

1 **A method-centric ‘User Manual’ for the mitigation of diffuse**  
2 **water pollution from agriculture**

3 S. P. CUTTLE <sup>a1</sup>, J. P. NEWELL PRICE <sup>b\*</sup>, D. HARRIS <sup>c</sup>, D. R. CHADWICK <sup>d2</sup>, M. A.  
4 SHEPHERD <sup>b3</sup>, S. G. A. ANTHONY <sup>e</sup>, C. J. A. MACLEOD <sup>d4</sup>, P. M. HAYGARTH <sup>d5</sup>  
5 & B. J. CHAMBERS <sup>b</sup>

6

7 <sup>a</sup> *Institute of Grassland and Environmental Research (IGER), Plas Gogerddan (now Institute*  
8 *of Biological, Environmental and Rural Sciences - IBERS - Aberystwyth University),*  
9 *Aberystwyth, Ceredigion SY23 3EB, UK, <sup>b</sup>ADAS Gleadthorpe, Meden Vale, Mansfield, Notts.*  
10 *NG20 9PD, UK, <sup>c</sup>ADAS Leeds, Rubicon Square, Pentagon 2, 4205 Park Approach, Thorpe*  
11 *Park, Leeds LS15 8GB, UK, <sup>d</sup>IGER, North Wyke (now Rothamsted Research, North Wyke),*  
12 *Okehampton, Devon, EX20 2SB UK, <sup>e</sup>ADAS Wolverhampton, Pendeford House, Pendeford*  
13 *Business Park, Wolverhampton WV9 5AP, UK*

14 <sup>1</sup>Now retired, <sup>2</sup>Now at the *School of Environment, Natural Resources and Geography,*  
15 *Bangor University, Bangor LL57 2UW, UK, <sup>3</sup>Now at AgResearch, Ruakura Research Centre,*  
16 *Hamilton 3214, NZ, <sup>4</sup>Now at The James Hutton Institute, Craigiebuckler, Aberdeen AB15*  
17 *8QH, UK, <sup>5</sup>Now at Lancaster Environment Centre, Lancaster University, Lancaster LA1 4YQ,*  
18 *UK*

19 **\*Corresponding Author:** P. Newell-Price. (E-mail: Paul.Newell-Price@adas.co.uk)

20

21 **Running Title:** Manual for mitigation of diffuse water pollution

## 22 **Summary**

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

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

41 **Introduction**

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

55 In this paper we describe one of the first attempts to provide policy makers with an  
56 integrated assessment of the cost-effectiveness of a range of potential mitigation measures to  
57 control losses of the most important forms of diffuse water pollution from agriculture  
58 (DWPA): nitrogen (N) in the form of nitrate-N, phosphorus (P) and faecal indicator  
59 organisms (FIOs) originating from animal excreta and manures. This was presented in the  
60 form of a 'User Manual', which in addition to information about their cost-effectiveness also  
61 provided specific information about how the methods operate, their applicability to different  
62 types of farm and the wider implications of their use. A novel feature of the 'User Manual'  
63 was that it adopted a 'method-centric' approach, focussing on each method in turn and its  
64 simultaneous impact on all three pollutants. Preparation of the 'User Manual' also recognised  
65 that for some methods and circumstances the evidence base will always be incomplete and it

66 was necessary to rely on expert elicitation to fill the gaps where scientific data were lacking,  
67 accepting the uncertainties associated with this process. Expert elicitation is recognised as  
68 making a valuable contribution to the description and modelling of complex environmental  
69 systems, especially where evidence is incomplete and the implementation of policies or  
70 actions cannot be delayed until all the necessary knowledge becomes available (Kreuger *et*  
71 *al.*, 2012).

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

## 79 **Method**

### 80 *Development of the ‘User Manual’*

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

89 controlling losses of N, P and FIOs, their cost and effectiveness and the potential for their  
90 application within different farming systems and soil types.

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

#### 96 *Model farms, climate and soil types*

97 Pollutant losses were expressed at the whole-farm level. It was therefore necessary to define  
98 specific model farms to use as the basis for the calculations. These were chosen to be  
99 representative of the main UK farming sectors and were closely defined in terms of farmed  
100 area, field size, cropping, livestock numbers and ages, housing period, fertiliser and  
101 manure/slurry management, using typical values obtained from published data (e.g. MAFF,  
102 2000; Smith *et al.*, 2000; Goodlass & Allin, 2004) and expert judgement. Characteristics of  
103 the seven model farm types are outlined in Table 1.

104 All farms were assumed to be located in a medium rainfall area (850 mm rain/year).  
105 Estimates were prepared for farms on a clay loam soil (assumed to be artificially drained  
106 under arable production) and on a sandy loam soil (assumed to be freely drained and not  
107 requiring artificial drainage), representing the dominant contrasting soil types in England and  
108 Wales (Avery, 1980). Around 56% of lowland soils in England and Wales have topsoil  
109 textures that are either sandy loam or clay loam (Anthony, 2006). The model outdoor pig farm  
110 was restricted to the sandy loam soil as such enterprises are only suited to free-draining sites.  
111 For farms on clay loam soil, an expert judgement approach was used to decide on the  
112 proportion of fields having artificial drainage: all fields on the arable farms were assumed to

113 have an effective drainage system installed, but only two-thirds of fields on the dairy farm and  
114 one-third on the suckler beef farm. Sandy loam soils were assumed to be at risk of capping  
115 (Catt *et al.*, 1998; Chambers *et al.*, 2000), with the result that surface run-off would be greater  
116 than from the clay loam soil but with less transport of suspended soil particles.

117 *Estimates of baseline losses and the effectiveness of mitigation methods*

118 The first stage of the estimations was to determine baseline pollutant losses for each of the  
119 farms in the absence of any mitigation methods. The NITCAT (Lord, 1992), NCYCLE  
120 (Scholefield *et al.*, 1991), MANNER (Chambers *et al.*, 1999) and SLIMMER (Anthony *et al.*,  
121 1996) models were used to estimate nitrate-N losses and the PSYCHIC model (Davison *et al.*,  
122 2008) for P losses for each area of the farm under a particular management regime. These  
123 were validated using field experimental evidence (e.g. Oliver *et al.*, 2005) and combined to  
124 obtain an overall, average loss for the whole farm area (in kg/ha/year).

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

134         The estimated baseline losses are summarised in Table 2. The lowest losses of N and P  
135 were from the model suckler beef farm and the largest from the outdoor pig unit, which also  
136 had the highest baseline loss of FIOs, almost double that from the reference dairy farm. There

137 were much smaller losses of FIOs from farm types that applied farmyard manure (FYM)  
138 because FYM was assumed to be stored long enough for most organisms to die off before the  
139 material was spread. FIO losses would have been higher if these farms had been assumed to  
140 apply fresh manures or slurry. Losses of N were slightly greater for the model farms on the  
141 sandy loam soil than on clay loam while losses of P and FIOs were appreciably higher on the  
142 clay loam soil.

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

156         In the 'User Manual', the effectiveness was summarised in a table for each method,  
157 listing the reduction in nitrate-N, total P and FIO losses at the farm scale and the baseline loss  
158 for each farm type on the sandy loam and clay loam soils (except for those farms where the  
159 method was not applicable). Reductions in P losses only referred to the short-term effect;  
160 some methods will achieve a greater reduction in the longer term (>10 years) as a result of a

161 slow decline in soil P contents, but because of the uncertainties in these estimates, they were  
162 not quantified in the ‘User Manual’.

### 163 *Estimates of baseline costs and the costs of implementing the mitigation methods*

164 Estimates of the cost of implementing each method were determined for each of the model  
165 farm types. Costs could be trading costs in terms of impacts on productivity, variable costs  
166 such as feed and fertiliser, fixed costs such as machinery and labour, management time or  
167 capital costs, which required converting to an annual value as appropriate for the different  
168 methods. Where a method resulted in land not being farmed, this could lead to a loss of  
169 support payments but this was not assumed in the estimates. Similarly, the costs did not  
170 include any impacts on the agricultural supply industry arising from reductions in stocking  
171 rates or in the area of land farmed. All estimates were based on typical costs as in autumn  
172 2006. In the ‘User Manual’, costs were presented for each method as a table with cost per ha  
173 and averaged over the whole farm area and, where appropriate, as capital and annual costs.

### 174 *Expert elicitation*

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

## 184 **Results**



185 *Description of the 'User Manual'*

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

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

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

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

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

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

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

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

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

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

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

#### 217 *Comparisons between farm types and methods*

218 When the full range of methods were compared there were large differences in their estimated  
219 cost and effectiveness and between farm types. The potential for reducing losses was greatest  
220 on those model farms with the highest baseline losses but there were differences in the extent  
221 to which the various methods could be applied to the different farm types. Although the  
222 outdoor pig farm was the most polluting of the model farms, only 18% of the 44 methods  
223 were applicable to this farm type, compared with 66% for the indoor pig and broiler chicken  
224 farms. The methods in the soil management category were most applicable to the various  
225 arable types of farm, with only Methods 10 (loosen compacted soil layers in grassland) and 12  
226 (allow field drainage systems to deteriorate) being applicable to the dairy and suckler beef  
227 farm types. Examples of the variation in cost and effectiveness are shown in Figure 1 for the  
228 model dairy farm and indoor pig farm, on a clay loam and sandy loam soil, respectively. The  
229 reductions in N and P losses are shown as a percentage of the baseline loss in the same way as

230 for FIOs. Only the methods that were applicable to the particular farm type are shown,  
231 arranged in order of increasing cost. It is apparent that the relative order of methods differs for  
232 the two farms and absolute costs for some methods, as £/ha, are much higher for the indoor  
233 pig farm.

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

249           The consideration of all three pollutants together helped provide a better assessment of  
250 the overall cost-effectiveness of each method, though there was no attempt to present this as a  
251 single effectiveness score. The additional information about possible impacts on other  
252 pollutants also contributed to this wider assessment, by indicating additional benefits or a risk  
253 of ‘pollution swapping’ increasing other forms of pollution. For example, Method 12  
254 (allowing field drains to deteriorate) reduced nitrate leaching losses, but the wetter soil may

255 increase denitrification and associated nitrous oxide emissions. Similarly, Method 14  
256 (reducing the length of the grazing season) would reduce N, P and FIO losses to water but at  
257 the whole-farm scale may increase gaseous emissions of ammonia and methane.

## 258 **Discussion**

### 259 *Limitations of the 'User Manual'*

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

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

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

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

#### 298 *Use of the 'User Manual' and its further development*

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

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

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

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

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

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

### 336 **Conclusions**

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

347

### 348 **Acknowledgements**

349 The funding provided by Defra and the feedback provided by Catchment Sensitive Farming  
350 Officers, River Basin Co-ordinators, Catchment Officers of Rivers Trusts and Environment  
351 Agency staff is gratefully acknowledged.



352 **References**

- 353 Anthony, S.G., Quinn, P. & Lord, E.I. 1996. Catchment scale modelling of nitrate leaching.  
354 *Aspects of Applied Biology*, **46**, 23-32.
- 355 Anthony, S.G. 2006. Cost and effectiveness of policy instruments for reducing diffuse  
356 agricultural pollution. Final report for Defra projects WQ0106 and ES0205. ADAS,  
357 Wolverhampton, 119 pp.
- 358 Avery, B.W. 1980. Soil Classification for England and Wales (Higher Categories). *Soil*  
359 *Survey Technical Monograph*, **14**. Harpenden.
- 360 Catt, J.A., Howse, K.R., Farina, R., Brockie, D., Todd, A., Chambers, B.J., Hodgkinson, R.,  
361 Harris, G.L. and Quinton, J.N. (1998). Phosphorus losses from arable land in England. *Soil*  
362 *Use and Management*, **14**, 168-174.
- 363 Chambers, B.J., Lord, E.I., Nicholson, F.A. & Smith, K.A. 1999. Predicting nitrogen  
364 availability and losses following application of organic manures to arable land: MANNER.  
365 *Soil Use and Management*, **15**, 137-143.
- 366 Chambers, B. J., Garwood, T. W. D. & Unwin, R.J. 2000. Controlling soil water erosion and  
367 phosphorus losses from arable land in England and Wales. *Journal of Environmental Quality*,  
368 **29**, 145-150.
- 369 Cherry, K.A., Shepherd, M., Withers, P.J.A. & Mooney, S.J. 2008. Assessing the  
370 effectiveness of actions to mitigate nutrient loss from agriculture: a review of methods.  
371 *Science of the Total Environment*, **15**, 1-23.
- 372 Cuttle, S., Macleod, C., Chadwick, D., Scholefield, D., Haygarth, P., Newell-Price, P., Harris,  
373 D., Shepherd, M., Chambers, B. & Humphrey, R. 2007. An Inventory of Methods to Control  
374 Diffuse water Pollution from Agriculture – User Manual. Prepared as part of Defra project

375 ES0203. Available at:  
376 [http://randd.defra.gov.uk/Document.aspx?Document=es0203\\_4145\\_FRA.pdf](http://randd.defra.gov.uk/Document.aspx?Document=es0203_4145_FRA.pdf); accessed  
377 27/9/2015.

378 Davison, P., Withers, P., Lord, E., Betson, M. & Stromqvist, J. 2008. PSYCHIC - A process  
379 based model of phosphorus and sediment mobilisation and delivery within agricultural  
380 catchments. Part 1 – Model description and parameterisation. *Journal of Hydrology*, **350**, 290-  
381 302.

382 Defra. 2004a. Cost curve of nitrate mitigation options. Final report for project NT2511.  
383 Available at:  
384 <http://randd.defra.gov.uk/Default.aspx?Module=More&Location=None&ProjectID=11431>;  
385 accessed 27/9/2015.

386 Defra. 2004b. Investigations of the routes by which pathogens associated with livestock  
387 slurries and manure may be transferred from the farm to the wider environment. Final report  
388 for project WA0804. Available at:  
389 [http://randd.defra.gov.uk/Document.aspx?Document=WA0804\\_3190\\_FRP.doc](http://randd.defra.gov.uk/Document.aspx?Document=WA0804_3190_FRP.doc); accessed  
390 27/9/2015.

391 Defra. 2005. *COST-DP: Cost effective diffuse pollution mitigation*. Final report for project  
392 ES0121. Available at:  
393 [http://randd.defra.gov.uk/Document.aspx?Document=ES0121\\_3701\\_FRP.doc](http://randd.defra.gov.uk/Document.aspx?Document=ES0121_3701_FRP.doc); accessed  
394 27/9/2015.

395 EU. 2000. Water Framework Directive. Directive 2000/60/EC of the European Parliament  
396 and of the Council of 23 October 2000 (OJ L 327, 22 December 2000). Available at:  
397 [http://ec.europa.eu/environment/water/water-framework/index\\_en.html](http://ec.europa.eu/environment/water/water-framework/index_en.html); accessed 27/9/2015.

398 Haygarth P.M. & Jarvis S.C. (eds.) 2003. *Agriculture, Hydrology and Water Quality*. CAB  
399 International Wallingford UK.

400 Haygarth, P. M., ApSimon, H., Betson, M., Harris, D., Hodgkinson, R., & Withers, P. J. A.  
401 2009. Mitigating diffuse phosphorus transfer from agriculture according to cost and  
402 efficiency. *Journal of Environmental Quality*, **38**, 2012-2022.

403 Gooday, R.D., Anthony, S.G. Chadwick, D.R., Newell-Price, J.P., Harris, D., Duethmann, D.,  
404 Fish, R., Collins, A.L. & Winter, M. 2014. Modelling the cost-effectiveness of mitigation  
405 methods for multiple pollutants at farm scale. *Science of the Total Environment*, **468**, 1198-  
406 1209.

407 Goodlass, G. & Allin, R. 2004. *British Survey of Fertiliser Practice: Fertiliser Use on Farm*  
408 *Crops for Crop Year 2003*. Defra/SEERAD. ISBN 1 86190 127 5.

409 Krueger, T., Page, T., Hubacek, K., Smith, L., & Hiscock, K. 2012. The role of expert opinion  
410 in environmental modelling. *Environmental Modelling & Software*, **36**, 4-18.

411 Lord, E.I. 1992. Modelling of nitrate leaching: Nitrate Sensitive Areas. *Aspects of Applied*  
412 *Biology*, **30**, 19-28.

413 Macleod, C.J.A., Blackstock, K.L. & Haygarth, P.M. 2008. Mechanisms to improve  
414 integrative research at the science-policy interface for sustainable catchment management.  
415 *Ecology and Society*, **13**, Article 48. Available at:  
416 <http://www.ecologyandsociety.org/vol13/iss2/art48/>; accessed 27/9/2015.

417 MAFF. 2000. *Fertiliser Recommendations for Agricultural and Horticultural Crops (RB209)*.  
418 7th edition. The Stationery Office Norwich UK.

419 Natural England. 2013. CSF052: Working towards Catchment Sensitive Farming. Available  
420 at: <http://publications.naturalengland.org.uk/publication/32034>; accessed 27/9/2015.

421 Newell-Price, J.P., Harris, D., Taylor, M., Williams, J.R., Anthony, S.G., Duethmann, D.,  
422 Gooday, R.D., Lord, E.I., Chambers, B.J., Chadwick, D.R. & Misselbrook, T.H. 2011.  
423 Mitigation Methods - User Guide. An Inventory of Mitigation Methods and Guide to their  
424 Effects on Diffuse Water Pollution, Greenhouse Gas Emissions and Ammonia Emissions  
425 from Agriculture. Prepared as part of Defra project WQ0106. Available at:  
426 [http://randd.defra.gov.uk/Document.aspx?Document=MitigationMethods-](http://randd.defra.gov.uk/Document.aspx?Document=MitigationMethods-UserGuideDecember2011FINAL.pdf)  
427 [UserGuideDecember2011FINAL.pdf](http://randd.defra.gov.uk/Document.aspx?Document=MitigationMethods-UserGuideDecember2011FINAL.pdf); accessed 27/9/2015.

428 Oliver, D. M., Heathwaite, L., Haygarth, P. M., and Clegg, C. D. 2005. Transfer of  
429 *Escherichia coli* to water from drained and undrained grassland after grazing. *Journal of*  
430 *Environmental Quality*, **34**, 918-925.

431 Scholefield, D. Lockyer, D., Whitehead, D. & Tyson, K. 1991. A model to predict  
432 transformations and losses of nitrogen in UK pastures grazed by beef cattle. *Plant and Soil*,  
433 **132**, 165-177.

434 Schoumans, O.F. (Ed.), Chardon, W.J. (Ed.), Bechmann, M., Gascuel-Oudou, C., Hofman,  
435 G., Kronvang, B., Litaor, M.I., Lo Porto, A, Newell-Price, P. & Rubaek, G. 2011. Mitigation  
436 options for nutrient reduction in surface waters and groundwaters. A study amongst European  
437 member states of Cost action 869. Alterra Report 2141. Alterra, Wageningen, The  
438 Netherlands. Available at: <http://www.cost869.alterra.nl/Report2141.pdf>; accessed 27/9/2015.

439 Sharpley, A.N., Withers, P.J.A., Abdalla, C.W. & Dodd, A.R. 2005. Strategies for the  
440 sustainable management of phosphorus. In: *Phosphorus: Agriculture and the Environment*  
441 (eds J.T. Sims & A.N. Sharpley), Agronomy Monograph 46, American Society of Agronomy  
442 Madison WI, pp 1069 - 1101.

443 Shepherd, M.A. & Chambers, B.J. 2007. Managing nitrogen on the farm: the devil is in the  
444 detail. *Journal of the Science of Food and Agriculture*, **87**, 558-568.

445 Smith, K.A., Brewer, A.J., Crabb, J. & Dauven, A. 2000. A survey of the production and use  
446 of animal manures in England and Wales: 1. Pig manure. *Soil Use and Management*, **16**, 124-  
447 132.

448

449 **TABLES**

450 **Table 1** Summary characteristics of the model farm types used for estimating the costs and  
 451 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

452

453 **Table 2** Estimated baseline losses of N, P and FIOs for the model farms with no mitigation  
 454 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

455

456 **Table 3** Mitigation methods selected for inclusion in the ‘User Manual’.

<b>Category</b>	<b>No.</b>	<b>Method</b>	
<b>Land use</b>	1	Convert arable land to extensive grassland	
	2	Establish cover crops in the autumn	
<b>Soil management</b>	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	
	<b>Livestock management</b>	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	
<b>Fertiliser management</b>	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	
<b>Manure management</b>	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	
<b>Farm infrastructure</b>	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	

457



458 **Table 4** Example of the format used to describe each method in the ‘User Manual’: Method 9.

459 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<sup>†</sup> offers options for strips between 2 and 6 m in width. Also, under the Higher Level Stewardship Scheme<sup>†</sup>, 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)

---

460 <sup>†</sup>These schemes were replaced by the Countryside Stewardship Scheme in 2015

461

462 **Table 4** (continued) Example of the format used to describe each method in the 'User  
 463 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.

<b>Reduction in pollutant loss at the farm scale</b>						
(baseline loss for the farm type is shown in parentheses)						
<b>Farm type</b>	<b>Nitrate (kg N/ha)</b>		<b>Total P (kg P/ha)</b>		<b>FIOs (%)*</b>	
	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.

464

465

466 **FIGURE CAPTION**

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