the uptake of bioremediation systems on-farm but where there is an obvious commitment to improve pesticide handling practices then proposals for biobeds will be considered on a case-by-case basis.

The Agencies have produced interim guidance in order to advise their staff on the position regarding the use of biobeds on-farm. The Environment Agency has produced an “Interim Position Statement on Agricultural Pesticide Handling and Washdown Areas in Relation to the Protection of Controlled Waters (focussing on biobeds)”. SEPA has produced an “Interim Regulatory Guidance Note on Biobeds and Soil/Grass Systems for Agricultural Pesticide Handling Areas”. A critical factor in deciding whether a biobed can be used in a particular situation is whether it is to be used for pesticide mixing/handling only or whether washdown is to take place. The Agencies have stated that, provided they are constructed and operated according to good practice, biobeds for pesticide mixing/handling do not require authorisation under the Groundwater Regulations. For washdown areas significant volumes of waste will be generated which could potentially pollute groundwater. Consequently the Agencies consider that where biobeds are proposed to be used for washdown, they should be lined and the drainage collected for subsequent disposal under a Groundwater Regulations Authorisation. Unlined biobeds are not encouraged for washdown areas and would again require a Groundwater Regulations Authorisation.

It is anticipated that the results of this project and the design concepts, whilst recognising the scientific and regulatory uncertainties, will be taken forward by the pesticide industry and by The Voluntary Initiative in particular. Bioremediation systems offer the potential to reduce surface water pollution by pesticides arising from the concrete farm yard but their potential detrimental impact on groundwater must be considered.

7. CONCLUSIONS AND RECOMMENDATIONS

The problem of point source contamination of water by pesticides is an issue which is of interest to a wide range of stakeholders. Solutions to the causes of contamination are complex and will involve a consensus of opinion, compliance with various EU and national legislative and voluntary requirements and a range of solutions which can be applied at a site specific level.

Activities that take place in the farmyard involving the handling, use and disposal of pesticide wastes all represent potential contamination sources. The potential environmental consequences of mistakes and accidents that may occur whilst using pesticides and pesticide application equipment in the farmyard could be considerably reduced through a better awareness of the problem. Training of all pesticide users in the correct manner to use and dispose of pesticides and associated wastes, dealing with spillages and keeping pesticide application equipment in good working order, are all seen as fundamental to limiting point source pollution on farms.

The design, management and operation of agricultural pesticide handling and washdown areas are considered as primary targets to limit point source pesticide pollution. The characteristics of the farmyard surface and associated drainage will control the rate at which any spilt pesticide, washings or waste reaches a water resource. The surface and underlying substrate also dictate whether opportunities exist for *in situ* pesticide retention and/or degradation through physical, chemical or biological processes.

Experimental tank studies undertaken within this project have indicated that when compared to the typical concrete surface found in most farmyards, the use of more permeable media, especially those with specifically designed bioremediation systems, could reduce pesticide losses by greater than 95%. In particular, biobeds (comprising a mixture of straw, loamy topsoil and peat-free compost) and good quality biologically active topsoil provided enhanced conditions for pesticide retention and/or degradation processes to take place, particularly if the water management in these systems was well controlled.

Investigations into the performance of three full-scale pesticide handling and washdown areas, linked to bioremediation systems, and designed to minimise surface water contamination, whilst taking account of the local groundwater vulnerability, demonstrated how effective they were in removing pesticides. Pesticide concentrations in the water entering these bioremediation systems were reduced by 10,000 to 100,000 fold by the time it was discharged to approved disposal areas in the environment. If the discharge waters are applied to appropriate designated soil areas significant opportunities will exist for further retention and/or degradation to take place before the waters finally reach surface or groundwaters.

It is recommended that further work is undertaken to investigate their longer term pesticide removal efficiency and lifespan under UK climatic conditions. This work would then consider the waste disposal options available, within current environmental regulations, when the organic matrices from the systems need to be replaced with fresh material. Investigations into maximising the potential of the biomix or soil to retain and/or degrade pesticides should also be undertaken.

This project has provided good evidence that redesigned agricultural pesticide handling and washdown areas, linked to bioremediation systems, can minimise point source pollution of surface waters. It must be recognised however, that the inappropriate use or management of such systems poses a risk of pesticide pollution of groundwater. There are outstanding scientific and regulatory issues with the use of bioremediation systems on-farm but these issues should be balanced with the potential improvements that could be seen by reducing pesticide pollution of surface waters from existing concrete pesticide handling areas.

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