A method-centric 'User Manual' for the mitigation of diffuse water pollution from agriculture

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Running Title: Manual for mitigation of diffuse water pollution

Summary

We describe the development of a manual of methods for mitigating diffuse water pollution from agriculture and its important influence on policy and practice in England and Wales. The objective of the 'User Manual' was to provide policy makers and those implementing policies with information about the cost, effectiveness and applicability of potential methods in a form that would be readily understood by non-specialists. The 'User Manual' was based on earlier reports synthesising available research data and, where data were unavailable, used expert elicitation. The outcome generated 44 potential methods (under the broad categories of land use, soil management, livestock management, fertiliser management, manure management and farm infrastructure) and described the simultaneous impact of applying each method on losses of nitrate, phosphorus and faecal indicator organisms relative to baseline losses. Estimates of cost and effectiveness were presented at the whole-farm level for seven model farm types. Methods differed widely in their cost-effectiveness and applicability to the different model farms. Advantages and limitations of the approach are discussed and subsequent developments of the original 'User Manual' are described, together with the opinions of catchment officers who have used the 'User Manual' to implement mitigation methods on farms.

Keywords: mitigation methods, cost-effectiveness, nitrate, phosphorus, faecal indicator organisms

Introduction

The European Union Water Framework Directive (EU, 2000) seeks to address all forms of water pollution by requiring that all surface waters and groundwater in member states should be of good ecological and chemical status by 2015 with a maximum derogation to 2027. A key requirement is that member states should implement River Basin Management Plans detailing the measures to be taken to tackle pollution at the catchment scale, including the diffuse pollution that originates from agricultural sources. Much research had been done to quantify the losses of diffuse water pollutants from agricultural land, to understand the processes controlling them and to develop practical measures to reduce losses (e.g. Haygarth & Jarvis, 2003; Cherry *et al*., 2008; Sharpley *et al*. 2005; Shepherd and Chambers, 2007); however, the further use of these findings to assist with the development of effective policies for the control of water pollution required that complex and sometimes conflicting information be made available in a form that was accessible and readily understood by those developing and implementing these policies.

In this paper we describe one of the first attempts to provide policy makers with an integrated assessment of the cost-effectiveness of a range of potential mitigation measures to control losses of the most important forms of diffuse water pollution from agriculture (DWPA): nitrogen (N) in the form of nitrate-N, phosphorus (P) and faecal indicator organisms (FIOs) originating from animal excreta and manures. This was presented in the form of a ‘User Manual’, which in addition to information about their cost-effectiveness also provided specific information about how the methods operate, their applicability to different types of farm and the wider implications of their use. A novel feature of the ‘User Manual’ was that it adopted a ‘method-centric’ approach, focussing on each method in turn and its simultaneous impact on all three pollutants. Preparation of the ‘User Manual’ also recognised that for some methods and circumstances the evidence base will always be incomplete and it was necessary to rely on expert elicitation to fill the gaps where scientific data were lacking, accepting the uncertainties associated with this process. Expert elicitation is recognised as making a valuable contribution to the description and modelling of complex environmental systems, especially where evidence is incomplete and the implementation of policies or actions cannot be delayed until all the necessary knowledge becomes available (Kreuger *et al*., 2012).

By analysing and bringing together the results of a wide range of scientific studies and presenting them in an accessible form, the 'User Manual' is seen as an important contribution to bridging the gap between scientists and policy makers to assist in the development of evidence-based policies (Macleod *et al*., 2008). We describe how the 'User Manual' was formulated, how it has been developed since its publication in 2007 and its subsequent use to help implement policy and DWPA methods in programmes such as Catchment Sensitive Farming (CSF) (Natural England, 2013).

Method

Development of the 'User Manual'

The requirement for a manual arose from a request from the UK Department for Environment, Food and Rural Affairs (Defra) to integrate and further develop a number of literature studies that examined the cost and effectiveness of a range of methods for reducing forms of DWPA, including N (Defra, 2004a), P (Haygarth *et al*., 2009) and FIOs (Defra, 2005). Information from these reports, which each dealt with a separate pollutant, was brought together in a single inventory to allow a more 'method-centric' approach to be adopted. The 'User Manual' was developed from this inventory to provide policy makers with a comprehensive description of how each of the 44 selected methods are implemented, how they work in controlling losses of N, P and FIOs, their cost and effectiveness and the potential for their application within different farming systems and soil types.

The 'User Manual' was prepared by an interdisciplinary team of scientists, including agronomists, biogeochemists, economists, hydrologists, modellers and soil scientists, with considerable experience in understanding the processes controlling the behaviour of the relevant pollutants and how these are influenced by agricultural practices. The 'User Manual' development process is described in the following sections.

Model farms, climate and soil types

Pollutant losses were expressed at the whole-farm level. It was therefore necessary to define specific model farms to use as the basis for the calculations. These were chosen to be representative of the main UK farming sectors and were closely defined in terms of farmed area, field size, cropping, livestock numbers and ages, housing period, fertiliser and manure/slurry management, using typical values obtained from published data (e.g. MAFF, 2000; Smith *et al*., 2000; Goodlass & Allin, 2004) and expert judgement. Characteristics of the seven model farm types are outlined in Table 1.

All farms were assumed to be located in a medium rainfall area (850 mm rain/year). Estimates were prepared for farms on a clay loam soil (assumed to be artificially drained under arable production) and on a sandy loam soil (assumed to be freely drained and not requiring artificial drainage), representing the dominant contrasting soil types in England and Wales (Avery, 1980). Around 56% of lowland soils in England and Wales have topsoil textures that are either sandy loam or clay loam (Anthony, 2006). The model outdoor pig farm was restricted to the sandy loam soil as such enterprises are only suited to free-draining sites. For farms on clay loam soil, an expert judgement approach was used to decide on the proportion of fields having artificial drainage: all fields on the arable farms were assumed to have an effective drainage system installed, but only two-thirds of fields on the dairy farm and one-third on the suckler beef farm. Sandy loam soils were assumed to be at risk of capping (Catt *et al*., 1998; Chambers *et al*., 2000), with the result that surface run-off would be greater than from the clay loam soil but with less transport of suspended soil particles.

Estimates of baseline losses and the effectiveness of mitigation methods

The first stage of the estimations was to determine baseline pollutant losses for each of the farms in the absence of any mitigation methods. The NITCAT (Lord, 1992), NCYCLE (Scholefield *et al*., 1991), MANNER (Chambers et al., 1999) and SLIMMER (Anthony *et al*., 1996) models were used to estimate nitrate-N losses and the PSYCHIC model (Davison *et al*., 2008) for P losses for each area of the farm under a particular management regime. These were validated using field experimental evidence (e.g. Oliver *et al*., 2005) and combined to obtain an overall, average loss for the whole farm area (in kg/ha/year).

There was less information from research studies about losses of FIOs and therefore greater uncertainty about our estimates. An expert judgement approach was used, largely based upon work undertaken in previous Defra projects (Defra, 2004b; Defra, 2005) but consulting with experts from outside the project team when necessary. FIO losses were expressed in terms of relative units where the baseline loss for the model dairy farm on a clay loam soil was arbitrarily set at 100 units/ha; made up of 40 units arising from livestock grazing in the field, 40 units from landspreading of manure, 10 units from hard standings, tracks, etc. and 10 units from excreta deposited directly into watercourses. All other model farm types were referenced to this.

The estimated baseline losses are summarised in Table 2. The lowest losses of N and P were from the model suckler beef farm and the largest from the outdoor pig unit, which also had the highest baseline loss of FIOs, almost double that from the reference dairy farm. There were much smaller losses of FIOs from farm types that applied farmyard manure (FYM) because FYM was assumed to be stored long enough for most organisms to die off before the material was spread. FIO losses would have been higher if these farms had been assumed to apply fresh manures or slurry. Losses of N were slightly greater for the model farms on the sandy loam soil than on clay loam while losses of P and FIOs were appreciably higher on the clay loam soil.

The effectiveness of the mitigation method was estimated by first dividing the baseline loss for each model farm between components originating from the soil, from manure and excreta and from fertiliser. These components were then used as the basis for determining the likely reduction in losses arising from the introduction of each of the mitigation methods. Initial estimates of impacts on N and P losses were taken from the previous Defra projects (Defra, 2004a, 2005; Haygarth *et al*., 2009) and an expert judgement approach used to estimate likely reductions in losses of FIOs. Because the earlier projects focussed on individual pollutants, not all of the methods were included in each report or they sometimes differed in detail from those described in the 'User Manual'. In these cases, it was necessary to estimate the effectiveness using the most closely analogous method and an expert judgement of the weighting to be applied. Reductions in N and P losses were expressed in kg/ha/year, whereas for FIOs the reductions were given as a percentage of the baseline loss (to the nearest 10%).

In the 'User Manual', the effectiveness was summarised in a table for each method, listing the reduction in nitrate-N, total P and FIO losses at the farm scale and the baseline loss for each farm type on the sandy loam and clay loam soils (except for those farms where the method was not applicable). Reductions in P losses only referred to the short-term effect; some methods will achieve a greater reduction in the longer term (>10 years) as a result of a slow decline in soil P contents, but because of the uncertainties in these estimates, they were not quantified in the 'User Manual'.

Estimates of baseline costs and the costs of implementing the mitigation methods

Estimates of the cost of implementing each method were determined for each of the model farm types. Costs could be trading costs in terms of impacts on productivity, variable costs such as feed and fertiliser, fixed costs such as machinery and labour, management time or capital costs, which required converting to an annual value as appropriate for the different methods. Where a method resulted in land not being farmed, this could lead to a loss of support payments but this was not assumed in the estimates. Similarly, the costs did not include any impacts on the agricultural supply industry arising from reductions in stocking rates or in the area of land farmed. All estimates were based on typical costs as in autumn 2006. In the 'User Manual', costs were presented for each method as a table with cost per ha and averaged over the whole farm area and, where appropriate, as capital and annual costs.

Expert elicitation

The development phase involved a structured set of expert elicitation workshops with invited expert research scientists to assess baseline losses and the cost and effectiveness of methods for each pollutant and each model farm. The assessment was carried out iteratively with both estimation and checking phases to validate outputs. The resulting values were documented by the project scientists and entered into a 'farm library' spreadsheet for use in the final 'User Manual'. Defra representatives also attended inception and mid-term meetings to represent the 'end-user' and provide some surety that what was being delivered would meet their needs. At a late stage of the work a near-final draft of the 'User Manual' was circulated to Defra and industry stakeholders and their comments incorporated into the final version.

Results

Description of the 'User Manual'

The 'User Manual' (Cuttle *et al*., 2007) contained 44 control measures, selected by the expert group as the most cost-effective of the 57 potential methods identified by the earlier reviews. These are listed in Table 3 and, as in the 'User Manual', grouped into six categories based on whether they involved a change in land use, soil management, livestock management, fertiliser management, manure management or a change to farm infrastructure.

Overall, the 'User Manual' provided a succinct description of the range of mitigation methods, their cost-effectiveness and applicability. Each method was described separately using the same form of presentation for each, with information provided under the following headings:

Description. Details of the actions to be taken to implement the method.

Rationale. The broad reason for adopting the method as a means of reducing pollution.

Mechanism of action. A description of the processes leading to a reduction in pollution.

Potential for applying the method. An assessment of the UK farming systems, regions, soils and crops to which the method is most applicable.

Practicability. An assessment of how easy the method is to adopt, how it may impact on other farming practices, problems with maximising effectiveness and possible resistance to uptake.

Costs. A table of how much it would cost to implement the method in terms of investment and operational costs.

Effectiveness. A table of the effectiveness of the method in reducing losses of N, P and FIOs.

Other benefits or risk of pollution swapping. An assessment of wider environmental benefits and how emissions of other pollutants might be reduced or increased if the method were to be adopted.

As an example of the format, the entry for Method 9, establishing in-field grass buffer strips, is presented in Table 4. In this example, the table of costs did not include the arable with manure farm because costs were assumed to be similar to those for the arable farm. Similarly, there were no values for the dairy and suckler beef farms in the cost or effectiveness tables because Method 9 was not applicable to these all-grass farms. The higher cost of implementing this measure on the outdoor pig farm arose from the additional need for a pig-proof fence on both sides of the strip. This was the only method where the reduction in P loss was greater for the farms on sandy loam than on clay loam soil, even though baseline losses were appreciably larger on the clay loam soil.

Comparisons between farm types and methods

When the full range of methods were compared there were large differences in their estimated cost and effectiveness and between farm types. The potential for reducing losses was greatest on those model farms with the highest baseline losses but there were differences in the extent to which the various methods could be applied to the different farm types. Although the outdoor pig farm was the most polluting of the model farms, only 18% of the 44 methods were applicable to this farm type, compared with 66% for the indoor pig and broiler chicken farms. The methods in the soil management category were most applicable to the various arable types of farm, with only Methods 10 (loosen compacted soil layers in grassland) and 12 (allow field drainage systems to deteriorate) being applicable to the dairy and suckler beef farm types. Examples of the variation in cost and effectiveness are shown in Figure 1 for the model dairy farm and indoor pig farm, on a clay loam and sandy loam soil, respectively. The reductions in N and P losses are shown as a percentage of the baseline loss in the same way as for FIOs. Only the methods that were applicable to the particular farm type are shown, arranged in order of increasing cost. It is apparent that the relative order of methods differs for the two farms and absolute costs for some methods, as £/ha, are much higher for the indoor pig farm.

When considered over all the farm types, a small number of the methods were particularly effective at reducing losses, often of more than one pollutant, but these were generally high-cost options (Methods 1, 13, 30 and 37). However, there were also methods of intermediate effectiveness but only low to moderate cost (e.g. Methods 25, 27, 35, 43 and 44) and a few that provided a ‘win-win’ solution, reducing pollution while at the same time achieving a cost saving for the farmer, either through reducing cultivation costs (Method 4) or fertiliser costs (Methods 20 and 22). Many methods, including most of the soil management methods, achieved only a small reduction in pollutant loss, but were relatively cheap to implement. The most effective soil management methods were Methods 2 (establish cover crops in autumn) and 9 (establish buffer strips). Method 9 was particularly effective at reducing losses of P on sandy loam soils and of FIOs from the outdoor pig farm (Table 4), but in all other respects Method 2 was as effective and at appreciably lower cost. In contrast, the least effective of all methods was Method 11 (maintaining soil organic matter contents in arable fields). This was relatively costly to implement, slightly increased losses of N and FIOs and would only be expected to reduce P losses and improve soil quality in the longer term.

The consideration of all three pollutants together helped provide a better assessment of the overall cost-effectiveness of each method, though there was no attempt to present this as a single effectiveness score. The additional information about possible impacts on other pollutants also contributed to this wider assessment, by indicating additional benefits or a risk of ‘pollution swapping’ increasing other forms of pollution. For example, Method 12 (allowing field drains to deteriorate) reduced nitrate leaching losses, but the wetter soil may increase denitrification and associated nitrous oxide emissions. Similarly, Method 14 (reducing the length of the grazing season) would reduce N, P and FIO losses to water but at the whole-farm scale may increase gaseous emissions of ammonia and methane.

Discussion

Limitations of the 'User Manual'

The 'User Manual' was successful in providing provisional estimates of cost and effectiveness in an accessible form; nevertheless, there were a number of unavoidable limitations to its content and application. It is useful to express the estimates of cost and effectiveness at the whole-farm level as this is the scale at which the methods are implemented; however, whole-farm values are reliant on the particular properties of the farms for which they are determined. Hence, the estimates in the 'User Manual' were only strictly valid for farms matching the defined model farm types and cannot be representative of the full range of farms found within a particular farming sector or of different soils and climate zones. For example, the model dairy farm was defined as an all-grass farm, but if the description had allocated part of the area to growing forage maize or cereals this would have changed the baseline losses and several additional methods targeted at arable land would have become applicable. Similarly, baseline losses and the cost and effectiveness of many methods were sensitive to the proportion of the farm contributing to the loss and to which the method could be applied; for example, the area of land susceptible to run-off or bordering a watercourse. Actual farms also differ in the extent to which mitigation methods have already been adopted, with fewer opportunities for improvements in water quality on those farms that have already applied some controls. In addition, the 'User Manual' only considered the cost-effectiveness of individual methods whereas, in practice, several may be applied together. The 'User

Manual' noted where particular methods were incompatible but it was beyond its scope to quantify the combined cost and effectiveness of combinations of methods.

Estimates of cost are subject to further uncertainty because there are likely to be different ways of implementing any particular method, even within a single farm, and their costs may differ from those assumed in the 'User Manual'. As the 'User Manual' makes clear, the estimates of cost and effectiveness only apply to the model farms and cannot be simply extrapolated to the whole of a farming sector across farms of different sizes and in different regions.

Further uncertainty arose from the difficulties of extending results from what was often a limited number of research studies to a whole-farm scale and to different soils. This particularly affected estimates of FIO losses, but for some methods there was a lack of information about all three pollutants; for example, there was little practical experience of operating artificial wetlands on UK farms (Method 44). Expert elicitation was a satisfactory procedure for dealing with these situations where evidence was lacking. However, since the preparation of the original 'User Manual' there has been recognition of the need for greater accountability in the elicitation process and quantification of the inherent uncertainty in the estimates obtained (Kreuger *et al*., 2012). Although the 'User Manual' did not attempt to provide a measure of the uncertainty attached to the individual estimates, the differences between effective and ineffective methods were often sufficient for these limitations to be of secondary importance.

Use of the 'User Manual' and its further development

The 'User Manual' has been used by policy makers in Defra, by the Environment Agency and by Catchment Officers providing advice to farmers as part of the CSF Programme designed to achieve the environmental objectives required by the Water Framework Directive. The 'User

Manual' was also an important source of information that was used with data from other countries to produce an on-line, Europe-wide register of methods for controlling DWPA (Schoumans *et al*., 2011).

More recent work for Defra has produced an updated and extended version of the 'User Manual'. This 'User Guide' (Newell-Price *et al*., 2011) retained a similar format to the 'User Manual', but included a wider range of pollutants and a greater number of potential mitigation methods, including methods for controlling gaseous pollutants. It addressed several of the limitations of the earlier 'User Manual' by including a wider range of model farm types and rainfall zones. It also recognised the high uncertainty associated with the estimates of effectiveness and presented these as a broad effectiveness range rather than attempting to assign specific values. Alongside this, a decision support tool, FARMSCOPER (Gooday *et al*., 2014), was developed for farmers and advisors to assess pollutant losses from the farm and quantify the impacts of mitigation methods. This model allows greater customisation of the farm systems to better describe actual farms and environmental conditions. It also has the ability to examine the effectiveness of combinations of methods and also takes account of uncertainties to allow selection of those methods that provide the greatest chance of success.

Opinions of catchment officers and advisors using the 'User Manual' in the field

In 2015, a number of users were asked a series of questions about the 'User Manual' and subsequent 'User Guide'. The contributors included Catchment Sensitive Farming Officers, River Basin Co-ordinators, Catchment Officers of Rivers Trusts and Environment Agency staff. Users stated that the 'User Manual/User Guide' was key to their work, giving structure in advice and in catchment planning. For those new to the subject, it provided a very good introduction to DWPA issues and helped them to select the most relevant mitigation methods in a given situation.

The more experienced officers tended to use the ‘User Manual/User Guide’ less frequently with time, although it was still used as a reference and to provide a benchmark. Individual interpretation is critical for each farm situation and the ‘User Manual/User Guide’ was used by officers to build up a picture of the farm, its place in the catchment, changes in pollution pressures over the seasons and the farmer’s attitude to various mitigation methods. Cost-effectiveness values play a large part in convincing farmers to take up mitigation methods. Implementation of methods is significantly influenced by grant support, where available, which is targeted at the main contributors to DWPA within CSF priority catchments. However, although for many farmers capital grants have provided an introduction to controlling DWPA, they account for a minor proportion of method implementation overall.

Conclusions

The ‘User Manual’ was successful in bringing together research data, expert opinion and advisory experience from a wide range of sources to provide succinct information on DWPA mitigation. The ‘User Manual’ and later ‘User Guide’ provide useful information to aid selection of methods at the field and farm scale. A limitation to the approach was that estimates of baseline pollutant losses and the cost-effectiveness of methods only applied to the model farms and climate described in the ‘User Manual’. Extending the information to the catchment and wider scales and to different environmental conditions can only be addressed through the greater flexibility of computer models such as the FARMSCOPER tool. In future versions of the ‘User Guide’ there may also be scope for greater consideration of socio-economic factors affecting the acceptability and uptake of mitigation methods by farmers.

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TABLES

Table 1 Summary characteristics of the model farm types used for estimating the costs and effectiveness of the mitigation methods.

Farm type	Total field area (ha)	Cropping & livestock	Average fertiliser-N (kg N/ha)
Arable farm	300	Mixed combinable crops.	165
Arable farm with manure	300	Mixed combinable crops: 60 ha received imported solid FYM or pig slurry.	165 or 140 with manure
Dairy farm	150	All-grass (grazing & silage). Bought-in concentrates. 150 adult dairy cows + 120 followers. Stock housed in winter with excreta managed as slurry and dirty water.	190
Suckler beef farm	100	All-grass (grazing & silage). Bought-in concentrates. Spring-calving herd (80 cows, 70 calves, 70 yearlings). Stock in concrete yards during winter. Excreta + straw bedding managed as FYM.	100
Broiler chicken farm	437	150,000 bird places. Litter managed as solid manure and spread on adjoining arable land. Mixed combinable crops.	145
Indoor pig farm	71	290 dry sow, 60 farrowing sow, 585 first stage weaner and 565 second stage weaner places. Excreta managed as slurry and spread on adjoining arable land. Mixed combinable crops.	145
Outdoor pig farm	24	Places for 500 dry sows, 92 farrowing sows and 1,944 first stage weaners. All feed bought-in. Sows have access to whole field area.	0

Table 2 Estimated baseline losses of N, P and FIOs for the model farms with no mitigation methods applied, on sandy loam and clay loam soils.

Farm type	**Baseline loss at the farm scale**					
	Nitrate (kg N/ha)		**Total P (kg P/ha)**		**FIOs (relative units)**	
	sandy loam	clay loam	sandy loam	clay loam	sandy loam	clay loam
Arable	51	47	0.3	2.3	0	0
Arable + manure	57	51	0.4	2.5	1	1
Dairy	61	34	0.2	2.8	36	100
Beef	18	12	0.2	1.0	15	43
Broilers	82	68	0.4	3.2	0	0
Indoor pigs	89	74	0.5	3.7	4	10
Outdoor pigs	108	n/a	10.5	n/a	190	n/a

Table 3 Mitigation methods selected for inclusion in the 'User Manual'.

Category	No.	Method
Land use	1	Convert arable land to extensive grassland
Soil management	2	Establish cover crops in the autumn
	3	Cultivate land for crop establishment in spring rather than autumn
	4	Adopt minimal cultivation systems
	5	Cultivate compacted tillage soils
	6	Cultivate and drill across the slope
	7	Leave autumn seedbeds rough
	8	Avoid tramlines over winter
	9	Establish in-field grass buffer strips
	10	Loosen compacted soil layers in grassland fields
	11	Maintain and enhance soil organic matter levels
	12	Allow field drainage systems to deteriorate
Livestock management	13	Reduce overall stocking rates on livestock farms
	14	Reduce the length of the grazing day or grazing season
	15	Reduce field stocking rates when soils are wet
	16	Move feed and water troughs at regular intervals
	17	Reduce dietary N and P intakes
	18	Adopt phase feeding of livestock
Fertiliser management	19	Use a fertiliser recommendation system
	20	Integrate fertiliser and manure nutrient supply
	21	Reduce fertiliser application rates
	22	Do not apply P fertilisers to high P index soils
	23	Do not apply fertiliser to high-risk areas
	24	Avoid spreading fertiliser to fields at high-risk times
Manure management	25	Increase the capacity of farm manure (slurry) stores
	26	Minimise the volume of dirty water produced
	27	Adopt batch storage of slurry
	28	Adopt batch storage of solid manure
	29	Compost solid manure
	30	Change from slurry to a solid manure handling system
	31	Site solid manure heaps away from watercourses and field drains
	32	Site solid manure heaps on concrete and collect the effluent
	33	Do not apply manure to high-risk areas
	34	Do not spread farmyard manure to fields at high-risk times
	35	Do not spread slurry or poultry manure to fields at high-risk times
	36	Incorporate manure into the soil
	37	Transport manure to neighbouring farms
	38	Incinerate poultry litter
Farm infrastructure	39	Fence off rivers and streams from livestock
	40	Construct bridges for livestock crossing rivers and streams
	41	Re-site gateways away from high-risk areas
	42	Establish new hedges
	43	Establish riparian buffer strips
	44	Establish and maintain artificial (constructed) wetlands

Table 4 Example of the format used to describe each method in the 'User Manual': Method 9.

Establish in-field grass buffer strips.

9. Establish in-field grass buffer strips

Description: On sloping fields, establish grass buffer strips along the land contour, in valley bottoms or on upper slopes to reduce and slow down surface flow. Cut regularly in the first 12 months to control annual weeds and encourage grasses to tiller.

Rationale: In-field buffer strips can reduce P and, where manures are applied to tillage land, FIO losses by slowing run-off and intercepting the delivery of sediment.

Mechanism of action: An in-field buffer strip is a vegetated strip of land, located along the land contour, on upper slopes or in valley bottoms. It is usually a permanent feature, although it can be temporary. The Entry Level Environmental Stewardship Scheme[†] offers options for strips between 2 and 6 m in width. Also, under the Higher Level Stewardship Scheme[†], there is the option to establish in-field grass areas to prevent erosion and run-off (with a maximum permissible area of 30% of each field).

The strip acts as a natural buffer to reduce the transfer of diffuse pollutants in surface run-off from agricultural land to water. Buffer strips can act as a sediment-trap, as well as helping to reduce nutrient and pesticide losses in run-off. The strip has no effect on nitrate other than *pro rata* for the area taken out of production (i.e. the buffer strip is similar to unfertilised grass).

Potential for applying the method: In-field buffer strips are applicable to all arable farming systems on sloping land. They are particularly suited to fields with long slopes, where high volumes of surface run-off can be generated.

Practicability: The buffer strips will reduce the length of fields, but increase the time taken for field operations by around 10%. They are reasonably acceptable to farmers who are keen to improve the environmental potential of their farm and are compatible with the Entry Level and Higher Level Environmental Stewardship schemes. They may be more effective when combined with additional riparian buffer strips (Method 43).

Cost: It has been assumed that 10% of the farm area will be put into buffer strips (see Appendix II).

Annual costs for farm system	**Arable**	**Dairy**	**Beef**	**Broilers**	**Pigs (indoor)**	**Pigs (outdoor)**
Cost £/ha of strip	31.6	n/a	n/a	31.6	31.6	440
Cost £/farm	9,480	”	”	13,630	2,240	10,530

(continued)

[†]*These schemes were replaced by the Countryside Stewardship Scheme in 2015*

Table 4 (continued) Example of the format used to describe each method in the 'User Manual': Method 9. Establish in-field grass buffer strips.

Effectiveness:

N: The benefit will be from taking land out of production and will be confined to the area of the buffer strip. The nitrate loss from the strip will be similar to that from ungrazed, zero-N grassland. The buffer strips are assumed to occupy 10% of the farm area; the reduction in leaching at the farm scale will therefore be 10% of the arable reversion value for the particular model farm system and soil type (see Method 1(a)).

P: PE0203 Method 40 ‘Grass buffers’ was used, as applied to the all-arable and grassland scenarios. After adjusting for the expert weighting, this reduced the overall P loss by 40% on both soil types. The benefit was confined to the 10% buffer strip area on the clay loam soil but was effective over 100% of the area on the sandy loam.

FIOs: <10% reduction. Even without the mitigation method, losses of FIOs from arable land are generally small because the storage period for manures is sufficient for most organisms to die-off before spreading and manures are then ploughed in after application.

	Reduction in pollutant loss at the farm scale (baseline loss for the farm type is shown in parentheses)					
Farm type	**Nitrate (kg N/ha)**		**Total P (kg P/ha)**		**FIOs (%)***	
	sandy loam	clay loam	sandy loam	clay loam	sandy loam	clay loam
Arable	4.9 (51)	4.5 (47)	0.14 (0.3)	0.09 (2.3)	0 (0.0)	0 (0.0)
Arable + manure	5.5 (57)	4.9 (51)	0.14 (0.4)	0.10 (2.5)	0 (0.4)	0 (1.0)
Dairy	n/a (61)	n/a (34)	n/a (0.2)	n/a (2.8)	n/a (35.7)	n/a (100)
Beef	n/a (18)	n/a (12)	n/a (0.2)	n/a (1.0)	n/a (15.5)	n/a (43.2)
Broilers	8.0 (82)	6.6 (68)	0.17 (0.4)	0.13 (3.2)	0 (0)	0 (0)
Indoor pigs	8.7 (89)	7.0 (74)	0.19 (0.5)	0.15 (3.7)	0 (4.0)	0 (10.3)
Outdoor pigs	14.0 (108)		4.38 (10.5)		20 (191)	

**Baseline losses for FIOs are in relative units, where the loss from the dairy farm system on a clay loam soil = 100 units. Reductions are shown as percentages of the baseline FIO loss.*

Other benefits or risk of pollution swapping: Buffer strips can also reduce the transfer of BOD and ammonium-N to surface waters by intercepting organic matter in surface run-off. The risk of pollution is increased if fertiliser or manure is spread on the buffer strips and if the buffer strips are used for regular access, turning or storage.

FIGURE CAPTION

Figure 1 Estimates of the reduction in losses of nitrate-N, phosphorus and FIOs as a percentage of the baseline loss for the mitigation methods applied to (a) the model dairy farm (on clay loam soil) and (b) the indoor pig farm (on sandy loam soil) and the annual cost of the methods, arranged in order of increasing cost. Where costs are negative this represents a saving. Methods that are not applicable to the particular farm type are omitted.