ESTIMATING IMPACTS OF ELS ON KEY BIODIVERSITY INDICATORS AND DIFFUSE POLLUTION OF SURFACE WATERS BY NUTRIENTS

DEFRA CONTRACT NO. MA01041

FINAL REPORT

AUGUST 2008

Nigel Boatman
Simon Conyers
Hazel Parry
Stephane Pietravalle
Carmel Ramwell

Central Science Laboratory
Sand Hutton, York, YO41 1LZ

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ACKNOWLEDGEMENTS

The authors are grateful to Paul Dutton of Natural England for provision of ELS uptake data, and to all the experts who contributed comments and scores, especially Dr. Tom Brereton (Butterfly Conservation), Dr. Nigel Critchley (ADAS), Professor David Goulson (University of Stirling), Dr. Juliet Osborne (Rothamsted Research), Kate Still (Plantlife), and Dr. Philip Wilson (Wessex Environmental Associates). The project was funded by Defra Environmental Land Management Division

NOTE ON TIMING

This work was carried out during 2007 and the draft report submitted in November 2007.

EXECUTIVE SUMMARY

Introduction

1. An evaluation of Environmental Stewardship had recently been carried out by CSL (Boatman *et al*., 2007). As part of this project, a modelling process was developed which attempted to estimate the impact of ELS on a range of environmental indicators. The process adopted depended on expert scores for the effectiveness of each option, and estimates of the optimal area required to achieve targets. These were used to estimate the impact of the ELS in terms of the observed pattern of option uptake, in relation to optimal uptake for each indicator. This project extends the work on estimating the environmental value of ELS in two areas, biodiversity and water quality.

Biodiversity

2. Although the method worked well for biodiversity indicators, the number of experts able to provide estimates of optimal areas was limited, and so model outputs for most indicators were based on values provided by only one or two expert assessors. It was decided to develop an alternative approach for a few key biodiversity indicators based on a combination of literature search and expert knowledge as derived from advisory literature etc. to estimate habitat requirements. Results would be validated through consultation, and then provision of appropriate habitats by ELS options assessed.

3. The objectives of this part of the project were as follows:

   - To determine the key habitat factors limiting the population of the selected indicators;
   - To estimate, the amount of key habitat required to maintain viable populations
   - To identify the relevant options under ELS which provide the habitat requirements of the indicator species/groups, and propose a target area for the indicators concerned;
   - To compare habitat provision through ELS under current and projected uptake with estimated requirements, using the previously developed model.

4. Three biodiversity indicators were selected: (i) Rare arable flora, (ii) Brown hairstreak butterfly, and (iii) Bumblebees.

5. Relevant literature was examined to determine the key habitat factors likely to limit the population size of the species concerned. Estimates of the amounts of key habitats required to maintain a viable population were made, which were reviewed by appropriate experts, and the assessment revised accordingly. Relevant options addressing these habitat requirements were then determined and target amounts of these options derived, based on estimation of optimal requirements for the indicator species, modified where appropriate by considering the proportion of the points requirement which an agreement holder could reasonably be expected to devote to a specific indicator. Habitat provision through ELS was compared with that estimated to be required, using the model previously developed. In order to estimate the impact at maximum levels of uptake considered likely in the short to medium term, a projected future uptake of 70% of farmland within the scheme was assumed, but with current option uptake frequencies.

6. For arable flora, ELS option uptake was analysed only within JCAs with a score higher than 175 for importance in terms of arable flora, on a scoring

system developed by Plantlife, plus a number of JCAs with lower scores, based on expert knowledge (73 JCAs in total). For brown hairstreak, the analysis was applied only within the current distribution range, defined as 10km squares in which the species had been recorded between 1995 and 2004, in data provided by Butterfly Conservation (155 squares in total). The analysis for bumblebees was not spatially restricted.

7. Arable plants require disturbed soil and freedom from herbicides, high rates of fertiliser use and intense crop competition. Conservation action is best targeted at field edges, where occurrence and diversity of rare species are greatest. Key options for arable plant conservation are conservation headlands (EF9 & 10) and uncropped cultivated margins on arable land (EF11); overwinter stubbles (EF9), cereals for whole crop silage followed by over-wintered stubbles (EG4) and brassica fodder crops followed by overwinter stubbles (EG5) can also make a contribution. Recent work suggests that the value of EF9 (conservation headlands, with no restriction on fertiliser use) for the arable flora is more limited than previously thought, however, as EF9 was previously identified in advisory literature as beneficial for arable flora, farmers may have chosen this option believing it to be useful in this context, so it was been included in the analysis.

8. Brown hairstreaks are limited by breeding habitat, i.e. young blackthorn shoots from two years old. High egg mortality is therefore caused by annual cutting. Cutting at intervals of three years or longer is necessary to ensure colony survival. The key option providing breeding habitat for brown hairstreak is enhanced hedgerow management (EB3 & EB10). Management of woodland edges (EC4) can also be valuable. Wild bird seed mixtures (EF2/EG2) and pollen and nectar mixtures (EF4/EG4) can provide nectar sources, whilst buffer strips (EE1-6) and field corners taken out of production (EF1/EK1) can protect hedgerows and may also provide nectar.

9. Of the three indicators selected, bumblebees have had the greatest amount of research effort expended on them. For this group, suitable pollen and nectar sources appear to be the limiting factor, and key options are pollen and nectar mixtures (EF4/EG4), which were developed specifically for bumblebees, and provide nectar in flowers suitable for exploitation by the rarer long-tongued species as well as the more common and widespread species. Wild bird seed mixtures (EF2/EG2), conservation headlands (EF9 & 10) and uncropped cultivated margins on arable land (EF11) can also provide some nectar and pollen. A range of options including hedge management, buffer strips, field corners and beetle banks (EF7) can provide breeding habitat.

10. Expert scores for the value of each of the options identified on a scale of 0-10, plus target amounts, were used as inputs for the model. The model was run using two ELS uptake datasets, from November 2006 (comparable with earlier ES evaluation) and September 2007. There was little difference between the results, indicating little change over this period in terms of option uptake.

11. For arable flora and bumblebees, three independent sets of scores were available. There was little variation in the outputs between assessors. Weighted output values, which took account of differences in farm size, were higher than unweighted values, indicating that greater benefits were accruing on larger farms.

12. Output values for arable plants were low, indicating a limited impact of ELS reflecting the low uptake of relevant options for this group. However, because

arable plants have limited dispersal capabilities, options can be targeted very precisely and amounts required may only be small provided they are in the right place. The model therefore gives a pessimistic view because it considers the whole of each JCA whereas in practice only a small proportion would need appropriate options to be implemented to make a major contribution to arable plant conservation.

13. Brown hairstreak achieved an average score of three out of ten within its range. Over 40% of holdings had adopted relevant options, over 20% had a score greater than 5 and over 5% had the maximum score of ten. The fact that 5% of holdings achieved the maximum possible score in a non-targeted scheme shows that ELS is capable of providing suitable habitat combinations for brown hairstreak conservation even on the basis of free choice by farmers, and that there is scope for improvement through the provision of targeted advice. Additionally, further research could provide for a tighter specification of the optimal amounts and spatial arrangement of the key habitats.

14. Results for bumblebees showed the greatest potential benefits. The weighted mean overall score was just below seven out of ten; around 80% of holdings had relevant options (score>0), more than half achieved a score greater than five, and nearly a quarter achieved the maximum score. This suggests that even without targeted advice, ELS is making a substantial contribution to bumblebee conservation.

15. ELS could be improved for arable plants by:

- Providing advice in the most important areas to encourage uptake of the key options EF10 and EF11;
- Making uncropped cultivated strips more attractive to farmers by allowing control of pernicious weeds (e.g. thistles) at intervals, at the same time removing competition from the rare species in the following year. Rare species can survive a year without setting seed as they can re-establish from dormant seed in the soil;
- Allowing use of selective graminicides for pernicious grass weed species
- Increasing points allocation to allow for additional management costs of pernicious weed control;
- Allow conservation headland management outside the cropped area, with an increased number of points to compensate for lost yield;
- Remove reference to arable weeds under option EF9 (if kept in the scheme), as this option has little value for this group.

16. ELS could be improved for brown hairstreak by:

- Providing targeted advice within the limited range of brown hairstreak
- Developing an option combining enhanced hedgerow management with mature hedgerow trees
- Developing combined options providing enhanced hedgerow management next to field corners or buffer strips containing suitable nectar-producing plants.

17. ELS could be improved for bumblebees by:

- Allowing the establishment of pollen and nectar mixtures on permanent grassland receiving medium or high levels of fertiliser;
- Recommending the use of non-agricultural varieties to prolong longevity;
- Replacing the restriction on number of blocks/strips of pollen and nectar mixtures with a restriction on area, to allow more blocks or strips of smaller area to be established;

- Providing recommendations for perennial species to sow in buffer strips or field corners to benefit bumblebees
- Developing combined options providing feeding and nesting habitat.

Water quality

18. The original modelling methodology was not as successful as intended for resource protection because the impact of many options on water quality depends on their location. An alternative method of estimating the impact of ELS uptake on water quality has therefore been developed, considering the effect of ELS on phosphate and nitrate losses from agricultural land.

19. The objectives of this part of the project were as follows:

    - To estimate the impact of ELS options on diffuse nutrient losses from agricultural land;
    - To estimate the amount of individual options required to maximise impact of the ELS on diffuse nitrate and phosphate losses,
    - To determine the optimal locations of options, where appropriate;
    - To compare estimated impacts on nitrate and phosphate losses based on current uptake data with potential impacts based on optimal uptake.

20. Options for reducing pollution may either lessen the quantity of the initial source, and/or retard or prevent, the mobilisation and transport of the pollutant to the surface water. Nitrate is highly water soluble and therefore readily leached from the soil. Nitrate is most prone to leaching in the late autumn when there is minimal plant uptake, rainfall is relatively high and evapo-transpiration is reduced. In contrast, phosphate rapidly binds to soil organic matter and clay, and the main source of losses is via sediments in runoff or sub-surface flow in cracks and drains, rather than leaching. These differences in N and P dynamics mean that the effect of introducing an ES option is likely to impact on either N, or P, but not significantly on both (with the exception of reduced inputs).

21. Impacts of ELS options on nutrient losses were estimated by assigning an analogous mitigation measure or farming type from key literature sources, mainly Cuttle *et al.* (2006), to the land on which an ELS option was situated, or affected by that option. Although such values are indicative, they are not absolute and they will be subject to variation according to prevailing conditions.

22. Soil, Nutrient, and Manure Management Plans constitute a special case, because each management plan may include a range of possible management techniques. For each Plan, the contents of the publications to which the user is referred were examined to identify farming practices that were analogous to the mitigation options listed in Cuttle *et al.* (2006). These were categorised according to their effects and the maximum value (of reduction in N and P loss) within a single category was used as the value of reduction in losses for all the management practices falling within that category. Different categories were assumed to have additive effects.

23. Because it is not known which of the individual practices have been implemented under the Management Plans, or their extent, it was necessary to develop a scenario of implementation to calculate ‘typical’ N and P losses for different farm types; these losses were then used in conjunction with the actual uptake data for EM1, EM2, and EM3 in order to provide some indication of how the Management Plans may impact on water quality in reality.

24. Three scenarios were developed – high, medium, and low – with ‘high’ having a large proportion of the farm under mitigation options, and vice versa for ‘low’. Mitigation options were divided into those that covered whole fields, those that may be implemented on a relatively small scale and measures that may apply to even more discrete areas and that may be more difficult to implement. Representative values of implementation were used to develop the scenarios for the purposes of this study.

25. The impact of ELS agreements containing measures likely to affect water quality on nutrient losses was calculated for the major farm types (cereals, general cropping, dairy, lowland beef & sheep, mixed), using recent option uptake data. The assessment was based on the 84% of holdings for which a CPH number was available, allowing linkage to the June Survey. Because of the need to use scenarios to estimate the impact of management plans, the effects of these were estimated separately.

26. The greatest estimated reductions in N losses were achieved by options taking land out of production, e.g. field corner options (EF1/EK1), taking archaeological features out of cultivation (ED2). Option EJ2 (management of maize crops to reduce soil erosion) also gave a substantial reduction. The greatest reductions in P losses resulted from field corner management and 6m buffer strips on cultivated land (EE3). Option ED2 also gave a substantial reduction.

27. The greatest estimated baseline (i.e. without ELS) N losses per hectare were from pig and poultry farms (around 89kg/ha), and the least were from lowland beef and sheep farms (around 25kg/ha). For other farm types (arable, dairy, mixed), losses were around 50kg/ha. Beef and sheep farms also showed by farm the greatest impact of non-management plan options on N losses, reducing them by 15-16% compared to the baseline. On other farm types, non-management plan options only reduced N losses by between 1.2 and 6.3%.

28. Estimated baseline P losses were around 3 kg/ha for cereals, general cropping, mixed and pig/poultry farms, slightly lower for dairy and lowland beef/sheep farms. The estimated reduction arising from the implementation of non-management plan options was around 4-5% for all farm types examined except mixed farms, for which it was only 1.4%.

29. On a per hectare basis, the greatest reductions in N losses due to management plans were seen on mixed, followed by beef and sheep farms, with the lowest reduction on arable and dairy farms. Soil management plans produced greater reductions in P losses than nutrient and manure management plans. Reductions in P losses from soil and nutrient management plans were greater for arable than for dairy and beef, but the effect was reversed for manure management plans

30. All three management plans, under the medium scenario, reduced estimated N losses considerably more than other options. However, for P, only the soil management plan gave larger reductions than non-management plan options.

31. Management plans appear likely to have the greatest impact on N losses, with other options having relatively small impacts. The options having the greatest impact on P losses are soil management plans and buffer strips on arable land. However, it must be remembered that *the impact of management plans depends on the measures identified in the plan being implemented, whereas points are awarded for merely preparing a plan*. Moreover it has been assumed that, for the medium scenario, all the

mitigation options are implemented to some degree although it is feasible that only a limited number may be implemented in reality.

32. Most elements of management plans are based on Codes of Good Agricultural Practice, and as such they do not necessarily provide additional benefit to the environment over and above that provided by GAP. A notable exception is calibrating the fertiliser spreader which is not included in the Codes, but that could provide considerable benefits.

33. A small number of key options could have a relatively large impact on N and P losses, including:

    a. Reducing field stocking rates when wet

    b. Slurry storage / Timing N application to requirement

    c. In-field buffer strips

34. Although in-field buffers have a substantial influence on the results, the supporting data on their effectiveness were weak. Moreover, if they are not installed correctly, they could create a larger problem (by channelling runoff) than they solve.

35. Efforts to reduce N pollution are likely to be more successful if the issue of over-application is addressed, as the rate of leaching trends towards exponential above the economic optimum, but there is a negligible reduction in leaching if applications are lowered below the optimum. Targeting high-risk areas could also be more beneficial than reducing losses from land already farmed according to Good Agricultural Practice (GAP).

36. The impact of ELS on water quality could be improved by targeting high risk areas on farms and ensuring the options are appropriately located. This process would benefit from advice being available.

37. ELS does not currently include grants for capital items, but this could encourage farmers to implement options that would otherwise be too costly, e.g. construction of watercourse fencing, alternative drinking facilities, installing/maintaining hedges.

38. The points system or choice of options could be modified so that farmers have to have a range of options addressing different issues (e.g. biodiversity, nutrient pollution, historic landscape). The provision of advice could also be an effective method of influencing the uptake of appropriate options, as indicated by the initial evaluation of ES.

39. In conclusion, for all outcomes, maximising and maintaining uptake and coverage of ELS will be a key factor, but the efficiency of delivery will be increased by measures to achieve uptake of relevant options in appropriate locations.

1. INTRODUCTION

An evaluation of Environmental Stewardship had recently been carried out by CSL (Boatman et al., 2007). As part of this project, a modelling process was developed which attempted to estimate the impact of ELS on a range of environmental indicators (see Annex A for further details). The process adopted depended on expert scores for the effectiveness of each option, and estimates of the optimal area required to achieve targets. These were used to estimate the impact of the ELS in terms of the observed pattern of option uptake, in relation to optimal uptake for each indicator. This project extends the work on estimating the environmental value of ELS in two areas, biodiversity and water quality.

1.1 BIODIVERSITY

1.1.1 Background

Although the method worked well for biodiversity indicators, the number of experts able to provide estimates of optimal areas was limited, and so model outputs for most indicators were based on values provided by only one or two expert assessors. In order to provide greater confidence in estimates of the impacts of ELS, it was decided to develop an alternative approach for a few key biodiversity indicators based on a combination of literature search and expert knowledge as derived from advisory literature etc. to estimate habitat requirements. Results would be validated through consultation, and then provision of appropriate habitats by ELS options assessed.

Farmland birds are key policy indicators, however the impacts of ELS on species of conservation concern within the Government's Farmland Bird Index have already been considered in a separate study (Vickery *et al*., 2007). This study will therefore consider some additional biodiversity indicators of conservation concern which are considered likely to benefit from ELS options, and for which sufficient information is likely to be available to make an assessment of the impact of ELS uptake.

1.1.2 Objectives

The objectives of this part of the project were as follows:

- To determine the key habitat factors limiting the population of the selected indicators;
- To estimate, if possible, the amount of key habitat required to maintain viable populations
- To identify the relevant options under ELS which provide the habitat requirements of the indicator species/groups, and propose a target area for the indicators concerned;
- To compare habitat provision through ELS under current and projected uptake with estimated requirements, using the previously developed model.

1.2 WATER QUALITY

1.2.1 Background

The original modelling methodology was not as successful as intended for resource protection because the impact of many options on water quality depends on their location. An alternative method of estimating the impact of ELS uptake on water quality has therefore been developed.

Originally, targets were set in terms of pollutant concentrations in surface waters, as these are the measures to be used in implementing the Water Framework Directive. However, these concentrations are not only a result of diffuse pollution from agriculture, but also point source pollution from agriculture and other sources (e.g. sewage works). Furthermore, the concentration in water depends on a range of factors including the size of the watercourse, its rate of flow etc. Determining the impact of measures to reduce losses from agriculture on nutrient pollutant concentrations in water is therefore complex; for the present purpose it is more appropriate to consider the effect of ELS options on losses from agricultural land only. Phosphate and nitrate losses from agricultural land were adopted as the indicators to be studied, because they are likely to be affected by a range of options, and the mechanisms underlying their movement to watercourses differ. In the case of phosphate, pollution is linked to soil erosion, and there is a Defra target for reduction of losses (48%), as quoted by Anthony (2006), which can be used as a benchmark.

1.2.2 Objectives

The objectives of this part of the project were as follows:

- To estimate the impact of ELS options on diffuse nutrient losses from agricultural land;
- To estimate the amount of individual options required to maximise impact of the ELS on diffuse nitrate and phosphate losses,
- To determine the optimal locations of options, where appropriate;
- To compare estimated impacts on nitrate and phosphate losses based on current uptake data with potential impacts based on optimal uptake.

2. BIODIVERSITY

2.1 GENERAL METHODOLOGY

2.1.1 Selection of indicators

After a preliminary literature search and brief consultation with key stakeholders, three biodiversity indicators were selected, on the basis of the criteria outlined above. These were:

- Rare arable flora;
- Brown hairstreak butterfly;
- Bumblebees.

Rare arable plants generally have similar requirements in terms of management, i.e. cultivation, freedom from herbicide application and ideally no fertiliser input. They are therefore treated as a group. Germination of non-dormant seeds is usually stimulated by exposure to light in conjunction with other favourable conditions (moisture, temperature etc.), but typically species are adapted to germinate in either the spring or the autumn, though some can germinate at both times of year. Spring and autumn-germinating species therefore differ in the ideal timing of cultivations, and have been treated separately.

Butterfly species differ in their requirements with respect to food plants, microclimate etc. The brown hairstreak was selected, with advice from Butterfly Conservation, as a species of conservation concern which could potentially benefit from sympathetic implementation of appropriate ELS/OELS options.

Like arable plants, bumblebees generally have similar requirements, though some are more specialised than others and require specific types of flower to provide their feeding requirements. Seasonality of activity also differs. In general, as for most organisms, more specialised species tend to be rarer. Key differences between common and rare species are described in the literature review below. In conservation terms, measures that benefit rare species are also likely to benefits the less specialised commoner species, hence the development of ELS options has focussed on the requirements of the less common and declining species.

2.1.2 Objective 1.

Relevant literature was examined to determine the key habitat factors likely to limit the population size of the species concerned. The aim was not to produce a comprehensive literature review, but to develop an assessment, based on the best evidence available, of the factors which would need to be addressed by ES schemes to maintain or increase populations. The review included journal publications, relevant conference publications and reports in the 'grey' literature. In addition, appropriate advisory material produced by Defra. Natural England and NGOs was consulted; this generally combines research evidence with expert judgement where scientific evidence is lacking, and so provides a distillation of the best available knowledge at the time of production. In some cases, advice has been produced specifically on how to use ELS/OELS to benefit these species.

2.1.3 Objective 2

Estimates of the amounts of appropriately managed *key* habitat required to maintain a viable population in the area(s) where the species occurs were made where possible, on the basis of the best available knowledge of (i) known habitat requirements, (ii) areas or lengths of habitat in areas where populations are thriving, (iii) data on home ranges/foraging/dispersal distances, which give a guide to the scale at which the organism uses the landscape. These were then reviewed by appropriate experts, and their comments taken into account in revising the assessment. This task often proved particularly difficult as the necessary research had either not been carried out or was not reported in an appropriate form. In such cases, the assessment from the literature was supplemented by expert opinion.

2.1.4 Objective 3

Relevant options addressing the habitat requirements identified under objective 2 were determined and target amounts of these options derived, based on estimation of optimal requirements for the indicator species, modified in some cases by consideration of the proportion of an agreement holders points requirement which could reasonably be expected to be devoted to a specific indicator. This was necessary because, in some cases, providing the optimal amount of habitat to maximise the populations of the species concerned would have taken up a substantial proportion of the points requirement, which would have created an unrealistic target. The 'hands-off' nature of the ELS means that applicants are free to choose whatever amounts of individual options, in whichever combination, they wish, constrained only by having the appropriate habitat or feature available on the farm and the need to achieve their points threshold. On average therefore, they are unlikely to devote a large proportion of their points to options relating to the requirements of a particular species or group of species especially if that species has specific requirements which can only be delivered by one or two key options. Indeed, this would not be desirable, because ELS is a multi-objective scheme, therefore in order to deliver the range of benefits required, a range of options addressing the different scheme objectives (biodiversity, landscape, resource protection and the historic environment) needs to be implemented. Further details of the approach adopted are given in Annex B.

As part of the consultation process, we asked experts to provide (or review if previously provided) scores for habitat value of different options. The appropriate area of interest (i.e. the current or potential range of the species concerned) was also determined. This was based on known species ranges, determined using the most suitable data sources available, for example Atlas and National Biodiversity Network data.

2.1.5 Objective 4

Habitat provision through the ELS was compared with that estimated to be required, based on (i) current, and (ii) projected future uptake, assuming 70% of farmland is under the schemes, but with current option uptake frequencies, using the model previously developed (Boatman *et al*., 2007; see Annex A). Assessments related to the areas of interest defined under objective 3, as uptake within these areas would provide maximal benefits, thus taking account of any bias in spatial distribution uptake. This has already been demonstrated in the case of arable flora, (Boatman *et al*., 2007), where uptake of relevant options was found to be more likely in Joint Character Areas of greatest interest for this group.

2.2 ARABLE FLORA

2.2.1 Sources of information

In addition to literature from scientific journals, information was gleaned from Plantlife publications, the arable plants website[1], and consultation with Plantlife staff and ecological consultants specialising in the arable flora.

2.2.2 Overview

Many species of the arable flora have declined significantly over the last century as a result of modern farming practices (Wilson, 1992; Rich & Woodruff, 1996; Sutcliffe & Kay, 2000; Wilson & King, 2003). Of the 100 species identified in the New Atlas of the British and Irish Flora to have shown the greatest relative decrease between 1930-69 and 1987-99, 37 occur on arable land, and 60% of the 30 species which have declined most are characteristic of arable and other cultivated land (Preston *et al*., 2002). The most recent red data list for vascular plants identifies seven species which are now extinct in the wild in the UK, and a further 54 which are threatened (Cheffings & Farrell, 2005). Twelve vascular plants and five bryophytes of arable land originally had Species Biodiversity Action Plans (Anon, 1998), and the number of vascular plant species on the priority list has increased to 26 under the recent review of Biodiversity Action Plans (Biodiversity Reporting and Information Group, 2007). Despite being the most threatened group of plants in the UK, the arable flora is the least studied plant community. However, their plight has received increasing attention in recent years, and a considerable amount of effort is now being directed towards their conservation.

As would be expected, many of the species which have suffered most have specific habitat requirements which limit their distribution. Some are restricted to certain soil types, e.g. spring speedwell *Veronica verna* and fingered speedwell *Veronica triphyllos*, which are found only on the calcareous sandy soils of the Brecklands; corn buttercup *Ranunculus arvensis* and shepherd’s needle *Scandix pectin-veneris*, which occur almost entirely on clay soils, and several species which are mainly found on chalky soils (Wilson, 1992; Wilson & King, 2003). A number of species are at the northern edge of their range in Europe and so restricted to the south-eastern counties of England.

Byfield & Wilson (1995) give the following list of causal factors implicated in the declines of arable flora:

- The widespread adoption of herbicides
- Efficient seed-cleaning techniques
- The increase in nitrogen fertiliser use
- The development of highly nitrogen-responsive crops
- Changes in crop rotations
- Loss of certain crop types (e.g. rye and flax)
- Loss of over-wintered stubbles and summer fallows
- Efficient field drainage
- Removal of field boundaries and loss of extensively farmed field margins.

These factors interact with the biology of the plants to determine their prospects of survival or decline.

---

[1] http://www.arableplants.org.uk/arable-projects-and-research-plantlife.html

The large majority of arable plants are annuals, depending on reproduction by seed. This life cycle enables them to survive the impacts of harvesting and cultivations for the following crop. A few species are perennial, surviving mainly by vegetative reproduction, e.g. couch *Elytrigia repens*, which persists as rhizomes in the soil. Most annuals exhibit seed dormancy, which allows them to survive in the soil for extended periods with a proportion germinating each year. Thus the risk of encountering adverse conditions is spread, increasing the chances that some seedlings will emerge into favourable situations allowing them to mature and set seed, replenishing the 'seed bank' in the soil. Most species produce large numbers of seeds on each plant, thus allowing for high natural wastage. Species which exhibit little or no dormancy are at a strong disadvantage. For example, corncockle *Agrostemma githago*, and darnel *Lolium temulentum*, appear to have relied for their survival on being re-sown with crop seed, and the advent of improved seed-cleaning techniques in the 19th century ensured their rapid decline and eventual demise.

Susceptibility to the early growth regulator herbicides was a key factor in the decline of some formerly very common species, such as corn buttercup and shepherd's needle. Interestingly, shepherd's needle has shown a resurgence in some parts of its range in the 1990s, possibly as a result of greater resistance to more modern herbicides.

Many arable plants are small in stature and have low competitive ability compared with crop plants and more aggressive weed species, especially under conditions of high fertility (Wilson, 1990, Kleijn & van der Voort, 1997). Thus, the extinction of lamb's succory *Arnoseris minima* and small bur-parsley *Caucalis platycarpos* in the UK may be largely due to the development of nitrogen-responsive crops coupled with increases in the rates of applied nitrogen (Eggers, 1984; Wilson, 1992).

Life cycles for some species do not fit well into modern cropping cycles. The move away from spring sowing and towards sowing in autumn has disadvantaged spring-germinating species such as corn marigold *Chrysanthemum segetum* and weasel's snout *Misopates orontium*, whilst early sowing dates may also have affected autumn germinating species, as crops are well established by the time they emerge, thus increasing the level of competition (Wilson, 1992). Certain groups of species associated with specific crops, e.g. flax, have disappeared along with these crops (Eggers, 1984; Wilson, 1992).

Drainage has reduced habitat availability for species which thrive on damp soils, such as mousetail *Myosurus minimus.* Some species require disturbance but are unable to survive competition with crops. These species are characteristic of irregularly cultivated margins and former fallow fields, and have suffered particularly from more efficient farming methods (Wilson & King, 203). Examples are ground pine *Ajuga chamaepitys* and cut-leaved germander *Teucrium botrys*.

Because of their characteristic seed dormancy, the distribution of arable plant species is particularly difficult to determine, as they may be present in the seed bank even if few or no plants are evident on the surface. For this reason, the distribution of many species was poorly known until recently. In order to provide a better basis for targeting conservation action, Plantlife has developed an arable plants database in 2002, and provided survey forms for consultants, volunteers and others visiting farms to record sitings of rare species[2]. The results were used in combination with data from earlier surveys to identify 'Important Arable Plant Areas' (Byfield & Wilson, 1995). Species were scored on the basis of their rarity and extent of decline, and these scores added to give an assessment of the importance of a site, based on the species present. The same system has since been applied to vice-counties and

[2] http://www.arableplants.org.uk/arable-projects-and-research-plantlife.html

Joint Character Areas (Still & Byfield, 2007). The maximum score for a JCA is 362, for the South Suffolk and North Essex Clayland.

2.2.3 Habitat provision and amounts

Rare arable plants are largely restricted to the edges of arable fields, and species diversity is also highest at field edges (Wilson & Aebischer, 1995; Walker *et al*., 2007), and this is therefore where conservation action is best targeted. Arable field margins are a BAP habitat, and the current target values for cultivated, low input field margins in England are 10,000 ha by the year 2010, and 11,000 ha by 2015. There are also targets for areas of margin providing wild bird seed, flower-rich margins and permanent grass margins.

Progress towards these targets is measured in terms of Environmental Stewardship (ES) uptake data. Options included in the definition of cultivated, low-input margins are:

EF9	Conservation headlands in cereal fields
EF10	Conservation headlands in cereal fields with no fertilisers or manure
EF11	6m uncropped, cultivated margins on arable land
HF16/20	Cultivated fallow plots or margins for arable flora
HF13/17	Fallow plots for ground-nesting birds
HF14/19	Unharvested, fertiliser-free conservation headlands

Key options identified by Still and Byfield (2007) for arable plant conservation are conservation headlands and uncropped cultivated margins on arable land. Plantlife produce information sheets for farmers on these and other options, including spring cereals and low input stubbles, low input cereals and fodder crop management[3]. The ELS options relevant to arable plant conservation are shown in Table 1.1

Table 2.1 ELS options relevant to arable plant conservation

Option code	Description	Points
Key options		
EF9	Conservation headlands in cereal fields	100
EF10	Conservation headlands in cereal fields with no fertilisers or manure	330
EF11	6m uncropped, cultivated margins on arable land	400
Other options		
EF6	Overwintered stubbles	120
EG4	Cereals for whole crop silage followed by over-wintered stubbles	230
EG5	Brassica fodder crops followed by overwinter stubbles	90

Walker et al (2007) evaluated four agri-environment scheme options for the conservation of arable plants: uncropped cultivated margins, spring fallow, and conservation headlands with or without fertiliser inputs. The highest species diversity was found in the uncropped cultivated margins, followed by spring fallow and conservation headlands without fertiliser. Conservation headlands (with fertiliser) were the least diverse, largely similar to the controls (conventionally managed cereals). Sixty-seven percent of uncropped cultivated margins contained one or more rare species, compared to 39% of conservation headlands without fertiliser,

[3] http://www.arableplants.org.uk/arable-agri-environment-england-mansheets.html

31% of spring fallows, 21% of conservation headlands, and 15% of controls. The incidence of rare species was much higher than in previous surveys, as the sample was biased towards areas richer in arable species.

It is suggested that assessment of the impact of ELS should concentrate on the key options as listed in Table 1.1 (there is no ELS option for spring fallow). The results reported by Walker *et al*. (2007) indicate that the value of EF9 (conservation headlands, with no restriction on fertiliser use) for the arable flora is limited compared to EF11 (uncropped cultivated margins) and EF10 (conservation headlands without fertiliser), and its inclusion as a beneficial option in this context is open to debate. However, as EF9 was previously identified in advisory literature as beneficial for arable flora, farmers may have chosen this option believing it to be useful in this context, so it has been included with analysis of uptake to date.

For maximum impact, options should be targeted towards field margins where rare species are known, or likely, to occur. The area of suitable margin will vary between farms, but on the great majority of farms only a small amount of margin would need to be appropriately managed to conserve rare weed populations, provided this was implemented in the correct locations. One hectare of 6m margin is equivalent to 1.67km of margin length. Thus one hectare per square kilometre of agreement would provide 1.67km/km^2 of margin. This is equivalent to 1% of the area under agreement, and would be worth 3.3, 11 and 13.3% of the total points requirement for conservation headlands, conservation headlands with no fertiliser and uncropped cultivated margins, respectively.

If we assume that it is reasonable for a farmer to devote 10% of his points target to the conservation of arable flora in areas where this is a priority[4], this would be equivalent to 0.75ha of uncropped cultivated margins, 0.9ha of conservation headlands with no fertiliser, and 3ha of conservation headland per square kilometre (i.e. 0.75, 0.91 and 3% of the agreement area respectively), or 1250, 1500 and 5000m of 6m wide margin per km^2. It is proposed that these would be reasonable targets for areas where the conservation of arable flora is a priority.

2.2.4 Area included in analysis

As arable plants are restricted to areas where crops are grown, it is logical that ELS uptake of the appropriate options should be compared with target uptake within areas containing arable land. The assessment could be further refined by considering only those areas with high scores under the scoring system used to identify Important Arable Plant Areas. In consultation with Plantlife, all JCAs with a score higher than 175 plus a number of those with lower scores (based on expert knowledge) were selected as key target areas. This was to provide for inclusion of JCAs which may have not scored so highly based on the assemblage of species present, but may be important for either the occurrence of a UKBAP species, or for the occurrence of one or more important species that have only ever been quite localised and so potentially only occur in a particular JCA. For example, West Penwith JCA only scores 79 as a species assemblage but is known to be very important for *Echium plantagineum,* and the Isles of Scilly have an unique arable flora but only score 139. based on these criteria, 73 JCAs were selected, out of a total of 159 (see Annex C).

In basing the area analysed on the JCA scores, two important caveats should be borne in mind. The data used for deriving the JCA scores were sourced from the Plant Atlas (Preston *et al*., 2002), which includes some older records for species

[4] see Annex B

which are no longer found in certain areas as a result of subsequent declines (e.g. *Scandix pecten-veneris, Ranunculus arvensis, Scleranthus annuus*). Also, the Atlas data are at $10km^2$ level, which may lead to some inaccuracies when allocating to JCAs. It would be possible to carry out a more accurate scoring exercise for JCAs using only more recent data at a higher resolution, but this was not possible within the timescale of the current project.

2.3 BROWN HAIRSTREAK *Thecla betulae*

2.3.1 Sources

Research publications are limited. Some research was undertaken by J.A. Thomas for a PhD study (1974), but not published. However, information on the ecology, life cycle and habitat requirements is available from a number of reports and advisory leaflets. In particular, Bourn and Warren (1998) provide a useful summary of the ecology and conservation requirements for the species. Up-to-date information is provided in the report of a recent seminar on the Brown Hairstreak (Wigglesworth, 2005).

2.3.2 Overview

A local species, which has declined severely in many areas since the 1950s especially in central and eastern counties. It has recently become a BAP priority species (Biodiversity Reporting and Information Group, 2007). Analysis of its distribution between 1970-82 and 1995-9 showed a reduction of 34% in the number of 10 km grid squares where the butterfly was found (Asher *et al*, 2001). It is also far scarcer and more restricted in its remaining strongholds on the heavily wooded clays of the west Weald in West Sussex and Surrey and the sheltered low-lying valleys of north Devon and south-west Somerset, although there may be under-recording in some areas. Population size is difficult to determine, as adults are elusive and live mainly in the tree canopy and tops of hedges. Thus the total number of colonies/sites is unknown as well. Egg counts in winter may provide the best monitoring data. The main threats to colony survival are: annual hedge trimming, hedge removal and browsing by deer and cattle. The bulk of the decline is probably due to loss, and changing management of, hedgerows and woodland margins.

The brown hairstreak occurs in regions of extensive hedgerows, scrub pockets and woodland edges with sheltered bays, usually on heavy soils where the larval foodplant, blackthorn, *Prunus spinosa*, is abundant. Bullace *Prunus domestica ssp. insititia* is also used at a few sites. It responds positively to sensitive hedgerow and woodland management. The main threats to its existence are hedgerow removal and intensive hedgerow management, with annual mechanical cutting the main cause of egg mortality.

This species has a single generation a year and flies from late July to mid September. Usually no more than one or two adults emerge per kilometre of hedgerow during the three or four-week emergence period. In order to find a mate, the adults congregate early in the flight season on ‘master trees’. Some of these have been identified and large ash *Fraxinus excelsior* trees with a full canopy and an open structure predominate ash is used in preference to oak (*Quercus* sp.), which in turn is preferred to elm (*Ulmus* sp.)and hawthorn (*Crataegus monogyna*). Large trees growing near the lowest point of the area where there is a colony are utilised. These trees have large aphid populations and their honeydew is a main food source for the adult butterflies. However these ‘master’ trees do not seem to be as important over some of its range, e.g. in Sussex.

Males emerge first and are rarely seen at ground level. Once female numbers at a congregation point reach a certain level, the surplus emigrate beyond the colony boundaries, limiting the size of the colony far below the apparent carrying capacity of the available blackthorn (Thomas, 1991). Females remain at the tree for 6-10 days maturing their eggs before dispersing over the extensive breeding area. Several kilometres may be covered while egg laying. Females regularly feed on late summer flowers like hemp agrimony *Eupatorium cannabinum*, fleabane *Pulicaria dysenterica*, bramble *Rubus fructicosus* and thistles *Cirsium* spp. while dispersing to lay eggs.

Eggs are usually laid singly on bark at the base of a spine on young growth proud of the hedge, or on suckers at the hedge bottom, the optimum site for laying where they occur. Searches for eggs have shown that most are found between zero and one metre from the ground, but in other areas they occur up to two metres. The preference is for plants in a dynamic growth state where young growth is selected for laying, with heavily browsed hedges avoided completely. Egg laying is densest in hedges near 'master trees'. The butterfly overwinters as an egg, the larvae hatching in late April or early May. Egg mortality on undisturbed sites seems to vary greatly with about 15% caused by an unidentified disease. Up to 80% of larvae are killed by predators, especially birds (e.g. willow warbler *Phylloscopus trochilus*) and a further 80% in the pupal stage on the ground are eaten by small mammals.

Brown hairstreaks are found predominantly in small, hedged fields with sunny sheltered aspects. Each population requires several kilometres of uncut hedgerow with accompanying 'master trees'. The number and type of these trees required is poorly known.

Evidence from coppicing at Noar Hill, Selborne, Hants showed that Blackthorn shoots from two years old are favoured for laying with a peak preference for 3-5 years old. Therefore long hedge-cutting rotations are required to provide suitable conditions with the majority of hedges at a site uncut each year. A three-year rotational cut is the most practical for colony maintenance. Cutting should be carried out in winter, although a proportion of eggs will be damaged. In some regions cutting occurs in August after harvest, which is the best practice as the eggs are laid into the cut hedge, but is not recommended for other wildlife and therefore should only be considered for important Brown Hairstreak hedges. Hedges should be kept quite tall (>1.5 m) and any hedgerow trees retained or encouraged, especially ash and oak. Buffer strips will also benefit the butterfly as they protect the hedge and allow suckering Blackthorn.

2.3.3 Habitat provision and amounts

Butterfly numbers and the amount of habitat required are difficult to determine. In active colony sites it is easier to determine numbers as the adults are drawn to the master trees. There appears to be an adult carrying capacity for these sites and excess females have been seen dispersing away from the colony. The active colonies require several kilometres of uncut hedgerow over which they lay and few eggs are laid beyond the colony boundary. This quantity of hedgerow seems to far exceed the carrying capacity of the habitat when the actual number of females is considered. The most compact colony that has been surveyed uses c 5,750 *Prunus* bushes growing along 16km of hedges and wood within an area of c.30 ha which was assessed during a 7-year study (Thomas and Emmet, 1989). However, it is likely that with such a density many of the *Prunus* bushes would not be used for egg-laying i.e. the actual number required would be much lower. A population model based on this study predicted various outcomes depending on the hedge management regime used (Table 2.2). This shows that cutting a third of the hedges every year is almost as good as no cutting for population survival.

In areas such as Surrey and Sussex, the butterfly breeds at very low numbers (10 eggs per 100 m length of hedge) over wide areas of the countryside, often covering hundreds of hectares, and it is difficult to know whether there are discrete colonies. In these cases the population may be so thinly spread that congregations at 'master trees' may not be possible. Colonisation rates appear to be low in the highly fragmented landscape of lowland England and colonies tend to remain in the same areas from year to year.

Table 2.2 Predicted size of the mean adult emergence and life-span of a population of *Thecla betulae* under six different hedgerow management regimes*

Cutting regime	Mean number Adults	Years to Extinction
No cutting	126	1179
All cut every year	3	3
All cut every other year	48	125
Half cut every year	67	388
All cut every third year	47	65
Third cut every year	81	1082

*Data from Thomas 1974 and Thomas unpublished

2.3.3.1.1 Solutions

Ideal management for the brown hairstreak is outlined below:

- Hedges with a southerly aspect are preferred for egg laying and should thus be treated as priority hedges.
- Hedges grown to at least 2m high and wide provide optimum shelter and oviposition sites.
- A three year hedge cutting rotation should be used, with only light flailing.
- Gap up hedges with at least 50% blackthorn.
- Ensure planting of new hedges in Brown Hairstreak areas uses a high proportion of blackthorn
- Retain mature hedge ash and oak trees and allow suitable saplings to grow or be planted
- Retain at least a 2m grass strip adjacent to hedge. Encourage nectar sources such as brambles, fleabane and hemp agrimony along the side of the hedgerow. Cutting at intervals may be necessary to maintain the level of flowering plants in the sward.

2.3.3.2 Habitat Provision through ELS

Key options for breeding habitat

EB3: Enhanced hedgerow management.

Height at least 2 m, cut no more than one third of hedges each calendar year and cut each hedge no more than once every three calendar years. Uncultivated land 2 m from centre of hedge.

EB10: Combined hedge and ditch management incorporating EB3 hedgerow management.

As EB3 with ditch management.

Other options for breeding habitat:

EC4: Management of woodland edge.:

No cultivation of woodland edge and allow woodland edge to grow out for up to 2 m. Trim only one third of shrubby growth in any one year.

Protection of hedges and woodland (may also provide some nectar)

EE1: 3: 2, 4 and 6 m buffer strip on cultivated land.

Grassy strip, cut no more than 1 year in 5.

EE4: 6: 2, 4 and 6 m buffer strip on intensive grassland.

Cut no more than 1 year in 5.

EF, EK1: Field corner management:

Grassy corner in arable fields

EK1: Take field corners out of management in lowland grassland.

No fertiliser use, cut only once in 5 years.

Options providing nectar:

EF2/3, EG2: Wild bird seed mixture.

Primarily intended to provide seed for birds, but some seed crops and also weeds within crop will provide nectar.

EF4/5, EG2: Pollen and nectar flower mixture.

Mixture of legume species with optional grass. Designed particularly for bumble bees, but will also provide nectar for butterflies, especially if appropriate additional flowering plants which are attractive to Brown Hairstreak (e.g. fleabane and hemp agrimony) are included in the mix.

2.3.3.3 Assessment of uptake patterns: deriving optimal amounts of options for comparison with observed uptake

It is clear that hedgerow management is crucial to the survival of this species. Most suitable breeding habitat is in hedgerows. Option EB3 (Enhanced hedgerow management) is the key option, as this provides the combination of height and infrequent cutting which is most beneficial. To be of greatest value hedges need to contain a high proportion of blackthorn and a southerly aspect is ideal, but these properties cannot be assessed from uptake data.

In terms of the amount required, this is difficult to estimate because this has not been specifically studied. The reference quoted above to a compact colony located on 16km of hedges and woodland in approximately 30ha, is equivalent to 53km/km^2, far higher than would be encountered on most farmland. Countryside Survey data give the average length of hedgerow in the Western Lowlands environmental zone (containing the majority of Brown Hairstreak sites) as 3.9km/km^2 (Petit et al., 2003). This figure could be adopted as a target, however, it is probably unrealistic to expect farmers to include all their hedgerows in option EB3, or EB10, which includes EB3 hedgerow management combined with ditch management. Some hedges may not be suitable for this option, e.g. those where the agreement holder only has control of one side. Furthermore, in order to benefit the brown hairstreak, hedges must have a good proportion of blackthorn present. A reasonable target for agreement holders in areas where the butterfly occurs might be to enter a third of the average length of hedgerow into EB3 or EB10, (i.e. 1.3 km/km^2). This would use 18% of the points requirement (Table 2.3), leaving some scope for other options. This would be an average target, as individual holdings will obviously vary in terms of their potential to enter these options. Although higher than the 10% suggested as an average proportion of the points target for individual species (see Annex B), management for brown hairstreak is only applicable in a relatively small area where it could be regarded as a high priority compared to other potential objectives. Advice and appropriate literature (e.g. Barker et al., 1998) could encourage entry of the most suitable hedges into these options where brown hairstreaks occur.

Where woodlands are present with blackthorn at the edges, option EC4 could provide equivalent benefits to EB3/10.

The value of the other options would be conditional on the presence of one or more breeding habitat option(s), as without suitable breeding habitat, the butterflies would not be able to maintain their population. Ideally, options such as field corners and buffer strips would be situated adjacent to suitable breeding hedges, in order to allow blackthorn to sucker without interfering with an adjacent crop.

Target amounts:

Buffer strips:

Ideally, all hedges managed as EB3 would have an adjacent buffer strip, so target is 1.3 km/km2.

Field corners:

Maximum permitted is 1ha/20ha, i.e. 5ha/km^2 (5%). However, this would take up two thirds of the points requirement. A more realistic target might be 1ha/km^2 (1%), which would account for just over 13% of the points allocation (Table 2.3).

Wild bird seed mixture, Pollen & nectar mixture:

Maximum permitted 0.5ha/20ha, i.e. 2.5ha/km^2 (5%[5]). Suggested target 0.5ha/km^2.

2.3.4 Area included in analysis

The analysis of uptake was restricted to those 10km squares in which the brown hairstreak had been recorded between 1995 and 2004 (data kindly provided by Butterfly Conservation). This is the most recent distribution dataset available. In total, 155 squares were included, mostly in the south and south-west of England and the south-west of Wales (Figure 2.1)

[5] The prescriptions as they stand are not ideal, as they stipulate a maximum block size of 0.5 ha, and a maximum density of one block per 20 ha. For the brown hairstreak (and other invertebrates such as bumble bees, see below), 0.5ha is larger than necessary, but a higher density of smaller blocks would be beneficial.

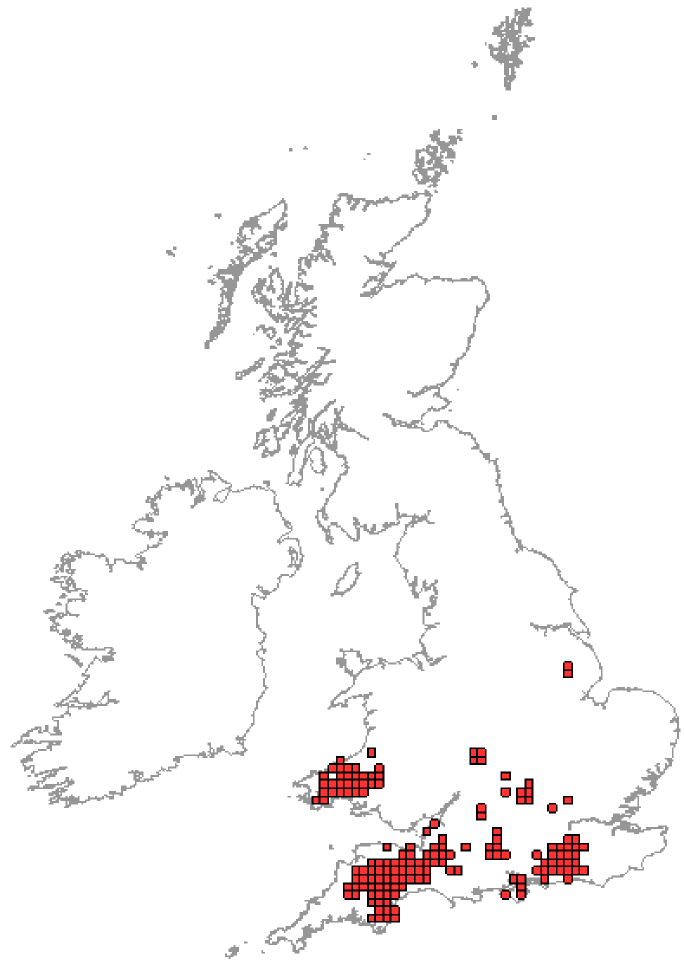

Figure 2.1 **Distribution of brown hairstreak (presence in 10km squares). Data courtesy of Butterfly Conservation.**

Table 2.3 Target average amounts and percentages of total points requirements for options to conserve brown hairstreak.

Option code	Option description	Points	Units	Target amount	Area ha/km^2	Points/km^2	% points requirement
EB3	Enhanced hedgerow management	42	100m	1.3km/km^2		546	18.2
EC4	Management of woodland edges	380	ha	1.3km/km^2	0.26	380	3.3
EE1/EE4	2m buffer strip	300	ha	1.3km/km^2	0.26	78	2.6
EE2/EE5	4m buffer strip	400	ha	1.3km/km^2	0.52	208	6.9
EE3/EE6	6m buffer strip	400	ha	1.3km/km^2	0.78	312	10.4
EF1/EK1	Field corner management	400	ha	0.5ha/80ha	1.0	250	8.3
EF2[1]/EG2	Wild bird seed mixture	450	ha	1.0ha/km^2	0.5	225	7.5
EF4/EG3	Pollen & nectar mixture	450	ha	1.0ha/km^2	0.5	225	7.5

[1]Options EF3, wild bird seed mixture on set-aside land, and EF5, pollen and nectar flower mixture on set-aside land, have different points allocations, however these option are likely to disappear within the next two years when set-aside is abolished, so they have not been considered separately here.

2.4 BUMBLEBEES (HYMENOPTERA: APIDAE)

2.4.1 Sources

A large amount of research has been carried out in recent years, and is available in the published literature and project reports on the Defra website. Research is ongoing, e.g. the 'Big Bee Project', which is in its final year and will provide evidence as to how proportion and quantity of wild flower mixture in farmland affects bumblebee populations[6].

2.4.2 Overview

Available evidence suggests that many bumblebee species have declined dramatically in recent decades in England and also continental Europe and North America, though it is difficult to give an accurate estimate as there are no data on original population sizes (Goulson, 2003). However in the UK a comparison of pre-1960 records (Williams, 1982), with a detailed survey under the Bumblebee Distribution maps scheme between 1970-1974 (Alford, 1980) showed a dramatic decline, which has continued into recent times, as shown by the studies of the Bumblebee Working Group (Edwards, 1998; 1999; 2000; 2001). This has coincided with a loss in habitat, as the UK lost 97% of its unimproved, the main former habitat of the majority of bumblebee species, between 1932 and 1984 (Fuller, 1987).

Bumblebees are considered a crucial part of the ecosystem as they provide a vitally important pollination service for plants, thus helping to maintain plant species diversity (Corbet *et al*., 1991; Dicks *et al*., 2002; Kwak *et al*., 1998; Memmott *et al*, 2004)). Carvell *et al.,* 2006 showed that of 97 preferred bumblebee plant forage species, 71% have suffered range restrictions and 76% have declined in abundance over the past 80 years in the UK. There are also economic reasons for conserving bumblebees, as yields of many field, fruit and seed crops are enhanced by bumblebee visitation (Goulson, 2003).

The UK has 24 species in the genus *Bombus*, of which six species are cuckoo bees (subgenus *Psithyrus*, parasites of other species). This includes *B. hypnorum* which was first recorded from UK in 2001 (Goulson & Williams, 2001) and has the potential to spread throughout mainland Britain, having reached as far as Northumberland by 2007 (D. Goulson, pers. comm.). Important areas in England with high species numbers for bumblebees include Salisbury Plain, South Essex, North Kent, Dungeness and the Somerset Levels (Goulson *et al*., 2005). There are six species found throughout England: *Bombus hortorum, B. lapidarius, B. lucorum, B. terrestris, B. pascuorum* and *Bombus pratorum*, all of which are common throughout mainland Britain (Table 2.4). Even amongst these however, it appears distributions are changing, with *B. pratorum* becoming increasingly urban because it is intolerant of agricultural intensification (Benton, 2000). The common species are mainly short-tongued bees, and the long-tongued bees have declined especially due to the reduced use of leguminous crops as part of crop rotations with the advent of cheap nitrogen fertilisers, making the nitrogen fixing properties of legumes less important as a source of fertility (Rasmont, 1988; Edwards, 2000).

---

[6] Defra project code: CSA6437/BD1625

Table 2.4 Characteristics of the six common species of bumblebee in England (Adapted from Williams (1986) and Edwards and Jenner (2005))

Species	Queen size	Tongue length	Nest location	Colony size	Habitat type*
B. hortorum	Medium	Long	Below ground	Small	A B C D E
B. lapidarius	Large	Short	Below ground	Large	A B C D
B. lucorum	Medium	Short	Below ground	Large	A B C D E F G
B. pascuorum	Medium	Medium	On surface	Medium	A B C D E F
B. pratorum	Small	Short	Below ground	Small	A B C
B. terrestris	Large	Short	Below ground	Large	A B C D E

* A = gardens, B = farmland, C = woodland glades and edges, D = grassland, E = heathland, F = uplands, G = marshes and bogs

The other species have more local distributions and also tend to be less abundant where they occur (Williams, 1986) with five species found mainly in the north of England (Table 2.5) where they are strongly associated with Ericaceae and Heathland habitats (Goulson *et al*., 2005).

Table 2.5 Characteristics of the four species of Bumblebee which are predominantly found in the North West of England (Adapted from Williams (1986) and Edwards and Jenner (2005)).

Species	Queen size	Tongue length	Nest location	Colony size	Habitat type*
B. jonellus	Medium	Short	Below ground	Small	A, D E F
B. magnus	Medium	Short	Below ground	Large	F
B. monticola	Medium	Short	Below ground	Small	F
B. muscorum	Large	Medium	On surface	Medium	B D E G
B. soroeensis	Small	Short	Below ground	Small	C D E F

* A = gardens, B = farmland, C = woodland glades and edges, D = grassland, E = heathland, F = uplands, G = marshes and bogs

Four more species have a distribution based in the south and are also at the edge of their geographic range, which may have rendered them more sensitive to environmental change (Williams 2005) (Table 2.6). It is also notable that the rarer species are those whose queens emerge late from hibernation (May) and are therefore at a disadvantage where nesting habitat is scarce with the early emergers taking the best sites (Goulson *et al*., 2008). Those species which were found to be seriously threatened with extinction were all included in the Biodiversity Action Plan for priority species (Edwards and Jenner, 2005).

Table 2.6 Characteristics of the four species of Bumblebee, which are restricted to southern England (Adapted from Williams (1986) and Edwards and Jenner (2005)).

Species	Queen size	Tongue length	Nest location	Colony size	Habitat type *
B. humilis	Small	Medium	On surface	Small	D E
B.ruderarius	Large	Medium	On surface	Small	A B D
B. ruderatus	Large	Long	Below ground	Large	A B D G
B. sylvarum	Small	Medium	Below ground	Small	B D G

* A = gardens, B = farmland, C = woodland glades and edges, D = grassland, E = heathland, F = uplands, G = marshes and bogs

Biodiversity Action Plan priority species in England include: *Bombus humilis, B. muscorum, B. ruderarius, B. ruderatus, B. sylvarum, B. monticola* and *B. soroeensis*.

At present there are few indications as to why bumblebee species differ so widely in range, abundance and susceptibility to environmental change. Morphologically they are very similar, with differences mainly in size and tongue length; they have annual life cycles, and all depend exclusively on nectar and pollen (Goulson and Darvill, 2004). Leguminous plants are the preferred food plants, particularly for long-tongued species, though all species use these for pollen collection (Goulson *et al*., 2005). All species gather nectar from a broader range of flowers than pollen and the longer tongued species have a narrower diet breadth when collecting nectar. These rare species may be those with short colony cycles, which require a high quality food supply, thus forcing flower specialisation (Goulson and Darvill, 2004).

Most researchers believe that the declines are linked to intensification of farming practices (Williams, 1986; Osborne and Corbet, 1994). Declines were probably driven mainly by reduced availability of floral resources, rather than by nesting habitat. For bumblebees to thrive they require a succession of flowers from April to August, because they do not have large stores of pollen and honey in their nests (Fussell and Corbet, 1991). The best situations for this floristic succession are usually found in perennial semi-natural habitats (Corbet, 1995). They are therefore vulnerable to discontinuities in the food supply (Shelly et al., 1991; Williams and Christian, 1991). Studies in Poland, Finland and the UK have all demonstrated a direct correlation between the floral diversity of an area and the number of bee species (Banaszak 1983; Kells et al, 2001; Bäckman and Tiainen, 2002). Chapman *et al*. 2003 showed that beneficial forage sites will attract many individuals and are able to support different colonies. One such site in a London park of around one ha was used by 96 colonies of *B. terrestris* and 66 colonies of *B. pascuorum*.

There is a requirement for undisturbed habitats characterised by coarse vegetation for nesting either in leaf litter or small mammal burrows (Goulson, 2003). Lower populations of these mammals in the agricultural environment have led to a reduction in potential nest sites for both above and below-ground nesting bumblebee species (Goulson *et al*, 2008). Potential nest sites are found in perennial semi-natural habitats within agricultural landscapes (Kells and Goulson, 2003). Sowing a mixture of annual or perennial grassland species on arable field margins has been shown to be beneficial and to significantly enhance the abundance and diversity of bumblebees (Meek *et al*., 2002, Pywell *et al*., 2005; 2006). They have an advantage over uncropped margins, which have been left to regenerate naturally, as this can take several years and can encourage pernicious weeds (Carvell *et al*., 2004).

Bumblebees require a large home range with a single colony foraging over a radius of perhaps one kilometre, sometimes more. A species that may appear abundant, in terms of workers, may have only a very small effective population (Goulson, 2003). Small populations are inherently more vulnerable to local extinctions and if these populations form part of a larger metapopulation then extinctions can be balanced by repopulation. However if habitat fragmentation is severe it will lead to isolation without the possibility of repopulation and subsequent loss of genetic cohesion, with the attendant danger of genetic inbreeding. (Goulson *et al*., 2008).

It appears that bumblebees do not forage close to their nests. Flight times are short relative to the time spent within patches of flowers, so that a more distant site does not have to be much more rewarding to be the better option (Cresswell *et al*., 2000). However there is some evidence that bumblebee species may differ in foraging range and that this correlates to colony size. Those with large nest sizes such as *B. terrestris* and *B. lapidarius* forage further than those with smaller nest sizes such as *B. pascuorum*, *B. sylvarum* and *B. ruderarius* (Walther and Frankl, 2000). Further evidence is provided by Darvill *et al*. (2004), using genetic markers to quantify foraging ranges, with *B. pascuorum* foraging over distances less than 312 m and *B. terrestris* less than 625 m. Knight *et al*. 2005 found that the former species had the least (449 m) and the latter species had the greatest minimum estimated maximum range. They also found that, unusually, *B. lapidarius* (large colony size) had a range similar to *B. pascuorum* (small colony size).

Studies of foraging bumblebees involving mark-recapture or tracking using harmonic radar have shown that individuals and colonies tend to be area constant (Saville *et al*, 1997; Osborne and Williams, 2001). They have also demonstrated that workers may fly hundreds of meters from their nests to forage (e.g. mean of 275m with maximum of 631m (Walther-Hellwig and Frankl, 2000); mean of 339m, maximum 631m (Osborne et al, 1999)), though the harmonic radar technique requires line of sight and often bees flew beyond the range of the radar. However these results are supported by genetic analysis of spatial foraging patterns of bumblebees in the urban environment using microsatellite markers where estimated median foraging distances of 0.62-2.8km were derived for *B. terrestris* and 0.51-2.3 km for *B. pascuorum*, although these estimates are based on assumed nest densities (Chapman *et al.,* 2003). Mass flowering crops can act as attractants for foraging and Westphal *et al.,* 2003 showed that common bumblebee species will make use of these over a foraging range of up to 3000m. However there is evidence that the foraging range may be even larger as marked bumblebees have returned home after being released 9.8 km away (Goulson and Stout, 2001). The likely mechanism is through the use of familiar landmarks and it is improbable that the bee that returned from 9.8 km would have been able to do so unless its home range was several kilometres in radius. The species with large foraging ranges forage on a scale that buffers the effects of forage patch and flowering crop heterogeneity but the species with shorter foraging ranges, including the rarer ones, may experience highly variable colony success because they are unable to overcome these problems (Osborne et al., 2007)

In the long term it will be necessary to provide enough habitats for many colonies and this habitat cannot be supplied by the average small nature reserve. Edwards, (1999) suggests that a healthy bumblebee population may need 10 km^2 at least, supported by the fact that populations of *B. sylvarum* (Almondsbury Hill Common, South Gloucestershire) and *B. distinguendus* (NW Scotland) are found on areas of that size. These areas must obviously contain the necessary habitat for bumblebee survival. A study of bumblebee richness at the 10km^2 scales was positively correlated with land use heterogeneity, the proportion of grassland and the abundance and diversity of dicotyledonous flowers (Pywell *et al*., 2006). Therefore in the flower-impoverished agricultural landscape only a few generalist species are able to survive. Even these are greatly reduced in numbers, and their distributions are becoming associated with the much more floristically rich gardens of the increasing urban environment, which have enabled them to remain common and widespread.

2.4.3 Measures to reverse the decline

Flower type is important for bumblebees. Medium and long-tongued species visit deep flowers (e.g. Asteraceae, Fabaceae and Lamiaceae), whereas short-tongued species are more generalised but still have preferences (e.g. Asteraceae). In general it seems that perennials and biennials are favoured over annuals probably because they produce more nectar (Dramstad and Fry, 1995). Carvell *et al*. 2006, investigating a range of seed mixtures, showed that foraging bumblebees displayed contrasting patterns of visitation with longer-tongued species preferring perennial mixes in which *Trifolium pratense* was dominant, whilst shorter tongued species visited mainly *Borago officinalis* in the annual mix. Goulson *et al.* (2005) also found that *T. pratense* was the most favoured plant; 28.8% of all bumblebee pollen-collecting visits in their study were made to *T. pratense*, and Fabaceae as a whole received 61.1% of visits. Westphal *et al* 2003 showed that *B. terrestris*, *B. lucorum*, *B. lapidarius* and *B. pascuorum* were able to take advantage of annual mass flowering crops such as oilseed rape. These crops can have benefits for the generalist species, but as they only flower for a short period, crops are unable to provide the succession throughout the season April to August that bumblebees require (Goulson *et al*, 2008). Options that allow perennial plant communities to develop are more likely to benefit the rarer, more specialised bumblebees. Where seed banks are impoverished through weed management, or soil fertility is high, then sowing wild flower mixes can accelerate succession, although these are expensive (Corbet, 1995). Most of our information on favoured plant species of bumblebees refers to the six most common UK species (Annex D) and thus if we are to encourage the most threatened species to extend their range, further efforts will have to be made to identify their requirements (Goulson, 2003). However the development of uncropped field margins sown with a range of the species from Annex D will certainly aid the six common species and may also assist the rare species as well. Six metre wide uncropped field margins have been shown to support approximately six times as many flowering plant species, ten times as many flowers, and ten times as many foraging bumblebees as cropped margins (Kells *et a*l, 2001).

Some of the new ELS/OELS options will provide new nesting sites and over-wintering sites for bumblebees, another area requiring further research for the rare species. The undisturbed nature of the habitat is paramount, as found in long-term set aside, permanent uncropped field margins and beetle banks. Replanting and renovation of hedgerows provides more potential nesting sites for those under ground nesters reliant on old mammal nests. In the countryside, the area occupied by linear features is small, however linear features contain the high densities of bumblebee nest sites and therefore the management options affecting such features may have a disproportionately large effect on bumblebee nesting opportunities (Osborne *et al*, 2007). The increase in organic farming will also assist. Apart from the obvious avoidance of pesticide usage, organic farms are favourable because they depend heavily on rotations involving legumes such as clover to maintain soil fertility. Organic livestock farms may in the long term provide excellent habitat for bumblebees, as some of the best remaining habitats are unimproved grasslands grazed by cattle (Goulson, 2003).

Arable farms are inherently unsuitable for bumblebees and much other wildlife because of the large areas dominated by annual crops. If sufficient uncropped areas can be provided, populations of bumblebees can be expected to increase, though the extent of habitat required is still unknown. However as bumblebees forage over large areas it is also important that neighbouring farms also adopt the new management schemes (Goulson *et al*., 2002). The width of field margins was significantly related to total bumblebee density, but not species number or diversity in a study in Finland (Bäckman and Tiainen, 2002). Long-term options are required with no cutting of margins between April and September. Unimproved grassland is of even greater value and if pasture is to be reseeded, inclusion of red clover will provide great benefits. Deep cultivation (30-40 cm) would aid this as it caused significant reductions in soil P and K concentration which had a significant beneficial effect on the establishment and persistence of sown forbs and corresponded most closely to the specified target communities (Pywell *et al*., 2002). In order to sustain the abundance and diversity of insect pollinators in intensively farmed agricultural landscapes it is essential to preserve the remaining semi-natural grasslands and recreate other flower-rich resources (Ockinger and Smith, 2007). A project concerned with the restoration and management of bumblebee habitat in agricultural landscapes in England supported by Defra reports at the end of this year and hopes to answer questions on how much suitable habitat is required to sustain bumblebee populations and how the surrounding habitat quality influences bumblebee response to newly created habitats provided by Environmental Stewardship (Anon, 2007a).

2.4.3.1 Research on bumblebee abundance and diversity in field margins

Removing land from intensive arable production and replacing it with low cost mixtures which include agricultural varieties of legumes is an effective method for creating high quality foraging habitat for bumblebees (Pywell *et al*. 2005; 2006). Importantly it has also been shown that the impact of sown patches in terms of attracting foraging bumblebees was greatest where the proportion of arable land was highest (Heard et al, 2007). The use of agricultural varieties is recommended as some of the species in the wild flower mixes failed to establish or persist on the fertile ex-arable soils (Pywell *et al*., 2003). A comparison of different Environmental Stewardship options for field margins on arable land has shown uncropped margins sown with mixtures of nectar and pollen-producing plants were more effective in providing bumblebee forage than margins with a grass mix (Carvell *et al*., 2007). This was supported by Carvell *et al*. (2004), who showed that grass and wildflower mixtures had the highest bumblebee abundance and by Pywell *et al*. (2006), who showed that bumblebee abundance was significantly higher on pollen and nectar margins (86 ± 14 bees/100 m) compared to wildflower margins (43 ± 14), mature grass margins (6 ± 14) and recently sown grass margins (8 ± 4). Carvell *et al*. (2007) also showed that mixtures of agricultural legumes established quickly and attracted on average the highest total abundance and diversity of bumblebees, but there were problems with achieving flowering throughout the bumblebee season and with the longevity of the mixtures. Such improvements for bumblebee foraging should preferably be carried out at the large ($100km^2$) scale (Bäckman and Tiainen, 2002). Such habitat creation would help reduce the loss of landscape heterogeneity that can be seen over most of England, which has had an impact on a wide range of farmland species (Benton *et al*., 2003). The mixed farming regions in the Southwest and West Midlands have a high level of heterogeneity in their land use and also a greater species richness of bumblebees and a greater abundance of long tongued bees (Pywell *et al*., 2006).

Bumblebees can respond to spatial and temporal changes in resource supply at scales greater than a single farm, but provision of some form of nectar and pollen source on each farm would be an ideal target. Currently, Entry Level Stewardship allows a single patch of 0.5 ha of pollen and nectar seed mixture per 20 ha of farmland (Defra, 2005) but it is uncertain whether this is sufficient to sustain bumblebee populations in the long term.

2.4.3.2 Habitat Provision through ELS/OELS

Key options for providing nectar and pollen

EF4/5 Pollen and Nectar flower mixture

Mixture of agricultural (fodder) legume species (red clover, alsike clover, birdsfoot trefoil, sainfoin) and knapweed (~2%) with optional grass. Designed particularly for bumblebees, but will also provide nectar for butterflies.

EG3 Pollen and nectar seed mixtures in grassland areas

May not be used on fields which have been in permanent grass for five years or more. As EF4

Additional options providing some nectar and pollen

EF2&3: Wild bird seed mixture

(Will also provide seed for small mammals that provide bumblebee nest sites)

EG2 Wild bird seed mixture in grassland areas

EF9&10: Conservation headlands in cereal fields

EF11: 6 m uncropped cultivated margins on arable land

Options for providing breeding habitat

EB3 Enhanced hedgerow management:

Height at least 2 m, cut no more than one third of hedges each calendar year and cut each hedge no more than once every three calendar years. Uncultivated land 2 m from centre of hedge.

EB10 Combined hedge and ditch management incorporating EB3 hedgerow management.

As EB3 with ditch management.

EB1&2 Hedgerow management:

Height at least 1.5 m, cut each hedge no more than once every two calendar years.

EE1-2: 2 and 4 m buffer strips on cultivated land.

Grassy strip cut no more than 1 year in 5.

EE3: 6 m buffer strip on cultivated land.

Grassy strip, cut no more than 1 year in 5 or wildflower/fine-leaved grass mixture cut once a year in August/September.

EF, EK1: Field corner management:

Grassy corner in arable fields.

EF7: Beetle banks:

Tussocky grass ridge, at least 2 m wide and 0.4 m high.

2.4.3.3 Assessment of uptake patterns: deriving optimal amounts of options for comparison with observed uptake

Nectar and pollen mix options (EF4&5, EG3) are crucial for the survival and spread of bumblebees. These have been shown to have the most visits from bumblebees when provided on farms (Carvell *et al*, 2007), particularly fodder legumes with red clover an essential part of these mixes, which have an added advantage of being cheaper per kg than the wildflower seed mixes and are the best option for the provision of nectar and pollen on arable farms. A recent report suggests that some species may already be responding to the provision of these mixtures, e.g. *Bombus ruderatus*, *B. ruderarius* (Baldock, 2007). It is important that resources are provided throughout the season. It appears that these margins lose their flowering density after 3 years with a subsequent dramatic drop off in bumblebee numbers (Edwards and Jenner, 2005). It may be necessary sow fresh strips as mature strips go into decline, or possibly replace agricultural legumes with wild cultivars, which live much longer.

ELS rules allow for 0.5 ha of these options per 20 ha. If pollen and nectar mixtures were implemented throughout a farm using a simplistic block design and using the maximum amount in one block, this would mean that the shortest distance a bumblebee would have to fly to reach the edge of a patch would be 189 m with the longest 267 m at the adjoining corners of the blocks (Figure 2.2). This is well within the flight range of all species of bumblebees in England. However, implementing pollen and nectar strips at the maximum density permitted would take up 37.5% of the points requirement for a lowland farm. If the density was reduced to 0.5ha per 80ha, the distances would increase to 412 m with a maximum of 582m (Figure 2.2(b)) and still be within the minimum estimate maximum foraging distances for the common species (Knight *et al*., 2005), thus reducing the amount of points used to just over 9% of the total requirement, and allowing more points to be available for other beneficial ELS options. The requirement in terms of size for these areas is difficult to assess but it would seem that the larger the better as this would offer the highest chance of flowers being available for foraging at any one time and many bumblebee colonies are able to share the same resource (Chapman *et al*., 2003). However the rarest species may be the ones with the shortest foraging ranges (a few hundred metres) and these can only survive in places where nest and food opportunities are spatially coincident (J. Osborne, pers. comm.) which would suggest that more smaller blocks were a better strategy. This is supported by the work of Heard *et al.,* 2007, which showed that total forager numbers were proportional to the patch area. Positioning of these blocks or strips would be important with a southerly aspect, improved when next to hedge, providing the ideal location with optimum warmth and shelter for plants and bumblebees.

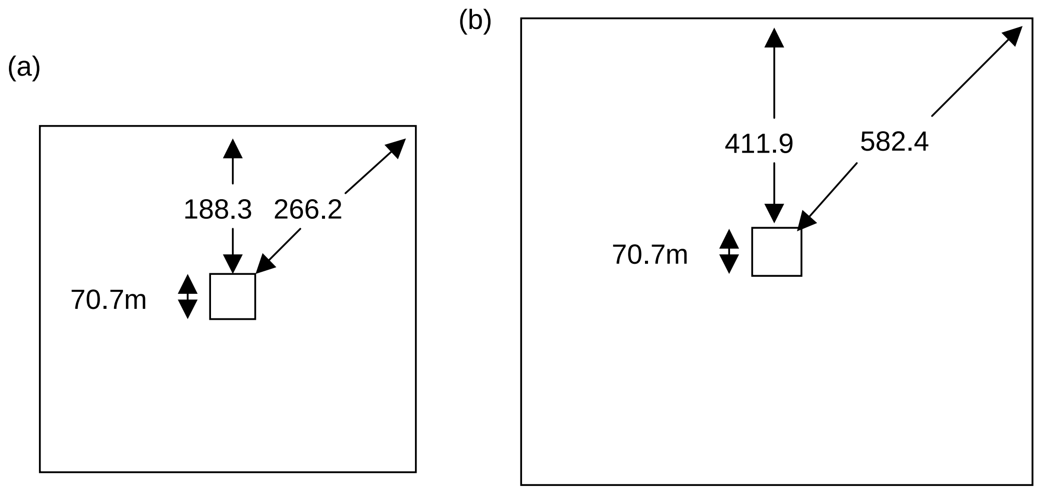

Figure 2.2 Diagrammatic representation of standardised block layout, showing maximum bumblebee flight distances at densities of one 0.5ha block per 20 (a) and 80 ha (b) (not to scale).

EB1-3 (Hedgerow management), EF7 (Beetle bank), EK1 (Field corner) and EE1&2 (Buffer strips) provide shelter and development of perennial vegetation that provides opportunities for nesting sites for surface nesters, and increased likelihood of small mammal nesting for the underground nesters. The 3-year rotation for cutting in EB3 provides a greater likelihood of flowering of shrubs, which are important early season nectar sources e.g. blackthorn, pussy willow (*Salix caprea*) and gorse (*Ulex europaeus*). EE3 6 m (Buffer strip) and EF1 (Field corner management), as well as providing nesting habitat, have an option to sow a mix of fine-leaved grasses and flowers and this should be encouraged to provide further sources of nectar and pollen. EF2, 3, 9, 10 and 11, and EG2 allow for the further development of heterogeneity within the arable landscape and although these are not as beneficial as the pollen and nectar options they will provide some forage for bumblebees.

The main area where there is a lack of suitable options for grassland farms. The exception is EG3, but this can only be used if the grassland is less than 5 years old.

Target amounts:

Pollen & nectar mixture:

Maximum permitted is 0.5ha/20ha, i.e. 2.5ha/km^2 (5%). Suggested target: 0.5ha/40ha, i.e. 0.625ha/km^2

Hedgerows:

Target is for a third of hedgerows to be managed under option EB1-3. At an average density of 3.0km/km^2 (eastern lowlands; Petit *et al*., 2003), this would be equivalent to 1.0km/km^2

Buffer strips:

All hedges managed as EB3 would have an adjacent buffer strip at least 2m wide. At an average density of 0.75km/km^2 (eastern lowlands; Petit et al., 2003), 2, 4 and 6m buffer strips on one side of all hedges would be equivalent to 0.6, 1.2 and 1.8ha/km^2 respectively.

Field corners:

Maximum permitted is 1ha/20ha, i.e. 5ha/km^2 (5%). Suggested target: 0.5ha/80ha (as for pollen and nectar mixture) i.e. 0.625ha/km^2.

Conservation headlands, Uncropped cultivated margins, Wild bird seed mixtures:

Suggested target 0.6ha/km^2

Beetle banks:

Only appropriate in large fields 16 ha or more. Maximum density at one bank 400m long per 16ha is 0.5% of field area. Halve this to allow for variation in field size; target density = 0.25% or 0.25ha/km^2

Suggested target amounts and equivalent percentages of the total points requirement are summarised in Table 2.7. If all these options were implemented, they would take up just over 55% of the points requirement, leaving flexibility for increased amounts of some options or additional options to benefit other environmental priorities. However, as some options provide similar resources, not all of those listed would need to be implemented to ensure the maintenance of bumblebee populations. It is suggested that a minimum requirement should be pollen and nectar strips plus one or more options to provide nesting habitat.

2.4.4 Area included in analysis

As bumblebees are widely distributed, the area analysed was not restricted, i.e. scheme uptake throughout England was included.

Table 2.7 Target average amounts and percentages of total points requirements for options to encourage bumblebees.

Option code	Option description	Points	Units	Target amount	Area ha/km^2	Points/km^2	% points requirement
EF4/EG3	Pollen & nectar mixture	450	ha	0.5 ha/80ha	0.625	281	9.4
EF9	Conservation headlands (6m wide)	100	ha	100m/km^2	0.60	60	2.0
EF10	Conservation headlands, no fert.	330	ha	100m/km^2	0.60	198	6.6
EF11	Uncropped cultivated strips	400	ha	100m/km^2	0.60	240	8.0
EB3	Enhanced hedgerow management	42	100m	1.0km/km^2		315	10.5
EE1/EE4	2m buffer strip	300	ha	1.0km/km^2	0.2	60	2
EE2/EE5	4m buffer strip	400	Ha	1.0km/km^2	0.4	160	5.3
EE3/EE6	6m buffer strip	400	ha	1.0km/km^2	0.6	240	8
EF1/EK1	Field corner management	400	ha	0.5 ha/80ha	0.625	250	8.3
EF2/EG2	Wild bird seed mixture	450	ha	0.6 ha/km^2	0.6	270	9.0
EF7	Beetle banks (2m wide)	580	ha	200m/16ha	0.25	145	4.8

2.5 MODEL OUTPUTS

2.5.1 Method

Scores for the individual options identified as being important for habitat provision, based on the literature review and consultations, were input into the model along with target amounts determined as described above (section 2.1.1, see also Annex A). Uptake data were obtained from Natural England, as at 1 September 2007. Two runs were carried out, one using data from 2 November 2006 and a second using the more recent dataset. The earlier dataset was the one used in the evaluation of the operation of Environmental Stewardship (Boatman et al., 2007), and so results using this dataset are comparable with the results of the earlier study. Comparison of the model outputs from the two datasets gives a measure of change of the ten month period between them.

Scores for each indicator were calculated for individual farms on the basis of the amounts of relevant options taken up on that farm. These were then scaled up to England level to provide a national score per square kilometre of ELS agreement land (out of a maximum of ten) for each indicator. As in the previous evaluation, overall scores for England were presented in two forms: (i) weighted by farm area, and (ii) unweighted. The unweighted scored were simply the sum of the individual farm scores divided by the number of holdings in the scheme (equation (a) below). The weighted scores were calculated as in equation (b).

(a) unweighted national score = Σ farm scores/km^2/no. holdings in ELS

(b) $$\text{weighted national score} = \frac{\Sigma\,(\text{farm scores/km}^2 \times \text{ELS agreement areas})}{\Sigma\,\text{ELS agreement areas}}$$

The weighted scores give more emphasis to the effect of larger farms. This method gives a more balanced view of the value of the scheme, as the benefits are weighted in relation to the area they relate to. In method (a), each holding is given equal weight, regardless of its size. Method (a) is included for comparison, to show the impact of including farm size in the calculations.

In addition, overall scores were calculated per square kilometre of farmland, for comparison with potential target uptake. This was calculated as in equation (c).

(c) $$\text{score per km}^2\text{ farmland} = \frac{\Sigma\,(\text{farm scores/km}^2 \times \text{ELS agreement areas})}{\Sigma\,\text{agricultural area}}$$

The agricultural area was calculated as the total area registered in the June Agricultural Survey. This is slightly higher than the eligible area (i.e. that registered in the Rural Land Registry), but the difference is small (3.4%). The June Survey area was used because this was available also for the restricted areas used for brown hairstreak and arable plants. A target uptake of 70% of the agricultural area was used for comparison,representing a notional maximal level of uptake.

The area analysed for arable plants was restricted to 73 JCAs, as described earlier (section 2.2.3). For the brown hairstreak, only the 155 10km squares in which it had been recorded between 1995 and 2004 were included in the analysis (see section For arable plants and bumblebees, three independent sets of scores were available, so these were analysed separately to show the degree of variability between assessors.

2.5.2 Results

Results are shown in Table 2.8 and Table 2.9. Differences between the two data samples in terms of scores per square kilometre of ELS area are small, indicating little change between November 2006 and September 2007 in the likely impact on the indicators adopted on holdings with ELS agreements.

Weighted scores were generally higher than unweighted scores, indicating that larger farms are having more impact on the indicators than smaller ones. This is probably because larger farms have more scope for selecting a greater variety of options, and are more likely to choose less popular options of benefit to these species. The mean numbers of options taken up by small (<50ha), medium (50-149ha) and large (>150ha) in the ES evaluation were 4.5, 6.9 and 9.7 respectively (Boatman *et al*., 2007).

Scores for arable flora were low, less than one, reflecting the low uptake of relevant options for this group (less than 20% of holdings had a score >0, i.e. had any relevant options). Scores for spring-germinating plants were higher than for autumn-germinating plants. Different assessors gave similar scores, though expert 3 tended to score slightly higher than the other two.

Brown hairstreak achieved an average score of over three out of ten within its range. Over 40% of holdings in the area considered had a score of greater than zero, i.e. had adopted one or more relevant options, and over 20% had a score over five. More than 5% of holdings achieved the maximum score of ten.

Results for bumblebees showed the greatest potential benefits. The weighted mean overall score was just below seven out of ten; around 80% of holdings had relevant options (score>0), more than half achieved a score greater than five, and nearly a quarter achieved the maximum score. As for arable flora, there was relatively little variability between assessors.

The final two columns in the tables show the scores averaged over all farmland, rather than ELS area. Obviously the scores are lower, because no benefits are assumed for land not in ELS, but they are included to indicate the potential increases which would result from greater uptake of the scheme. In reality of course, even farmland not in ELS is likely to provide some value, though in many cases this may be low.

2.6 DISCUSSION

The results for bumblebees are very encouraging, and indicate that even without targeted advice, ELS is making a substantial contribution to the conservation of this group. Indeed, the scheme may already be affecting populations of some species: a recent report in the journal British Wildlife suggests that some species may already be responding to the provision of habitat within ELS (Baldock, 2007). A considerable amount of research has been carried out on bumblebees and their requirements, and this research underpinned the design of the pollen and nectar mixture. Although it is too early in the life of the scheme to be confident of outcomes, the early signs suggest that this group may provide an example of the value of well researched management options making a real difference to the survival of beneficial species in the rural environment, with additional value in terms of the ecological services (in this case, pollination) provided.

Table 2.8[7] Overall (whole England[8]) mean scores by indicator, weighted by individual holding area, as at November 2006.

Indicator	Expert	No. holdings	Overall score per km² ELS area (out of 10)		% of holdings with score		Maximum score (% holdings achieving it)	Score quartiles			Overall score per km² farmland	
			Weighted	Unweighted	> 0	> 5		25%	50%	75%	Nov 2006	70% uptake
Brown hairstreak	1	1,635	3.16	2.26	43.2	21.7	10 (5.2%)	0	0	4	0.63	1.58
Autumn-germinating flora	*2*	*15,678*	*0.21*	*0.15*	*3.1*	*1.4*	*10 (0.02%)*	*0*	*0*	*0*	*0.08*	*0.1*
	3	*15,678*	*0.74*	*0.49*	*19.1*	*1.5*	*10 (0.16%)*	*0*	*0*	*0*	*0.29*	*0.34*
	4	*15,678*	*0.21*	*0.14*	*2.6*	*1.4*	*10 (0.64%)*	*0*	*0*	*0*	*0.08*	*0.1*
	mean	15,678	0.4	0.26	19.1	1.4	10 (0.03%)	0	0	0	0.15	0.19
Spring-germinating flora	*2*	*15,678*	*0.75*	*0.5*	*19.1*	*1.6*	*10 (0.13%)*	*0*	*0*	*0*	*0.29*	*0.35*
	3	*15,678*	*0.97*	*0.64*	*19.1*	*1.8*	*10 (0.27%)*	*0*	*0*	*0*	*0.38*	*0.45*
	4	*15,678*	*0.68*	*0.44*	*17.5*	*1.5*	*10 (0.69%)*	*0*	*0*	*0*	*0.26*	*0.31*
	mean	15,678	0.79	0.52	19.1	1.6	10 (0.18%)	0	0	0	0.31	0.37
Bumblebees	*5*	25,121	*6.56*	*5.33*	*80.0*	*51.3*	*10 (20.9%)*	*2*	*5.29*	*9.01*	*2.36*	*3.73*
	6	25,121	*7.14*	*5.96*	*80.0*	*57.5*	*10 (29.5%)*	*3*	*6.54*	*10*	*2.57*	*4.17*
	7	25,121	*6.46*	*5.22*	*80.0*	*50.4*	*10 (21.7%)*	*2*	*5.12*	*9.3*	*2.32*	*3.65*
	mean	25,121	6.73	5.51	*80.0*	52.4	10 (24.3%)	2	5.67	9.81	2.41	3.84

7 Because of the complexity of the model involved, interactions (positive and negative) were excluded from the analysis and the corresponding options were all treated as equivalent.

8 Restricted areas were used for autumn and spring-germinating flora (based on JCA) and for brown hairstreak (based on OS 10X10 km squares).

Table 2.9 Overall (whole England) mean scores by indicator, weighted by individual holding area, as at September 2007.

Indicator	Expert	No. holdings	Overall score per km² ELS area (out of 10)		% of holdings with score		Maximum score (% holdings achieving it)	Score quartiles			Overall score per km² farmland	
			Weighted	Unweighted	> 0	> 5		25%	50%	75%	Sept 2007	70% uptake
Brown hairstreak	1	1877	3.36	2.33	43.6	22.5	10 (5.75%)	0	0	4	0.79	1.63
Autumn-germinating flora	*2*	*17,566*	*0.2*	*0.14*	*3.0*	*1.3*	*10 (0.02%)*	*0*	*0*	*0*	*0.09*	*0.10*
	3	*17,566*	*0.72*	*0.47*	*18.4*	*1.4*	*10 (0.15%)*	*0*	*0*	*0*	*0.32*	*0.33*
	4	*17,566*	*0.2*	*0.13*	*2.5*	*1.3*	*10 (0.59%)*	*0*	*0*	*0*	*0.09*	*0.09*
	mean	17,566	0.38	0.25	18.4	1.3	10 (0.02%)	0	0	0	0.17	0.18
Spring-germinating flora	*2*	*17,566*	*0.73*	*0.48*	*18.4*	*1.5*	*10 (0.13%)*	*0*	*0*	*0*	*0.32*	*0.33*
	3	*17,566*	*0.95*	*0.62*	*18.4*	*1.7*	*10 (0.27%)*	*0*	*0*	*0*	*0.42*	*0.43*
	4	*17,566*	*0.66*	*0.42*	*16.8*	*1.5*	*10 (0.63%)*	*0*	*0*	*0*	*0.29*	*0.3*
	mean	17,566	0.77	0.5	18.4	1.5	10 (0.17%)	0	0	0	0.34	0.35
Bumblebees	*5*	*28,895*	*6.52*	*5.23*	*79.1*	*50.1*	*10 (20.54%)*	*2.0*	*5.05*	*9.0*	*2.71*	*3.66*
	6	*28,895*	*7.08*	*5.86*	*79.1*	*56.4*	*10 (28.67%)*	*2.93*	*6.23*	*10*	*2.94*	*4.10*
	7	*28,895*	*6.41*	*5.12*	*79.1*	*49.3*	*10 (21.21%)*	*2.0*	*5.0*	*9.16*	*2.66*	*3.58*
	mean	28,895	6.65	5.4	79.1	52.0	10 (21.77%)	2.33	5.46	9.46	2.76	3.78

Although at first sight results for brown hairstreak might seem disappointing, the fact that 5% of holdings achieved the maximum possible score in a non-targeted scheme is encouraging as it shows that ELS is capable of providing suitable habitat combinations for brown hairstreak conservation even on the basis of free choice by farmers, and that there is scope for improvement through the provision of targeted advice. The brown hairstreak is not a high profile species as far as the general public is concerned, and it is unlikely that many farmers would take it into account in their options choices without specific advice. Only a relatively small number of holdings were included in the distribution area (1635), and this number could be further reduced for the purposes of targeting advice, by identifying farms with suitable habitat in areas where with brown hairstreak was present or likely to be present, based on finer resolution data. Although some research has been carried out on this species, there is still a number of gaps in our knowledge of its habitat requirements, and further research could provide for a tighter specification of the optimal amounts and spatial arrangement of the key habitats.

Results for arable plants showed a severely limited impact of ELS in the area identified for this group. This is because there are only a few key options for the arable flora, and with the exception of stubbles (which have only limited benefit), uptake is very low. Options EF9, 10 and 11 were among the least popular options, as shown by the uptake analysis undertaken for the main ES evaluation (Boatman *et al*., 2007). The average percentage of agreements containing these options was 0.3, 0.7 and 1.5 respectively over all farm types, and even on cereals farms only 0.4, 0.8 and 2.6% took up options EF9, 10 and 11 respectively, though uptake of conservation headlands was slightly higher on general cropping farms (0.7 and 2.4% for options EF9 and EF10 respectively). Option EF9 (conservation headlands with fertiliser use allowed) is now considered to be of limited value for rare arable flora, so if this option were removed from the model, the results would be even less encouraging.

However, the earlier evaluation showed that there was higher uptake of key options in the JCAs with the highest scores, suggesting that there is scope for increasing impact by targeted advice. Most rare arable plant species have limited dispersal capabilities, so once their locations are known, options can be targeted very precisely at a field scale, and the amount of each option required may not be very large. Because the model considers the whole of each JCA identified, it gives a pessimistic view because in reality, only a small proportion of each JCA would need appropriate options to be implemented to make a major contribution to arable plant conservation, provided that these options were located in the right places. The model is therefore less robust at the level of spatial resolution considered for species with such strongly site-specific distribution characteristics species than for more mobile species such as bumblebees, where the precise location of options is likely to be much less important. More specific location data could be input into the model, but this would need to be done on an individual species basis.

In the setting of target amounts of options, some compromises had to be made between the ideal based on existing knowledge of the ecology, and what was considered a realistic target based on the proportion of points which an agreement holder could be expected to devote to the indicator concerned. Thus, for bumblebees, one of the experts consulted felt that the targets for pollen and nectar mixture and field corners should be set at the maximum permitted (1.0ha and 0.5ha per 20ha respectively) to maximise bumblebees numbers. However, this would have required farmers on average to devote over a third of their points to pollen and nectar mixtures and two thirds of their points to field corners. This is clearly unrealistic in a non-targeted scheme, especially for a widespread group such as bumblebees where there is limited scope for specific targeting of key areas through advisory input as for arable plants and the brown hairstreak.

Although the approach adopted here, of combining literature review with expert opinion, and taking a reasoned approach to the allocation of points to objectives within a multi-objective scheme, has provided a workable method of analysing uptake, there is still clearly a need for better information on optimum amounts and densities of key habitats for species of conservation concern. This aspect has not been widely researched in most cases, and the resulting data are sparse for most biodiversity indicators. A greater emphasis on amounts of habitat required in the agricultural landscape in future projects would provide a firmer basis for assessing the impact of ELS on a wider range of indicators.

2.6.1 Improving the impact of ELS

The following measures could be considered in order to improve the impact of ELS on the biodiversity indicators examined in this report.

2.6.1.1 Arable Flora

Two key options for conserving arable flora, uncropped wildlife strips and conservation headlands without fertiliser, are available in ELS and are well supported by research data in terms of their efficacy. The main problem is in terms of uptake. As rare flora are limited in distribution, not only in terms of farms and fields, but often within fields, there is a good opportunity for targeting options to sites where they will be most effective. Specialist advice in the most important areas could be especially helpful here.

Making the options more attractive could increase uptake, e.g. by allowing measures to control pernicious weeds in uncropped wildlife strips. Weeds such as thistles often become increasingly dominant with time, suppressing the rare species and potentially causing agronomic problems. Because the great majority of rare species exhibit dormancy, they do not need to set seed every year, indeed one good seeding year should maintain the population for a number of succeeding years (hence the old adage: “one year’s seeding makes seven year’s weeding”). Hence, occasional use of a broad-spectrum herbicide such as glyphosate to clear out perennial weeds should not affect the conservation value of the strips in terms of long term conservation of arable flora, in fact it should increase it in the following year by removing competition. It is recommended that herbicide be applied at the optimum time for control of the target species, regardless of the impact on the rare plants (which will regenerate in the following year from seeds in the soil), but only be allowed once every (say) three years. Where grass weeds become established, the use of selective graminicides could help to keep them under control. Where weed problems become unmanageable in spite of these measures, strips could be rotated, but this is only beneficial for rare arable plants where occur in more than one area.

If herbicide use is approved, consideration should be given to increasing the number of points to cover the costs of herbicide and application.

Removing conservation headlands from the cropped area could reduce concern about the impact of weeds in the crop, but points allocation would have to be increased to allow for loss of the unharvested grain.

Conservation headlands with fertiliser allowed (EF9) appear to have limited value for rare arable flora and the reference to these under this option in the handbook should therefore be removed.

2.6.1.2 Brown hairstreak

There are already suitable options for providing breeding habitat (EB3/EB10/EC4) in hedges and woodland edges where blackthorn is present. Although overall uptake of these options is relatively high, there may be scope for increasing it within the range of brown hairstreak.

With its restricted distribution, there is considerable opportunity for targeted advice to promote the uptake of suitable options or combinations of options for this species, as noted above. Emphasis should be placed on the location of suitable options where blackthorn is a significant component of the hedge or woodland edge.

An option giving additional points for EB3-type management of hedges with mature hedgerow trees which could e used as 'master trees' (ideally ash for brown hairstreak) would be beneficial.

There is also scope for combined options, providing breeding habitat adjacent to nectar plants, with the added benefit of protecting the blackthorn shrubs from crop management operations. These could take the form of EB3 or EC10 type management adjacent to field corner management, pollen and nectar mix or buffer strips. Consideration could be given to recommending the inclusion of appropriate nectar-providing species (e.g. fleabane, hemp agrimony) in seed mixtures where conditions are appropriate. These species prefer damp conditions; further research into possible additional plant species used for nectaring, suitable for different soil types/growing conditions would be useful.

2.6.1.3 Bumblebees

As for arable flora and brown hairstreak, suitable options already exist for the conservation of bumblebees in ELS/OELS, strongly underpinned by ecological research. Pollen and nectar mixtures, in particular, have been developed primarily for bumblebees, however this option is not available in areas of permanent grassland. It is suggested that this prohibition could be reconsidered for permanent grassland receiving moderate or high levels of fertiliser, as these are unlikely to be of significant conservation value and only a small area of the grassland would need to be cultivated to create pollen and nectar plots.

There is evidence that pollen and nectar mixtures established using agricultural varieties decline after 2-3 years. This is likely to be a result of the characteristics of the cultivated varieties, which have been bred for erect habit and to partition a high proportion of their biomass to above ground vegetative parts, at the expense of longevity. Consideration should be given to the use of wild-type varieties which have not been bred for high yield and are likely to be more persistent, to avoid the need for regular re-sowing.

Experts consulted during this project questioned the provision of pollen and nectar mixtures in large blocks and considered that more smaller blocks or strips would be more beneficial. It is therefore recommended that the restriction on number of blocks or strips be removed and replaced by a restriction on area (e.g. total of 0.5ha per 20ha).

Recommended perennial species for inclusion in seed mixes for sowing buffer strips etc. for those who wish to encourage bumblebees, could be listed in the handbook (possibly in an appendix if there is insufficient room in the body of the text) (see Annex D).

Again, there is scope for combined options, e.g. flower rich buffer strips, field corners or pollen and nectar mixtures next to beetle banks or hedges managed under option EB3 to provide nesting habitat. (see Annex D).

3. WATER QUALITY

3.1 QUANTIFYING THE IMPACTS OF ELS ON WATER QUALITY

In understanding how Environmental Stewardship (ES) options may reduce diffuse pollution of surface waters it is advantageous to understand the mechanisms via which pollution may occur. Fundamentally, there must be a pollutant source, an initial mobilisation of the pollutant and a means via which it is then transported to a surface water body. Options for reducing pollution are therefore to either lessen the quantity of the initial source, and/or to retard (thus providing time for other processes (e.g. uptake; demineralisation) to occur), or prevent, the mobilisation and transport of the pollutant to the surface water. A brief overview of the processes affecting nitrate and phosphorus is given below.

3.1.1 Dynamics of diffuse pollution

3.1.1.1 Nitrogen

Nitrate is an inorganic form of nitrogen (N) that is highly water soluble and therefore readily leached from the soil. Nitrate is formed by the mineralisation of organic N (organic N → ammonium → nitrite → nitrate) and it is the principal form in which plants assimilate nitrogen. The primary sources of nitrate in agriculture are: inorganic fertiliser, organic fertilisers (manure, slurry, sewage sludge etc), excreta voided *in situ*, and green mulches. Mineralisation of organic N is an important component of diffuse pollution; soil disturbance is possibly the most notable practice that encourages mineralisation through the creation of aerobic soil conditions, particularly where this involves the incorporation of stubble/vegetation back into the soil, i.e. an N source. Such practices could include common agricultural requirements such as ploughing, tilling etc.

The timing of soil disturbance is also relevant to nitrate leaching. The primary process (other than leaching) that removes soil nitrate is plant uptake during the growth period. When plants are not actively growing, or growing at a slow rate, less nitrate is removed from the soil and more is available for leaching. Consequently, nitrate is prone to leaching in the late autumn when there is minimal plant uptake, rainfall is relatively high and evapotranspiration is reduced so there is both a source of nitrate and the means of transport via greater hydrological connectivity.

3.1.1.2 Phosphorus

Phosphorus exists in inorganic (phosphate) and organic forms, but the inorganic fraction of the total phosphorus pool is small because phosphate rapidly binds to soil organic matter and clay, both irreversibly and biologically-reversibly. Mineralisation of soil organic P is therefore a minor source of inorganic P compared to the nitrogen cycle. The predominant source of P to agricultural land is therefore in inorganic and organic fertilisers.

Although phosphate is soluble, leaching is not the predominant transport mechanism for phosphorus (with the possible exception of phosphorus enriched soils), and P losses are primarily associated with the fine fraction of sediments in runoff or sub-surface flow in cracks and drains. Factors influencing P losses are therefore associated with those factors affecting sediment transport, and significant P losses can arise from discrete, high risk areas (e.g. eroded areas around gates in close proximity to drains). Soluble and 'incidental' losses of P account for approximately

40% of total losses (Anon, 2002); incidental losses are those from a source that has had insufficient time to interact with the soil (e.g. runoff after fertiliser application; animal excretion into surface waters).

The differences in N and P dynamics mean that the effect of introducing an ES option is likely to impact on either N, or P, but not significantly on both (with the exception of reduced inputs). For example, options aimed at reducing runoff and erosion, e.g. by interrupting the flow of water (in-field buffers, hedges, no tramlines – EM1) could reduce P losses, but they are unlikely to reduce leached N. Similarly, minimising soil disturbance could reduce nitrate production and subsequent losses, but the impact on P will be minimal. It is important to recognise that different options will affect different pollutants and diverse options may be required to have a significant impact on water quality.

3.1.2 Background Literature

There has been a wealth of research into processes affecting N and P losses. This literature was reviewed to ascertain values of N and P losses associated with different types of farming and/or farming practices that were analogous to management techniques outlined in the ELS. Two key reviews were identified as highly relevant to the current project; namely: An inventory of measures to control diffuse water pollution from agriculture (DWPA), Cuttle *et al.*, 2006, and the Defra-funded project PE0203 which in itself was used in Cuttle *et al.,* 2006.

Project PE0203 was a significant study collating research relating to P losses and mitigation techniques; the study focused on the UK, but experiences in Europe were also considered. Expert opinion was then used to estimate the extent to which mitigation options could reduce P losses in the UK. It was noted that the effectiveness of options varied considerably with location and that there were many areas where the evidence underpinning the proposed mitigation options was limited, and the study was therefore heavily dependent on 'expert opinion'. Consequently there was necessarily a large amount of uncertainty in the values of P losses associated with the mitigation options and the authors proposed that findings should be used merely to prioritise mitigation techniques. Since PE0203 was completed, there have been attempts to address some of the gaps of the underpinning science and Defra have funded work to investigate mitigation options for phosphorus and sediment (MOPS) due for completion in 2008. This project examines the effectiveness of P and sediment loss mitigation options at high risk sites where treatments include:

- Minimum tillage
- Contour cultivation
- Tramline disruption
- Crop residue management
- Vegetative barriers

The work includes specific ELS options such as beetle banks. The MOPS study is not yet completed, and it is proposed that the findings of MOPS should be used to refine the outcome of the work reported here.

The values of N and P losses given in Cuttle *et al*. (2006) and those in PE0203 provide the basis for quantifying the impact of ELS on water quality in the current study. Henceforth, the reference "Cuttle *et al* (2006)" has been shortened to "Cuttle" due its frequency of use.

It must be noted that quantifying losses of N and P is not an exact science. Variations can occur depending on soil type, rainfall, soil moisture, temperature etc *and interactions between these variables; losses of N and P can vary even within a single field. Computer models have been developed to consider these interactions but there are limitations to their accuracy, particularly if attempting to scale up results from the field to the landscape scale. Values of N and P losses used in this study can be considered as indicative of N and P losses. The results of this study will allow those options that are likely to have a greater impact on N and P losses to be highlighted compared to other options, but it should be noted that the values of N and P calculated should not be considered absolute and they will be subject to variation. Moreover, it was beyond the scope of this study to attempt to validate the findings.*

3.2 METHODOLOGY

3.2.1 Estimating impacts of ELS options on nutrient losses

The general approach to estimating the impact of ELS on N and P losses was to assign an analogous mitigation measure or farming type from Cuttle to the land to which the ELS is implemented. For example, 'reducing the depth of cultivation to preserve archaeological features' was assumed to be equivalent to 'minimum or no tillage'; 'field corner management in arable land' was equivalent to 'reduced input'. Sections 3.2.1.2 to 3.2.1.14 provide full details of the baseline land use type ('From') and the subsequent land use type/mitigation option ('To'), if the ELS was implemented, for all the individual options.

Cuttle provides values of reductions in N and P losses. It was therefore necessary to assume an initial loss in the absence of any ELS being implemented. Baseline losses for N were 50, 50, 20, 2 kg/ha/yr for arable, dairy, beef and ungrazed grass respectively (Cuttle *et al*., 2006; Anthony, 2007), and, for P, 3.8, 2.2, 1.6, 3.9 kg/ha/yr for arable, dairy, beef and pigs respectively (PE0203).

3.2.1.1 Management Plans

Options EM1 – EM3 Soil, Nutrient, and Manure Management Plans (now no longer available within ES) consider a multitude of management techniques within a single option. For each Plan, the contents of the publications to which the user is referred were examined to identify farming practices that were analogous to the mitigation options listed in Cuttle, e.g. 'Check fields regularly; be prepared to move stock' (Soil Erosion manual) was analogous to 'Reduce field stocking rates when wet' in Cuttle.

Several of the proposed farming practices were not independent in relation to the impact they would have on water quality. For example, 'minimise dirty water' and 'compost to reduce volume' will have the same impact as 'increase storage capacity'. A category of impact was therefore assigned to each of the mitigation options. The maximum value (of reduction in N and P loss) within a single category was used as the value of reduction in losses for all the management practices falling within that category. It was reasoned that if a single practice, 'a', acted to reduce N and P losses more than 'b' and 'c' then the overall impact of practices 'a', 'b', and 'c' could not be less than 'a', thus it was inappropriate to average the values. Similarly, practicing 'b' and 'c' would not increase the value of the impact above 'a' as the practices within a single category are assumed to have a single, overall impact, thus summing 'a', 'b' and 'c' would also be inappropriate.

Different categories were assumed to have additive effects.

The ELS dataset includes details of the area of land under each option, but it is not possible to know how many, or which, of the individual practices have been implemented under the Management Plans, and/or whether they have been applied to the whole farm. It was therefore necessary to develop a scenario of implementation to calculate 'typical' N and P losses for different farm types; these losses were then used in conjunction with the actual uptake data for EM1, EM2, and EM3 in order to provide some indication of how the Management Plans may impact on water quality in reality.

Three scenarios were developed – high, medium, and low – with 'high' having a large proportion of the farm under mitigation options, and vice versa for 'low'. Mitigation options were divided into those that covered whole fields (e.g. minimum cultivation, drill across slope), those that may be implemented on a relatively small scale (e.g. construct bridges) and measures that may apply to even more discrete areas and that may be more difficult to implement (e.g. relocate gateways). Arbitrary values of implementation were used to develop the scenarios for the purposes of this study (Table 3.1). It should be noted that the 'high' scenario is unlikely to be attained in reality, but the values were included to illustrate the area of land that may be required to be farmed according to ELS to achieve noticeable reductions in N and P losses, under the current system.

Table 3.1 Land areas covered by mitigation option type for different scenarios

Type of option	% of land under mitigation option		
	High	Medium	Low
Whole field	75	50	25
Small scale	25	10	0
Discrete	10	5	0

Standard farm areas were taken from Cuttle: Arable = 300 ha; Dairy = 125 ha; Beef = 100 ha. These values were used to calculate the area of land under the mitigation option for the different scenarios (e.g. a whole field option under the 'high' scenario would cover an area of 225 ha on an arable farm and 75 ha on a beef farm). These areas of land were then used to calculate baseline N and P losses for the different farm types (in the absence of any mitigation options). Similarly, the areas of land were used to calculate N and P losses for the different farm types if a mitigation option was implemented. A percent reduction in N and P losses for each mitigation option was then calculated. The maximum 'percent reduction' for each different category within the typology (e.g. storage, runoff) was summed to give a total percent reduction for each scenario and each farm type (arable, dairy and beef); the percent reductions of arable and dairy were averaged to give a percent reduction for mixed farming. The overall 'percent reduction' for the different scenarios (high, medium and low) was used in conjunction with the baseline loss values (Section 3.2) to calculate losses of N and P in kg/ha for the different farm types and Management Plans. These values of reduced losses (kg/ha) were then used with the uptake data for EM1, EM2 and EM3 (given in ha) to provide an indication of actual N and P losses (kg).

Full details for the individual Management Plans are provided in sections 3.2.1.11to 3.2.1.14.

3.2.1.2 Options EB01-11: Hedge and ditch management

The main effect of implementing these options is that a strip of land is taken out of cultivation alongside the hedge and/or ditch, extending 2m from the centre of the hedge or ditch. It is not unusual for a ditch or hedge to be between 0.5 and 1 m wide, and the land next to the hedge is likely to be unsuitable for cropping. Consequently, in reality, these options will take ~ 1m, or even less, out of cultivation compared to the *status quo*. It is likely that the hedge and its undergrowth are better barriers to runoff than an additional 1m strip of poor vegetation. Given the uncertainties surrounding quantification of nutrient losses, the overall impact of these options on N and P losses is considered to be negligible for the purposes of this study.

3.2.1.3 Options EC01-04: In-field trees and woodland boundaries

N and P losses arising from a single land management technique will naturally vary spatially and temporally on the scale of a few metres to field or farm scale. It is very unlikely that excluding treatments from under the area of a tree canopy or along a woodland edge will have any *measurable* difference to N and P losses over the entire field given the very small areas involved. The impact of these options is therefore considered to be negligible.

3.2.1.4 Options ED01-05: Protection of archaeological features

Efforts to protect archaeological features include taking land out of cultivation and reducing the depth of cultivation. These practices therefore have some potential for reducing N and P losses. (Although ED05 includes practices such as "do not supplementary feed" and "do not locate water troughs on archaeological sites", both of which could reduce P losses in particular (Cuttle *et al*, 2006) it has been assumed that the feeders or troughs would still need to be located somewhere on the farm so there would be no overall reduction in N and P losses over the farm as a whole.) The impacts of the ED options are summarised in Table 3.2.

Table 3.2 Farming practices related to options ED01-ED05

Option code	ELS option description	Magnitude of impact	Equivalent farming practice	
			From	To
ED01	Maintenance of traditional farm buildings	None	-	-
ED02	Take archaeological features currently on cultivated land out of cultivation	Medium	Arable	Extensive grazed
ED03	Reduce cultivation depth on land where there are archaeological features	Small	Arable	Min till
ED04	Management of scrub on archaeological sites	None	-	-
ED05	Archaeological features on grassland (Do not plough or reseed).	Small	Dairy	Extensive grazed

3.2.1.5 Options EE01-08: Buffer strips

These options are for implementing buffer strips 2m, 4m, or 6m wide alongside environmental features such as ponds, ditches, riverbanks, hedges and stone walls, and 10 m buffers around in-field ponds. (These options do not include in-field buffer strips for breaking up long slopes). The buffer strips cannot receive any applications of fertiliser or manure, but they may be grazed where the buffer strip is in intensive grassland and there is no requirement to fence the buffers. The mitigation option "establish riparian buffer strips" in Cuttle is therefore inappropriate to grasslands as it assumes the buffer distances agricultural activity from the riparian area; instead, 'reduced inputs' is the more appropriate measure. Similarly, in the ELS handbook it states that the buffers can be applied along boundaries. However, a hedge or stone wall would already provide a barrier to surface losses of nutrients, and the impact of creating a buffer strip along such boundaries is more akin to hedge management

(Section 3.2.1.2). Calculations for buffer strips in the current study have therefore assumed the buffers are riparian. Only 37% of buffer strips were actually found along watercourses in the main evaluation (Boatman et al., 2007), so the number of buffer strips reflected in the uptake data was multiplied by 0.37 to estimate the effects of riparian buffers on phosphate, on which they have their main impact.

The values provided by Cuttle are for a 6m riparian buffer. There are no data on the effectiveness of different widths of buffers in the UK context, although Parkinson *et al*. (2000) suggest that buffers should be at least 10m wide to be effective. In reality, it is difficult to provide a single value of optimum buffer width for all situations and buffer width may need to be decided on a field-by-field basis (Leeds-Harrison *et al*., 1996). For the purposes of this study, a linear response between buffer width and nutrient losses has been assumed. Reduction in N losses was minimal (only ~ 1kg for each ha of field with a 6 m buffer); P losses were reduced from 2.71 to 1.08 kg/ha for each field with a 6m riparian buffer.

It was beyond the scope of this study to examine the impact of ELS on the water quality of ponds, thus options EE07/08 have not been considered further.

Although values of N and P losses are given for implementing buffer strips, the results of the study should be considered in light of the fact that buffers have variable effectiveness, they may have limited lifespans and they should not be relied upon to control P loss in isolation (PE0203); where buffers have acted as a sink of nutrients, they could become a source under heavy rainfall conditions.

3.2.1.6 Options EF01-11: Options for arable land

The options for arable land are primarily concerned with increasing the diversity of plant species to provide habitat for wildlife. The areas covered by each option are small; most options do not allow the application of fertiliser or manure, thus inputs are reduced. Option EF7 Beetle banks could have a more significant impact on N and P losses as it creates a break across the slope, in effect providing an in-field buffer. The impact of beetle banks on P losses is currently under investigation in the MOPS study. For this study, the mitigation option “Install hedges” is considered to be a more appropriate analogy than in-field buffers as the latter are 6m wide, whereas hedge widths are more akin to the stipulated 2m (minimum) for beetle banks. The impacts of options EF01-11 on N and P losses are summarised below (Table 3.3).

3.2.1.7 Options EG01-05: Options to encourage a range of crop types

These options for arable and grassland increase the mix of vegetation. There was no benefit to water quality identified in any of the options. Although “Wild bird seed mixture in grassland areas” dictates that fertiliser or manure should not be applied other than at establishment, the land may be disturbed by sowing, and/or moved within the field. The disturbance of the soil is likely to negate the benefits of reducing fertiliser input, particularly given the relatively small areas of land considered (0.5 ha under the option in 20 ha farmland).

3.2.1.8 Options EJ1-2: Options to protect soils

Ceasing to farm outdoor pigs or root crops (potatoes, sugar beet, fodder maize and brassicas) in fields at risk of soil erosion or runoff is likely to reduce nutrient losses to water course, notably P. In this study it has been assumed that the land growing these crops would change to cereals, thus the impact is measured by the values of N and P losses assigned to the different farming types.

The careful management of maize to reduce soil erosion is likely to reduce nutrient losses. The mitigation options “Establish cover crops” and “Leave autumn seedbeds rough” were averaged to provide values of the benefit of this option.

Table 3.3 Farming practices related to options EF01-EF11

Code	Description	Impact size	Equivalent mitigation option	Nature of impact
EF01	Field corner management	Small	Extensive ungrazed	No F/M
EF02	Wild bird seed mixture	Small	Reduced input	Restricted F/M[+]
EF03	Wild bird seed mixture on set-aside land	None	-	-
EF04	Pollen & nectar flower mixture[†]	None	-	-
EF05	Pollen & nectar flower on set-aside land[†]	None	-	-
EF06	Over-wintered stubbles	None	-	-
EF07	Beetle banks	Small	Install hedge	Breaks up slope
EF08	Skylark plots	None	-	-
EF09	Conservation headlands in cereal fields	None	-	-
EF10	Conservation headlands in cereal fields with no fertilisers or manure	V small	Reduced input	Restricted F/M*
EF11	6m Uncropped, cultivated margins	Negligible	-	-

[†]Benefit of no fertiliser/manure negated by legumes and winter grazing
* No F/M application between harvest of previous crop & harvest of headland
[+]F/M only allowed during establishment

3.2.1.9 Options EK1-5: Options for grassland

Options for grassland are primarily concerned with reducing fertiliser additions in order to encourage a higher number of flora and fauna. However, the maximum quantities of N stipulated are relatively low (< 100 kg Total N/ha) and research into the effect of fertiliser on nitrate leaching has generally involved much higher levels of fertilisation (> 150 kg/ha). The few studies that have investigated the impact of lower rates of fertilisation found that there was no significant difference in rates of N loss from unfertilised grass (Malisauskas *et al*., 2005;) and the general consensus is that grazing intensity is more significant to nitrate leaching. In the ELS options there is no specific requirement to reduce grazing intensity, thus it is unlikely that these options will significantly reduce N and P losses. Similarly, most farms in England already apply substantially less fertiliser than the recommended rate (Anon, 2007b; D3), thus the implementation of lower application rates in line with ELS may already be occurring, and these options are unlikely to have any measurable impact on N and P losses.

3.2.1.10 Options EL1-6: Options for Less Favoured Areas

Less favoured areas (LFAs) are typified by extensive sheep and cattle farming. Areas of rough grazing and moorland, by their nature, will receive very little, if any fertiliser. The options EL5 and EL6 are therefore unlikely to result in any change from the current position with respect to nutrient losses. Similarly, in-bye land also receives relatively low inputs of fertiliser. Moreover, research has demonstrated that similar quantities of N are leached from unfertilised grass/clover swards and grass swards receiving fertiliser (Cuttle *et al*., 1998). It is therefore unlikely that any of the LFA options will have any *measurable* impact on water quality at the scale considered here, and “no change” has been assumed for the purposes of this study.

3.2.1.11 EM1 Soil Management Plan

The Soil Management Plan (SMP) is aimed at reducing the risk of erosion and maintaining good soil structure. This will benefit water quality by enhancing the potential for infiltration and water holding capacity, thus reducing the means via which nutrients may be transported to water courses. To comply with this option, the farmer must conduct a field-by-field assessment of runoff risk and soil erosion each year and record how they will manage the land appropriately. The farmers must use a number of Defra publications for guidance including:

- A field guide for an erosion risk assessment for farmers (PB 4092);
- An advisory booklet for the management of agricultural land (PB 3280);
- Controlling soil erosion: A manual for the assessment and management of agricultural land at risk of water erosion in lowland England (PB 4093);
- Controlling soil erosion: Incorporating former advisory leaflets on grazing livestock, wind, outdoor pigs and the uplands.

The advice is wide ranging, reflecting the diverse situations under which erosion and runoff may occur. Table 3.4 lists those practices that fall within the SMP that have been used to estimate the impacts of its implementation on N and P losses. The categories to which the mitigation measures have been assigned, and a brief explanation, are also given below.

Land use – This involves the conversion of an entire parcel of land to extensive grassland and this option could be implemented in addition to other measures. It has been assumed that this would only occur on a small proportion of the farm area where no other measures to reduce nutrient loss were available, because of the impact on productivity.

Soil – These measures enhance the potential for infiltration and hence reduce the potential for runoff. They are also most likely to be implemented on the whole field scale.

Runoff – The introduction of hedges and in-field buffers also act to interrupt the flow of runoff. It has been assumed that either in-field buffers, or hedges would be introduced, but not both, as the effect is the same. Similarly, 'move gateways' is included in this typology as the desired effect is the same. Whilst avoiding **tramlines** in winter will reduce the potential for runoff by reduced compaction and connectivity to water courses, this mitigation measure was placed in a separate category as it could be implemented in different areas of the farm and in addition to hedges etc.

Stock – These mitigation measures are primarily concerned with reducing soil compaction and poaching *in the field*.

Fencing – Whilst poaching may also occur at stream banks, the impact of losses in such close proximity to the water would be greater than from poaching within the field. Fences and bridges also prevent direct pollution of water courses through excreta, hence these options are additional to "Stock".

Table 3.4 Practices advised in the Soil Management Plan

Advice in Soil Erosion publications	Equivalent mitigation method	Category	Arable	Dairy	Beef	Mixed
Ideally keep the most vulnerable sites in grassland	Convert high risk land to extensive grassland	Land use	y	n	n	y
Establish an early-sown autumn cover crop before spring sown crops/Establish autumn-sown crops early enough to achieve good ground cover/Avoid late sowing	Establish cover crops in autumn	Soil	y	n	n	y
Delay cultivations for seedbed preparation until just before drilling/Avoid sowing early spring	Cultivate land for crop establishment in spring rather than autumn	Soil	y	n	n	y
Establish without ploughing	Adopt minimal cultivation systems	Soil	y	n	n	y
Work across slopes	Cultivate and drill across slope	Soil	y	n	n	y
Leave seedbeds as coarse as possible	Leave autumn seedbeds rough	Soil	y	n	n	y
Ideally drill without tramlines	Avoid tramlines over winter	Tramlines	y	n	n	y
Introduction of breaks on long slopes	Establish in-field grass buffers/strip contour	Runoff	y	y	y	y
Introduction of breaks on long slopes	Install hedges	Runoff	y	n	n	y
Check fields regularly; be prepared to move stock	Reduce field stocking rates when wet	Stock	n	y	y	y
Limit daily grazing time	Reduce length of grazing day	Stock	n	y	y	y
Site water troughs away from water; move feeders regularly	Move feed & water troughs regularly	Stock	n	y	y	y
Fence off to prevent stock access	Fence off river banks and watercourses	Fence	n	y	y	y
Provide bridge if possible	Construct bridges	Fence	n	y	y	y
Relocate farm tracks if could channel water	Move gateways	Runoff	y	y	y	y
Loosen compacted soils	Loosen compacted soils grass	Stock	n	y	y	y
Buffer strips*						

*Although buffer strips are included in the SMP by way of advice in the relevant literature, they constitute individual options in themselves and so have been excluded from the calculations in the SMP.

There was contrasting information regarding the drainage of land. In the publication PB4093 it states that under-drainage pipes and ditches should be installed and maintained where field drainage is necessary in order to prevent waterlogging and subsequent runoff. However, Cuttle *et al*., (2006) suggest that field drainage should be left to deteriorate to reduce mineralisation rates on heavy soils and to reduce the hydrological connectivity with surface water. The issue of drainage has therefore been excluded from this study, due to conflicting evidence.

A summary of the percent reductions in N and P losses for the different farm types and the different scenarios (assumed levels of implementation; see Table 3.1) for the Soil Management Plan is given in Table 3.5. The full details of the calculations are included in Annex E.

Table 3.5 Reduction in N and P losses compared to baseline losses resulting from implementation of a Soil Management Plan

Farm type	Category	% reduction in loss for uptake scenario					
		High		Medium		Low	
		N	P	N	P	N	P
Arable	Landuse	1.6	1.0	0.6	0.4	0	0
	Soil	15	21.9	10	14.6	5	7.3
	Tramline	0	7.3	0	2.9	0	0
	Runoff	1.5	20.0	0.6	8	0	0
	Total	**18.1**	**50.2**	**11.2**	**25.9**	**5**	**7.3**
Dairy	Runoff	1.5	20	0.6	8	0	0
	Stock	18	9.6	12	6.4	6	3.2
	Fence	0.3	3.2	0.1	1.3	0	0
	Total	**19.8**	**32.8**	**12.7**	**15.7**	**6**	**3.2**
Beef	Runoff	3.8	20	1.5	8	0	0
	Stock	45	9.6	30	6.4	15	3.2
	Fence	0.6	3.2	0.3	1.3	0	0
	Total	**49.4**	**32.8**	**31.8**	**15.7**	**15**	**3.2**

3.2.1.12 EM2 Nutrient Management Plan

The Nutrient Management Plan (NMP) fundamentally ensures good agricultural practice and requires:

- soil analysis every 3 to 5 years;
- an assessment of the nutrient requirement of the crop;
- an assessment of the nutrient supply from organic manures;
- calibration of equipment used to apply fertilisers/manures;
- maintaining records of cropping, manure and fertiliser applications;
- repeating the above every cropping year.

In essence the above practices should ensure that very little excess nutrients remain in the soil. Table 3.6 lists those practices that fall within the NMP that have been used to estimate the impacts of its implementation on N and P losses. The categories used were:

Fertiliser – The overall impact of these measures is to ensure that fertiliser applications meet plant requirements. This includes the correct timing of fertiliser/manure, which in itself can be dependent on the storage capacity of manure/slurry stores (Section 3.2.1.13).

Calibrate – Calibrating the sprayer is an option that could be implemented in addition to “Fertiliser” and it is assumed it will affect either the whole farm area (if adopted) or none of the farm area (if not adopted).

Incorporation – Once applied to the soil, incorporating the fertiliser can reduce losses further, hence these options are considered separately.

Table 3.6 Practices advised in the Nutrient Management Plan

Advice/Mitigation Method	Category	Arable	Dairy	Beef	Mixed
Fertiliser recommendation system	Fertiliser	y	y	y	y
Integrate fertiliser & manure	Fertiliser	y	y	y	y
Calibrate spreader - cereal	Calibrate	y	n	n	y
Incorporate organic manures	Incorporate	n	y	y	y
Time N application to requirement	Fertiliser	n	y	y	y
Incorporate P	Incorporate	y	n	n	y
Do not apply P to high index soil	Fertiliser	y	y	y	y

There was no direct measurement of ‘timing N application to requirement’ in Cuttle, thus “avoid spreading fertiliser at high risk times” was used as an analogous option. Cuttle assumes that high risk times include periods when there is little or no crop uptake, i.e. no requirement for N. The values given by Cuttle for avoiding ‘high risk’ times varied depending on the nature of the fertiliser and farming type:

Inorganic fertiliser: 0-15 kg N/ha from the area treated.

Slurry (averaged over farm area):

15 – 25 kg N/ha applied to arable (dairy slurry)

2 kg N/ha applied to grassland (dairy)

1kg N/ha applied to grassland (beef)

Farmyard manure: 1 – 12 kg N/ha, averaged over the rotation.

It was necessary to assign a single value of N reduction to “Time N application to requirement” for the purposes of this study. It has been assumed that inorganic fertilisers are used on all farm types; the impact of timing slurry applications correctly on dairy and beef farms will therefore be less important than the timing of inorganic fertilisers and this is reflected in the average values of reduction in N loss for the different farm types:13.5 kg/ha for arable; 7.5. kg/ha for dairy and beef.

It is worthy of note that below the recommended N application rates, there is little change in the leaching if nitrate from arable crops, with losses being ~ 50 kg N/ha. However, above the recommended rate, 50-80% of the surplus nitrogen may be available for leaching (Anon, 2007b D3). The impact of implementing EM2 is therefore far greater if the current practice is to over-fertilise. There is a higher potential of this occurring on arable farms than in grassland systems, where most farms in England apply substantially less fertiliser nitrogen that is recommended (Anon, 2007b D3).

A summary of the percent reductions in N and P losses for the different farm types and the different scenarios (assumed levels of uptake; see Table 3.1) for the Nutrient Management Plan is given in Table 3.7. The full details of the calculations are included in Appendix E.

Table 3.7 Reduction in N and P losses compared to baseline losses resulting from implementation of a Nutrient Management Plan

Farm type	Typology	% reduction in loss for uptake scenario					
		High		Medium		Low	
		N	P	N	P	N	P
Arable	Fertiliser	18.8	4.3	12.5	2.9	6.25	1.4
	Incorporation	0	0.6	0	0.4	0	0.2
	Calibrate	7.0	2.4	7.0	2.4	0	0
	Total	**25.8**	**7.3**	**19.5**	**5.7**	**6.25**	**1.6**
Dairy	Fertiliser	11.3	3.6	7.5	2.4	3.8	1.2
	Incorporation	0	0.6	0	0.4	0	0.2
	Total	**11.3**	**4.2**	**7.5**	**2.8**	**3.8**	**1.4**
Beef	Fertiliser	28.1	3.6	18.8	2.4	9.4	1.2
	Incorporation	0	0.6	0	0.4	0	0.2
	Total	**28.1**	**4.2**	**18.8**	**2.8**	**9.4**	**1.4**

3.2.1.13 EM3 Manure Management Plan

The Manure Management Plan (MMP) only applies to those farms that spread farmyard manure. The Water Code already covers many of the points that are raised in the MMP, thus, theoretically, it should not be necessary to repeat this guidance in the MMP. However, the MMP may have a greater effect in reality, as it will enable farmers to accrue more points for the ELS. Likewise, the NMP also has many commonalities with the Water Code, indeed the NMP applies to land that receives inputs of manure and/or fertilisers. The primary difference between the NMP and MMP is the provision of storage for manure.

Table 3.8 lists those practices that fall within the MMP that could be used to estimate the impacts of its implementation on N and P losses. The categories for mitigation measures identified were:

Storage – the loss of nutrients is related to the positioning and/or integrity of the store.

Fertiliser – This largely concerns having the ability to store slurry/manure in order to apply it when required by the plants. Actively composting manure reduces the readily available N, but the quantity of N in the manure should be accounted for when integrating manure and fertiliser supplies.

No spread - **I**dentifying high risk areas on the farm that should never receive manure is an option that could be implemented in addition to other categories.

It has been necessary to use the same mitigation option (avoid spreading at high risk times) given in Cuttle for "Time N application to requirement" in the NMP and "Do not apply at high risk times" in the MMP (Table 3.8). The ELS uptake dataset only gives areas of land under each option and it is possible that some land has been accounted for twice, i.e. in both Nutrient and Manure Management Plans. It was not possible to address this in the current study, and this should be taken into consideration when interpreting the results.

Table 3.8 Practices advised in the Manure Management Plan

Advice/mitigation option	Typology	Arable	Dairy	Beef	Mixed
Increase capacity slurry/manure stores for improved timing of application	Fertiliser	y	y	y	y
Identify high risk/no spread areas - manure	No spread	n	y	y	y
Minimise dirty water	Fertiliser	n	y	y	y
Composting can reduce volume	Fertiliser	n	y	y	y
Permanent manure stores - collect effluent	Storage	n	y	y	y
Site manure heaps away from water courses	Storage	n	y	y	y

A summary of the percent reductions in N and P losses for the different farm types and the different scenarios (assumed levels of uptake; see Table 3.1) for the Manure Management Plan is given in Table 3.9. The full details of the calculations are included in Appendix E.

Table 3.9 Reduction in N and P losses compared to baseline losses resulting from implementation of a Manure Management Plan

Farm type	Category	% reduction in loss for uptake scenario					
		High		Medium		Low	
		N	P	N	P	N	P
Arable	Fertiliser	**30**	**5.5**	**20**	**3.7**	**10**	**1.8**
Dairy	No spread	0.1	0	0.5	0	0.3	0
	Fertiliser	9.0	5.5	6.0	3.7	3.0	1.8
	Storage	0.8	5.5	0.5	3.7	0.3	1.8
	Total	**9.9**	**11.0**	**7.0**	**7.4**	**3.6**	**3.6**
Beef	No spread	1.9	0	1.3	0	0.6	0
	Fertiliser	22.5	5.5	15	3.7	7.5	1.8
	Storage	1.9	5.5	1.3	3.7	0.6	1.8
	Total	**26.3**	**11.0**	**17.5**	**7.4**	**8.7**	**3.6**

3.2.1.14 EM4 Crop Protection Management Plan

The Crop Protection Management Plan (CPMP) does not impact on nutrient losses over and above any practices already included in the SMP, NMP or MMP, hence it is not considered further in this report. Buffer strips would the primary recommendation in the CPMP that could impact on N and P losses.

3.2.2 Estimating national impacts of ELS on water quality

The estimates of the impact of individual ELS options on N and P losses were combined with ELS uptake data containing details of the areas covered by individual options, to provide an indication of the impact of ELS options at the national scale.

ELS uptake data were provided by Natural England as at 1 September 2007. The dataset provided had 'County/Parish/Holding (CPH) numbers for the majority of holdings, so these were used to link to June Survey data in order to assign farm types to holdings with ELS agreements. Option data were held in a separate database, and The 'Ag_ref' number of the holding level data was used to join the holding database to the individual option database, and thus link farm types to individual ELS options. Only 84% of holdings with ELS agreements had a corresponding CPH number, so it was only possible to assign a farm type to 79% of individual options. In total, 48,564 options had no associated farm type, and these data were excluded from the analysis.

The areas with and without non-management plan options are shown in Table 3.10. Over 405 of agreements by area in arable farm types, pigs and poultry, and dairy farms had ELS options relevant to water quality, but only a third of agreements on mixed farms and less than a quarter of those on lowland beef and sheep farms by area had relevant options.

Table 3.10 Area of holdings analysed and area with ELS options other than management plans influencing water quality (WQ options).

Farm type	Total ELS area	Total holding (ELS) area with WQ options	% total with WQ options
Cereals	3,284,659.84	1,519,686	46.27
General Cropping	1,483,228.15	652,911	44.02
Pigs/Poultry	13,818.09	5,788	41.89
Dairy	27,602.52	11,194	40.55
Lowland Beef & sheep	557,838.50	124,535	22.32
Mixed	610,369.04	206,792	33.88

For each of the ELS options identified as having an impact on N and P losses (Section3.2.1), data for the whole of England were used to identify the area of the options (136,962 individual options). Calculated values of N and P losses (Table 3.11) were then used to estimate a total N and P output for each individual ELS option. This was achieved by multiplying the area of the option by the values of N and P losses for the options ED2, 3, 5, EF1, 2, 9, 10, 11, EJ1, 2, EK1, 2, 3.

The greatest reductions in N losses were achieved by options taking land out of production, e.g. field corner options (EF1/EK1), taking archaeological features out of cultivation (ED2). Option EJ2 (management of maize crops to reduce soil erosion) also gave a substantial reduction. The greatest reductions in P losses resulted from field corner management and 6m buffer strips on cultivated land (EE3). Option ED2 also gave a substantial reduction (Table 3.11).

Table 3.11 Reduction in N and P losses for specified options

Code	Description	N kg/ha			% reduction		P kg/ha		% reduction
		From	To (min)	To (max)	Nmin	Nmax	From	To	
ED02	Take archaeological features currently on cult.	50	20	20	60	60	3.93	2.19	44.3
ED03	Reduce cultivation depth on land with archaeol.	50	50	45	0	10	3.83	2.71	29.2
ED05	Archaeological features on grassland	50	20	20	60	60	2.19	1.58	27.9
EE01	2m buffer strips on cultivated land	50	50	49	0	2	2.71	2.17	19.9
EE02	4m buffer strips on cultivated land	50	49	47	2	6	2.71	1.63	39.9
EE03	6m buffer strips on cultivated land	50	49	45	2	10	2.71	1.08	60.1
EE04	2m buffer strips on intensive grassland	50	40	35	20	30	2.19	2.18	0.5
EE05	4m buffer strips on intensive grassland	50	40	35	20	30	2.19	2.16	1.4
EE06	6m buffer strips on intensive grassland	50	40	35	20	30	2.19	2.14	2.3
EF01	Field corner management	50	5	5	90	90	3.83	1.58	58.7
EF02	Wild bird seed mixture	50	40	35	20	30	3.82	3.73	2.4
EF07	Beetle banks	50	50	50	0	0	2.71	2.03	25.1
EF10	Conservation headlands cereals, no fert/ manure	50	40	35	20	30	3.82	3.73	2.4
EF11	6m Uncropped, cultivated margins on arable land	50	40	35	20	30	3.82	3.73	2.4
EJ01	Management of high erosion risk cultivated land	100	50	50	50	50	3.9	3.83	1.8
EJ02	Management of maize crops to reduce soil erosion	60	50	15	17	75	3.87	2.75	28.9
EK01	Take field corners out of management - grassland	50	5	5	90	90	2.19	1.58	27.9
EK02	Permanent grassland with low inputs	50	50	40	0	20	2.19	2.14	2.3
EK03	Permanent grassland with very low inputs	50	40	35	20	30	2.19	2.14	2.3

The analogous mitigation options (Cuttle) and the reasoning behind them are described in section 3.2.1

For the remaining options, the total loss of N and P (kg) was calculated as the area affected by the feature (i.e. for buffers, beetle banks), on the basis that they would influence runoff form a larger area. These were calculated as follows:

- The average size of a field was assumed to be 3.1ha[9] i.e. 31,000m^2.
- Fields were assumed to be square; the length (l) of the side of a field, was therefore taken as $\sqrt{31,000}$ = 176.1m

Buffer strips (option EE*) could be placed along any number from one to four sides of a field. It was assumed that on average they would be placed along two sides of a field (Figure 3.1(a)), the same for cultivated margins (assumed to be of 2m width). Beetle banks run across the centre of a field as in Figure 3.1(b), therefore the length is equivalent to only one side of the field.

(a) (b)

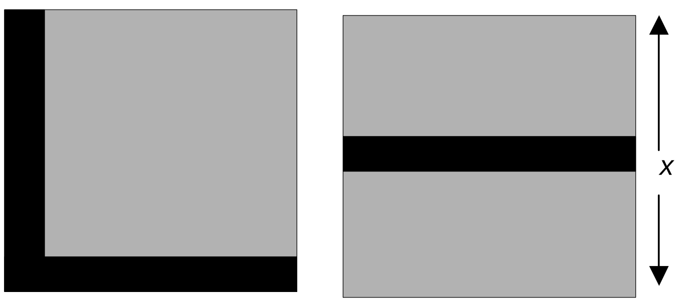

Figure 3.1 Calculation of lengths buffer strips and beetle banks: (a) buffer strips: length of field edge (L) = 2*x;* (b) beetle banks: length of field edge (L) = *x.*

The area affected by the buffers was calculated by first calculating the number of fields affected (assuming 8 ha fields), and then converting this into an area in hectares. The number of fields affected (n) was calculated as:

$$n = \frac{A \times 10,000}{W \times L}$$

where A = Area (in ha) of option (from ELS uptake data);
L = Length of field edge (m) attributed to option (i.e. *x*, 2*x* or 4*x*, calculated as above);
W = option width (m);

The total nutrient losses where options were implemented (C) for the area affected were then calculated as:

$$C = C_{ha} \times 3.1 \times n$$

where C_{ha} = nutrient losses per ha of field.

9 The average size of arable parcels in the Eastern Lowlands recorded in the Countryside Survey 2000 (Petit et al., 2002).

Boatman *et al*. (2007) found that only 37.3% of buffer strips in ELS on average were situated next to water courses. It was therefore assumed that P losses were only affected by 37.3% of buffer strips. Therefore total P losses for fields affected by buffer strips is:

$$C_{buffer} \times 0.373$$

Losses were calculated for the area occupied or affected by options as above, and the remaining area unaffected by ELS options on holdings with agreements was then calculated by subtraction from the total agreement area. Losses on this remaining area were assumed to be as per baseline, i.e. no reduction (see section 3.2.1). The total reduction over the whole area was then calculated by adding the area occupied or affected by options to the remaining area.

The ELS uptake data provides information on the area of the holding in the Management Plans, but it is not known what farming practices are actually implemented, hence it was necessary to create the theoretical scenarios (3.2.1.1). The percent reduction in N and P losses are given in Sections 3.2.1.11 - 3.2.1.13, and the relative impact of the Management Plan options and the non-Management Plan options are compared in section 3.3.3 (see also Sections 3.2.1.11 - 3.2.1.13 for further detail).

Table 3.12 shows the agreement areas in the three management plans with relevance for nutrient loss, and the percentages of the total ELS area which could be allocated to farm types, for the major farm types analysed. Around a third of the sample of arable farms had soil and nutrient management plans, but less than a quarter had manure management plans. Around a quarter of dairy farms had each of the management plan types, but less than ten percent of lowland beef/sheep and mixed farms had soil and nutrient management plans, though the proportion with manure management plans was higher at 12-15% (Table 3.12).

Table 3.12 Area of holdings analysed and area with ELS management plan options influencing water quality (MP options).

Farm type	Total ELS area	Total holding (ELS) area with MP options			% total with MP options		
		Soil MP	Nutrient MP	Manure MP	Soil	Nutrient	Manure
Cereals	3,284,660	1,076,303	1,195,213	688,517	32.77	36.39	20.96
General Cropping	1,483,228	528,931	562,735	358,719	35.66	37.94	24.18
Dairy	27,603	6,834	7,233	5,972	24.76	26.21	21.63
Lowland Beef/sheep	557,839	44,851	27,552	85,358	8.04	4.94	15.30
Mixed	610,370	53,433	39,693	73,736	8.75	6.50	12.08

3.3 RESULTS

3.3.1 Options other than management plans

Data on N losses were given as a range of reductions in losses by Cuttle. This is illustrated in the results as the minimum and maximum reduction in N; for P only one value was given.

Table 3.13 shows the total N losses for those of the 84% of holdings which it was possible to allocate to farm type, which had ELS options which affected water quality (other than management plans). The percentage reduction in losses is also shown. Management plans are excluded as their impact was calculated separately.

Table 3.13: Total N losses for lowland farm types, with relevant ELS options and without (baseline) (data relate to 84% of holdings in England).

Farm type	N total (kg)			% reduction	
	baseline	ELS min	ELS max	ELS min	ELS max
Cereals	76,183,267	74,854,238	73,241,787	1.74	3.86
General Cropping	32,758,923	32,225,085	31,613,450	1.63	3.50
Pigs/Poultry	515,985	508,581	503,683	1.43	2.38
Dairy	559,857	552,961	536,837	1.23	4.11
Lowland Beef & sheep	3,080,521	2,610,711	2,578,898	15.25	16.28
Mixed	10,349,770	10,113,773	9,699,651	2.28	6.28
Total	123,448,322	120,865,348	118,174,305	2.09	4.27

Mean N losses per hectare on holdings with options other than management plans affecting water quality are shown in Table 3.14.

Table 3.14 Mean N losses (kg/ha) by lowland farm type (calculated from 84% of holdings in England)

Farm type	Mean N loss kg/ha		
	baseline	ELS min	ELS max
Cereals	50.13	49.26	48.20
General Cropping	50.17	49.36	48.42
Pigs/Poultry	89.15	87.87	87.03
Dairy	50.01	49.40	47.96
Lowland Beef & sheep	24.74	20.96	20.71
Mixed	50.05	48.91	46.91
Average	52.38	50.96	49.87

The largest N losses arose from cereal farms because of the large area covered by this farm type (Table 3.13), but per hectare, the greatest N losses were from pig and poultry farms (Table 3.14). These generally occupy a small area but produce large quantities of organic manure. The lowest losses per hectare were from lowland beef and sheep farms (Table 3.14) and these also exhibited the highest percentage reduction in losses as a result of ELS options (Table 3.13).

Table 3.15 shows the total losses and mean losses per hectare of P on farms with relevant ELS options other than management plans, along with the percentage reduction due to ELS on those holdings. As for N, lowest losses per hectare were found on lowland beef and sheep farms, but the percentage reduction due to ELS options was similar on most farm types except mixed farms, where it was lower.

Table 3.15: Total and mean (kg/ha) P losses for lowland farm types, with ELS and without (baseline) (data relate to 84% of holdings in England).

Farm type	P total (kg)		% reduction	Mean P loss kg/ha	
	baseline	ELS		baseline	ELS
Cereals	4,687,450	4,488,439	4.25	3.08	2.95
General Cropping	2,003,868	1,919,295	4.22	3.07	2.94
Pigs/Poultry	19,403	18,737	3.43	3.35	3.24
Dairy	22,463	21,353	4.94	2.01	1.91
Lowland Beef & sheep	209,937	199,853	4.80	1.69	1.60
Mixed	572,889	564,895	1.40	2.77	2.73
Total (average)	1,136,832	830,877	4.04	(2.66)	(2.56)

These tables illustrate the findings of Section 3.2.1, where it was identified that ELS was more likely to provide greater reductions in P losses compared to N, and also that the overall impact is likely to be quite small, largely due to the much larger areas of land not covered or affected by ELS options.

The reduction in N and P losses in pigs/poultry is significant as this arises from only a single ELS option being implemented (EJ1) on high risk land, further supporting the findings of Section 3.2.1 where it was suggested that a small number of options could have a disproportionately high impact. For the purposes of this study it was assumed that the high risk land was converted to arable farming (for economic reasons); if this was converted to grassland further reductions in losses may be achieved.

In order to aid interpretation of the N and P loss data, the percentage of agreement holders in the ELS adopting each option affecting water quality by farm type is reproduced from Boatman *et al*. (2007) in Table 3.16.

Buffer strips on cultivated land, field corner management and permanent grassland with low or very low inputs generally have the highest uptake. The data also demonstrate that buffer strips on intensive grassland have a much lower uptake than on cultivated land. Whilst this may contribute to the reduction in P losses, buffer strips have little impact on N. It is not clear from these data, whether a small number of options have a disproportionately large impact on reducing N and P losses for the non-Management Plan options. It is worth noting that the high uptake of options for low input permanent grassland could be expected given that many farmers already apply a much lower rate than that recommended (Anon, 2007b; D3) and this option may therefore not be greatly different to normal practices.

Table 3.16 Percentage of agreement holders in the ELS adopting each option by farm type

Option code	Option	Cereals	General cropping	Mixed	Dairy	Lowland stock	Pigs
ED2	Take archaeological features out of cult.	1.5	1.4	1.5	0.5	0.4	0
ED3	Reduce cultivation depth	1.6	0.4	0.8	0.5	0.1	0
ED5	Archaeological features on grassland	7.1	3.9	10.6	9.5	8.5	3.6
EE1	2m buffer strips on cultivated land	9.6	10.1	6.9	1.7	1	7.1
EE2	4m buffer strips on cultivated land	21.7	19.8	9	3.9	1.1	3.6
EE3	6m buffer strips on cultivated land	33.3	32.2	17.2	6.1	1.6	25
EE4	2m buffer strips on intensive grassland	0.9	0.9	2.6	6.5	1.6	3.6
EE5	4m buffer strips on intensive grassland	1.5	0.9	3.7	6.2	2.5	0
EE6	6m buffer strips on intensive grassland	2.6	3.4	5.9	7.9	2.8	7.1
EF1	Field corner management	42.0	42.9	21.5	6.6	2.4	39.3
EF2	Wild bird seed mixture	17.7	21	10.2	2.8	1.6	17.9
EF7	Beetle banks	2.2	2.6	0.6	0.4	0	7.1
EF10	Conservation headlands, no fertiliser	0.8	2	0.6	0.2	0.1	0
EF11	6m uncropped, cultivated margins	2.6	2.4	1.3	0.3	0	3.6
EJ1	Management of high erosion risk land	1.1	1.4	1.1	1.6	0.1	3.6
EJ2	Management of maize crops (erosion)	0.2	0.7	2.8	5.1	0.3	0
EK1	Take field corners out of management	2.4	1.3	3.9	7.6	2.8	0
EK2	Permanent grassland with low inputs	35.9	29.7	49.1	36.8	60.1	21.4
EK3	Permanent grassland with v. low inputs	29.2	27.3	29.6	24.3	30	17.9

Source: Boatman et al., 2007

3.3.2 Impact of Management Plans

Table 3.17 shows the losses for agreements with management plans under the three scenarios[10] compared with the equivalent losses without management plans, based on the percentage reductions in N and P loss given in Table 3.5,Table 3.7 andTable 3.9 (for further details on derivation, see Annex E), and Table 3.18 gives the losses per hectare. On a per hectare basis, the greatest reductions in N losses due to management plans were seen on mixed, followed by beef and sheep farms, with the lowest reduction on arable and dairy farms. Soil management plans produced greater reductions in P losses than nutrient and manure management plans. Reductions in P losses from soil and nutrient management plans were greater for arable than for dairy and beef, but the effect was reversed for manure management plans (see Table 3.5,Table 3.7 andTable 3.9).

[10] based on the 84% of holdings with cph numbers

Table 3.17 Estimated N and P losses (kg) for agreements with management plans, under high, medium and low scenarios, and equivalent losses without management plans.

Farm type	Option code	Management Plan	Area (ha)	No Management plan		N Total			P Total		
				N	P	High	Medium	Low	High	Medium	Low
Arable[11]	EM1	Soil	1,076,303	53,815,151	4,089,951	44,074,609	47,787,854	51,124,393	2,034,213	3,035,175	3,788,587
Arable	EM2	Nutrient	1,195,213	59,760,642	4,541,809	44,378,253	48,107,317	56,055,482	4,207,149	4,290,814	4,470,096
Arable	EM3	Manure	688,517	34,425,832	2,616,363	24,098,082	27,540,666	30,983,249	2,471,775	2,519,971	2,568,167
Dairy	EM1	Soil	6,834	341,694	15,035	273,355	300,690	321,192	10,114	12,711	13,394
Dairy	EM2	Nutrient	7,233	361,671	15,914	318,270	332,737	347,204	15,263	15,480	15,697
Dairy	EM3	Manure	5,972	298,592	13,138	268,732	280,676	286,648	11,705	12,183	12,660
Beef/sheep	EM1	Soil	44,851	897,023	71,762	454,118	612,218	762,470	48,221	60,511	69,468
Beef/sheep	EM2	Nutrient	27,552	551,032	44,083	396,054	447,714	499,373	42,233	42,849	43,466
Beef/sheep	EM3	Manure	85,358	1,707,150	136,572	1,259,023	1,408,399	1,557,775	121,605	126,594	131,583
Mixed	EM1	Soil	53,433	2,671,629	160,298	1,364,668	1,550,881	1,723,201	90,034	125,032	146,405
Mixed	EM2	Nutrient	39,693	1,984,664	119,080	1,022,300	1,121,335	1,290,627	111,737	113,721	117,294
Mixed	EM3	Manure	73,736	3,686,782	221,207	1,843,391	2,083,032	2,331,889	204,616	210,147	215,677

[11] The arable scenario was applied to both Cereal and General Cropping farms.

Table 3.18 Estimated N and P losses (kg/ha) with and without management plans, under the three different scenarios.

Farm type	Option code	Management Plan	No Management plan		N Total			P Total		
			N	P	High	Medium	Low	High	Medium	Low
Arable[12]	EM1	Soil	50.00	3.80	40.95	44.40	47.50	1.89	2.82	3.52
Arable	EM2	Nutrient	50.00	3.80	37.13	40.25	46.90	3.52	3.59	3.74
Arable	EM3	Manure	50.00	3.80	35.00	40.00	45.00	3.59	3.66	3.73
Dairy	EM1	Soil	50.00	2.20	40.00	44.00	47.00	1.48	1.86	1.96
Dairy	EM2	Nutrient	50.00	2.20	44.00	46.00	48.00	2.11	2.14	2.17
Dairy	EM3	Manure	50.00	2.20	45.00	47.00	48.00	1.96	2.04	2.12
Beef/sheep	EM1	Soil	20.00	1.60	10.13	13.65	17.00	1.08	1.35	1.55
Beef/sheep	EM2	Nutrient	20.00	1.60	14.38	16.25	18.13	1.53	1.56	1.58
Beef/sheep	EM3	Manure	20.00	1.60	14.75	16.50	18.25	1.42	1.48	1.54
Mixed	EM1	Soil	50.00	3.00	25.54	29.03	32.25	1.69	2.34	2.74
Mixed	EM2	Nutrient	50.00	3.00	25.76	28.25	32.52	2.82	2.87	2.96
Mixed	EM3	Manure	50.00	3.00	25.00	28.25	31.63	2.78	2.85	2.93

[12] The arable scenario was applied to both Cereal and General Cropping farms.

3.3.3 Comparison of Management Plans with other options

Table 3.19 illustrates that N losses for arable and dairy are reduced by ~ 4% (maximum impact) if the non-MP options are implemented. Under a medium uptake scenario, losses from arable farms could be reduced much further if any one of the three Management Plans were implemented; the gains for dairy farming from nutrient and manure management plans are not as great, but considerable gains could still be made. For beef and sheep farms, the effects of non-MP options are greater, but would still be considerably enhanced by the addition of management plans. The impacts on mixed farms are greatest of all, with a potential reduction in N losses of over 40% from introduction of management plans assuming a medium scenario. (It is reiterated that the calculations for the Management Plans assume that mitigation options are actually implemented).

Table 3.19 Summary of estimated percentage reductions in N losses from management plans (medium scenario) and non-management plan options

Farm type	% N reduction from non-MP options		% reduction from management plans (medium scenario)		
	ELS min	ELS max	Soil	Nutrient	Manure
Arable	1.69	3.68	11.2	19.5	20.0
Dairy	1.23	4.11	12.0	8.0	6.0
Lowland Beef & sheep	15.25	16.28	31.8	18.8	17.5
Mixed	2.28	6.28	41.8	43.5	43.5

Table 3.20 summarises the reduction in P losses from management plans under the medium scenario and non-management plan options. The soil MP appears likely to have a considerably greater impact on P losses than non-MP options, and also the other Management Plans. The NMP may not be as effective as the non-MP options for reducing P losses, and the MMP only offers small additional improvements, unless uptake is high. The results further illustrate that targeting options to specific nutrients (i.e. SMP for phosphorus and NMP for nitrates) will have a greater impact on water quality than non-specific, non-MP options.

Table 3.20 Summary of estimated percentage reductions in P losses from management plans (medium scenario) and non-management plan options

Farm type	% reduction	% reduction from management plans (medium scenario)		
	Non-MP	Soil	Nutrient	Manure
Arable	4.24	25.8	5.5	3.7
Dairy	4.94	15.5	2.7	7.3
Lowland Beef & sheep	4.80	15.7	2.8	7.3
Mixed	1.40	22.0	4.5	5.0

3.4 DISCUSSION

Section 3.2.1 has illustrated that, excluding the Management Plans, the majority of options in the ELS will have limited impact on water quality; this is partly as these options are targeted towards other objectives and there are few designed specifically to improve water quality. In theory, it could be expected that N and P losses to surface waters will be reduced simply by having lower inputs, as required by many of the options. However, it has been difficult to demonstrate this with the available data. The land area covered by the options can be relatively small and any reductions in N and P losses may be the same order of magnitude as natural variation, thus it is not possible to quantify significant reductions. Moreover, as any benefits of reduced inputs could easily be negated by high inputs elsewhere, it may not be worth attempting to quantify these losses more accurately. This is more pertinent to nitrate where losses are relatively constant at below optimal application rates. Indeed, even with mitigation options in place, it may not be possible to reduce mean nitrate concentrations to below 50 mg/L from agricultural activities (Anon, 2007b; D3).

The few exceptions are the Management Plans, which are specifically aimed at protecting soil and water rather than enhancing biodiversity, specific options on high risk land (EJ1 and EJ2), and beetle banks. Beetle banks could offer reductions in P losses in particular. In the current study the Cuttle measure 'install hedges' has been applied to quantify a reduction in loss, but the MOPS study will allow more accurate calculations. Nevertheless, introducing beetle banks requires great care as N and P losses could be enhanced if conditions allow water channelling. They therefore need to be positioned across, and not diagonal to, the slope.

The calculations of estimated reduction in nutrient losses for the Management Plans should not be considered absolute values; indeed there are likely to be large regional variations. However, the exercise allows comparison of the different options and scenarios and it highlights differences between the nutrients and the different farming types. For example, the Soil Management Plan has a much greater impact on P than the Nutrient or Manure Management Plans, as could be expected, whereas the NMP and MMP have similar impacts on N for both arable and dairy farms. Although an overall reduction in nutrient loss is given for the different typologies, it should be noted that the reductions in nutrient losses were heavily skewed by a small number of management practices. These were:

- Reduce field stocking rates when wet
- Time N application to requirement
- Do not apply slurry at high risk times
- Integrate fertiliser and manure

In essence, 'integrate fertiliser and manure' should be considered if N application is timed to requirement, as the N content of the material applied should be known. Similarly, 'do not apply slurry at high risk times' is mostly analogous to 'Time N application to requirement' as a high risk time includes one where there is little or no crop uptake. Combining these management practices then leaves only two distinctive practices that substantially reduce N and P losses: 1) Time N application to requirement, and 2) Reduce field stocking rates when wet. For arable farms, the effectiveness of the SMP was largely due to controlling the 'soil' category of measures, but within this category the individual practices had similar weightings. In summary, based on the available literature to date, implementing the few management practices above could have a greater impact on reducing N and P losses than the sum of the other options (with the exception of P losses on arable farms where buffer strips could be important).

'Establish in-field buffers' substantially influenced the findings of the SMP as losses are calculated to be reduced from 2.71 to 0.54 kg TP/ha/year (Cuttle) and this measure accounted for the 20% reduction in P losses for the category 'runoff' in the Soil Management Plan. There have been few field experiments in the UK to substantiate this calculated reduction and the findings of the MOPS project should be used to provide an indication of its accuracy.

The calculations of the impact on Management Plans have necessarily assumed that the practices laid out in the plans are actually implemented, although it was not possible to ascertain the implementation rate from the ELS uptake data. However, a recent evaluation of Management Plans reported that over 75% of farms were implementing their SMP and/or NMP; for the MMP "no change had been recorded in the majority of cases as good practice was already being implemented" (ADAS, 2007). The findings of this evaluation indicate that the farmers are willing to adapt farming techniques to protect the environment and that the results of the current study are not unreasonable.

A notable absence of mitigation option from those that may have a substantial impact on reducing N losses is buffer strips. It was established in section 3.2.1.5 that buffer strips under the ELS are likely to be more effective when situated in the riparian zone than along boundaries such as hedges, and that grassland 'buffer strips' do not distance agricultural activities from water courses and, effectively, they are not buffer strips but grazed land with zero inputs. On arable farms, buffer strips will have little impact on N losses, but they could reduce P losses where they could be more effective than the Manure Management or Nutrient Management Plans. However, adopting minimal cultivation techniques on 75% of the farmed land could have similar benefits to introducing 6m buffer strips, if it is assumed that riparian buffer strips are present on a third of the farmed land. The effectiveness of buffer strips is highly variable and it is likely to vary on field-by-field basis. A blanket implementation of a 6m buffer may therefore be ineffective in some areas, but more effective in others, and individual examination of the needs may be more appropriate (Leeds-Harrison et al., 1996). This conforms with the results of the expert scoring exercise carried out for the initial evaluation (Boatman et al. (2007), where experts scored buffer strips as having a 'medium' impact, but there was little confidence in the score.[13]

It should be noted that the data used to calculate the reduction in N losses (Cuttle *et al*., 2006) were provided as reductions in kg/ha. The percent reduction was therefore dependent on the initial baseline loss. For example, N losses from beef farms are in the order of 20 kg/ha compared to dairy and arable at 50 kg/ha. A mitigation option that gave a reduction 5 kg/ha would therefore have a much greater impact on beef farms as calculated in this study. It has been necessary to make generalisations and it was not possible to refine the calculations within the scope of this study. It is possible therefore that the results for beef farms are more favourable than reality and this should be taken into consideration when interpreting the findings.

In terms of reducing P losses by 40%, the findings of this study indicate that buffer strips on arable land and the Soil Management Plan are the most relevant ES options. Whilst the high uptake scenario for the SMP exceeds the 40% P reduction target for arable farming, with dairy and beef farming close to this target, it must be remembered that 20% of this reduction is due to 'establishing in-field buffers', for which there is little supporting field data. On dairy and beef farms, reducing the field stocking rate when wet could be more relevant in reality. The findings have also highlighted that the options would have to be applied to a high proportion of the farmed land in order to achieve any substantial reductions in losses. However, it

[13] Although not considered in this study, it is worth noting that buffer strips are consistently beneficial in terms of reducing pesticide inputs to surface waters arising from spray drift (Ramwell et al., 2006).

should be noted that the time lag between changes in practices and the impact on water quality could be decades, particularly for P.

The results for Management Plans are based on substantial measures linked to the plans to reduce nutrient losses. Whilst the plans anticipate such measures being carried out, the points in the scheme are awarded for having the plan, and there is no additional benefits for the agreement holder related to the extent of management under the plan. This might discourage some agreement holders from undertaking some of the more demanding or expensive measures which might have been considered, especially if they are perceived to have an impact on profitability. In addition, Management Plans are largely based on the Soil and Water Code and the Fertiliser Recommendation system. As such, in theory, these practices should already be implemented. Indeed, in a recent evaluation of Management Plans in ELS (ADAS, 2007), many farmers reported no change in their farm practices, as good practice was already being observed. Nevertheless, the Plans did increase farmers understanding of diffuse pollution and encouraged them to think about the impact of their farming practices, and nearly 70% of farmers surveyed thought the Plans were likely to help with reducing diffuse pollution.

The limited impact of ELS options on N and P losses is possibly a reflection of the fact that a) many options are tailored to addressing other ES objectives and b) there are difficulties in quantifying N and P losses accurately in a dynamic, complex system. Taking relatively small areas of land out of production, reducing or terminating the use of a source of nutrients and leaving land undisturbed are all likely to have some positive impact, but it is difficult to quantify this accurately.

An examination of the impact of ELS on water quality has highlighted the following:

1. The calculation of N and P losses are based on limited data and the findings can only provide an overview of the impacts.
2. Those options tailored to other ES objectives will have a relatively low impact on reducing N and P losses.
3. Management Plans are tailored to addressing issues associated specifically with soil, manure, nutrients (and crop protection products), and therefore have the potential for a larger impact on N and P losses than non-MP options. However, Management Plans are largely based on existing agricultural Codes of Practice and therefore the Plans do not necessarily add anything above current requirements with the notable exception of calibrating the fertiliser spreader.
4. A small number of key options could have a relatively large impact on N and P losses including:
    d. Reducing field stocking rates when wet
    e. Slurry storage / Timing N application to requirement
    f. In-field buffer strips
5. Although in-field buffers have a substantial influence on the results, the supporting data on their effectiveness were weak. Moreover, if they are not installed correctly, they could create a larger problem (by channelling runoff) than they solve.

3.4.1 Improving the value of ELS

Excluding the Management Plans, ELS, at the time of this study, has relatively few options designed solely for reducing diffuse pollution on a large scale, and many of the options are designed to address other objectives. Consequently, it is unrealistic to anticipate that ELS in its current form will have a significant impact on N and P losses, particularly in the absence of Management Plans. If attempts are to be made to reduce diffuse pollution it may be more worthwhile to focus on practices covering large areas of farmed land, or high risk areas. For example, it has been identified that timing N application to requirement and integrating fertiliser and manure supplies could have a major impact on N and P losses. It may therefore be more beneficial to provide incentives for farmers to, for example, store manure/slurry (in a manner that would limit the production of gaseous pollutants) and/or quantify N and P content in soil/manure/slurry to calculate crop requirements more accurately. Even if only 50% of farmed land complied, N savings of 20% and 13% could be made by not applying slurry at high-risk times (i.e. it can be stored until a suitable time), and timing N application to requirement respectively (Table E.2). This compares to reductions of ~ 6% for a 6m buffer strip, which would also require land to be taken out of production.

The newly revised Nitrates Action Programme (NAP), undertaken as part of the implementation of the Nitrates Directive, could assist in addressing these issues, as it considers the need to ensure that nutrient application is tailored to requirements and also addresses slurry/manure storage.

Calibrating the spreader was included in the NMP, but it is not in the Soil or Water Code. It has been estimated that N losses could be reduced by ~ 5kg/ha if the spreader is calibrated (Anon, 2007b; D3). This is a greater reduction than introducing buffer strips, and the reduction in loss will apply to a much larger area of land. It could therefore be beneficial to introduce an option for regular calibration of the spreader.

Efforts to reduce N pollution are likely to be more successful if the issue of over-application is addressed, as the rate of leaching trends towards exponential above the economic optimum, but there is a negligible reduction in leaching if applications are lowered below the optimum (Anon 2007b,D3); the reductions in application rates in certain options of the ELS may therefore be more likely to enhance biodiversity than have a major impact on reducing diffuse pollution when compared to other farming practices that could be improved.

Targeting high-risk areas could also be more beneficial than reducing losses from land already farmed according to Good Agricultural Practice (GAP). Indeed, converting high-risk land to a low-risk activity was identified as having a significant impact on reducing N and P losses. This option was included in the Soil Management Plan and will therefore be excluded from future ELS. It may be beneficial to include this as a separate option within the ELS; the land taken out of production could also be developed for benefit to biodiversity. This could apply to both steep slopes at risk of runoff/erosion and flat land at risk of flooding. For this practice to be adopted on a scale that would have significant environmental benefit, the farmer would need to be compensated accordingly.

ELS does not currently include grants for capital items, but this could encourage farmers to implement options that would otherwise be too costly, for example fencing-off stream banks that are particularly susceptible to erosion, and installing or maintaining hedges. Such grants would need to be offered alongside one-to-one advice to ensure capital works were sited appropriately. Some farmers see the absence of capital grants as a major shortcoming in ELS particularly when compared to Countryside Stewardship (Farmers Weekly, 7 December 2007). Grants could also be available for very costly projects on high risk land such as re-siting gateways or tracks to prevent erosion and/or interrupting a hydrological pathway, but this would be more appropriate for HLS.

Current data, albeit very limited, indicate that in-field buffers could greatly reduce P losses. These have the advantage over riparian buffers that they are unlikely to act as a source of P if the land floods. Even if these buffers consisted simply of a strip of uncultivated grass, significant disruption to cultivation could occur as access would necessarily be restricted to prevent channelling of surface water and to maintain the integrity of the buffer. The farmer may be required to create additional entries to fields, which would be costly. The additional effort required by farmers to implement in-field buffers would need to be recognised and grants may be necessary to cover any capital items required, along with advice to ensure they were appropriately located.

The current points system allows farmers to choose any options to obtain their points and it is unlikely that the farmer will implement more options than is required once the threshold is attained. The points system could modified so that farmers have to have a range of options addressing different issues (e.g. biodiversity, nutrient pollution, historic landscape). The farmer would need to include some options from each 'theme' - possibly with different points target for the different themes. This would require substantial reworking of the points system, which is beyond the scope of this study. This may also be more confusing to the farmer. Targeted advice and/or help to farmers in drawing up their ELS applications could encourage farmers to select appropriate options.

REFERENCES

Alford, D. V. (ed.) (1980) Atlas of the Bumblebees of the British Isles. Institute of Terrestrial Ecology Publications, No. 30.

ADAS (2007). Evaluation of Management Plan options in Environmental Stewardship. Report to Defra, October 2007.

Anon (1998). *Biodiversity: the UK Action Plan*. HMSO, London.

Anon (2003). Cost curve assessment of phosphorus mitigation options relevant to UK agriculture. Defra Project PE0203.

Anon (2007a) *Restoration and management of bumblebee habitat in agricultural landscapes*. Research report for Defra project BD1625, Department for Environment, Food and Rural Affairs, London, UK.

Anon (2007b). Diffuse nitrate pollution from agriculture – strategies for reducing nitrate leaching. Supporting paper D3 for the consultation of the Nitrates Directive England. Defra report.

Anthony S. (2006). Cost and effectiveness of policy instruments for reducing diffuse agricultural pollution. Final report to Defra, projects WQ0106 and ES0205.

Anthony, S. (2007). Cost and effectiveness of policy instruments for reducing diffuse agricultural pollution. Final report to Defra, projects WQ0106 and ES0205.

Asher, J., Warren, M. S., Fox, R., Harding, P. Jeffcoate, G. and Jeffcoate, S. (2001) *The millenium atlas of butterflies in Britain and Ireland*. Oxford University Press, Oxford, UK. 433 pp.

Bäckman, J. C. and Tiainen, J. (2002) Habitat quality of field margins in a Finnish farmland area for bumblebees (Hymenoptera: Bombus and Psithyrus). *Agriculture, Ecosystems and the Environment* 89, 53-68.

Baldock, D. (2007). Wildlife reports – Bees, ants and wasps. *British Wildlife* 18, 440-442.

Banaszak, J. 1983 Ecology of bees (Apoidea) of agricultural landscapes. *Polish Ecological Studies* **9**, 421-505.

Barker, S., Warren, M. S., Williams, M and Davis, J. (1998). *Hedgerows for Hairstreaks: Hedgerow and woodland management to conserve the Brown Hairstreak Butterfly, (2nd edition)*. Butterfly Conservation (West Midlands Branch).

Benton, T. (2000) *The bumblebees of Essex* vii+180 pp. Ipswich

Biodiversity Reporting and Information Group (2007). *Report on the Species and Habitat Review.* Report to the UK Biodiversity Partnership, June 2007.

Boatman, N. D. (1992) Herbicides and the management of field boundary vegetation. *Pesticide Outlook* **3**, 30-34.

Boatman, N., Jones, N., Garthwaite, D., Bishop, J., Pietravalle, S., Harrington, P. & Parry, H. (2007). *Evaluation of the Operation of Environmental Stewardship*. Final report to Defra, project No. MA01028.

Bourn, N. A. D. and Warren, M. S. (1998) Species Action Plan: Brown hairstreak (*Thecla betulae*) Butterfly Conservation, Wareham, 21 p.

Byfield, A.J. & Wilson, P.J. (1995). *Important Arable Plant Areas. Identifying priority sites for arable plant conservation in the United Kingdom*. Plantlife, Salisbury.

Carvell C., Meek, W. R., Pywell, R. F., Nowakowski, M. (2004) The response of foraging bumblebees to successional change in newly created arable field margins. *Biological Conservation* **118**, 327-339.

Carvell, C., Meek, W. R., Pywell, R. F., Goulson, D. and Nowakowski, M. (2007) Comparing the efficacy of agri-environment schemes to enhance bumble bee abundance and diversity on arable field margins. *Journal of Applied Ecology* **44**, 29-40.

Carvell, C., Roy, D. B., Smart, S. M., Pywell, R. F., Preston, C. D. and Goulson, D. (2006) Declines in forage availability for bumblebees at a national scale. *Biological Conservation* **132**, 481-489.

Chapman, R. E., Wang, J. and Bourke, A. F. G. (2003) Genetic analysis of spatial foraging patterns and resource sharing in bumblebee pollinators. *Molecular Ecology* **12**, 2801-2808.

Cheffings, C.M. & Farrell, L. (Eds), Dines, T.D., Jones, R.A., Leach, S.J., McKean, D.R., Pearman, D.A., Preston, C.D., Rumsey, F.J., Taylor, I. (2005). The Vascular Plant Red

Data List for Great Britain. *Species Status* **7**: 1-116. Joint Nature Conservation Committee, Peterborough.
Corbet, S. A. (1995) Insects, plants and succession – advantages of long-term set-aside. *Agriculture, Ecosystems and the Environment* **53**, 201-217.
Corbet, S. A., Williams, I. H. and Osborne, J. L. 1991 Bees and the pollination of crops and wild flowers in the European Community. *Bee World* **72**, 47-59.
Cresswell, J. E., Osborne, J. L. and Goulson, D. (2000) An economic model of the limits to foraging range in central place foragers with numerical solutions for bumblebees. *Ecological Entomology* **25**, 249-255.
Cuttle S.P., Haygarth P.M., Chadwick D.R., Newell-Price P, Harris D., Shepherd M.A., Chambers B.J. & Humphrey R. (2006*). An inventory of measures to control diffuse water pollution from agriculture (DWPA)*: User Manual
Cuttle S.P., Scurlcok R.V. and Davies B.M.S. (1998). A 6-year comparison of nitrate leaching from grass/clover and N-fertilized grass pastures grazed by sheep. *Journal of Agricultural Science*, 131: 39-50.
Cuttle S.P., Scurlcok R.V. and Davies B.M.S. (1998). A 6-year comparison of nitrate leaching from grass/clover and N-fertilized rgass pastures grazed by sheep. *Journal of Agricultural Science*, **131**: 39-50.
Darvill, B., Knight, M. E. and Goulson, D. (2004) Use of genetic markers to quantify bumblebee foraging range and nest density. *Oikos* **107**, 471-478.
Dicks, I. V., Corbet, S. A. and Pywell, R. F. Compartmentalisation in plant-insect flower visitor webs. *Journal of Animal Ecology* **71**, 32-43.
Dramstad, W. and Fry, G. (1995) Foraging activity of bumblebees (*Bombus*) in relation to flower resources in arable land. *Agriculture, Ecosystems and the Environment* **53**, 123-135.
Edwards, M. (1998) U.K. *Biodiversity Action Plan Bumblebee Working Group Report 1998*. Unpublished report for the UKBAP bumblebee working group, Midhurst, UK.
Edwards, M. and Jenner, M. (2005) *Field guide to the bumblebees of Great Britain and Ireland*. Ocelli, Eastbourne, UK.
Eggers, T. (1984). Some remarks on endangered weed species in Germany. Proceedings of the 7th International *Symposium on weed biology, ecology and systematics*, Paris. COLUMA/EWRS
Fuller, R. J. (1987) The changing extent and conservation interest of lowland grasslands in England and Wales: a review of grassland surveys 1930-94. *Biological Conservation*, **40**, 281-300.
Fussell, M. and Corbet, S. A. (1991) Forage for bumblebees and honey bees in farmland: a case study. *Journal of Apiculture Research* **30**, 87-97.
Goulson, D, Lye, GC, Darvill, B. (2008). Decline and conservation of bumblebees. *Annual Review of Entomology* **53**: 11.1-1
Goulson, D. (2002) Colony growth of the bumblebee, *Bombus terrestris*, in improved and conventional agricultural and suburban habitats. *Oecologia* **130**, 267-273.
Goulson, D. (2003) *Bumblebees: Their behaviour and ecology*. Oxford University Press, Oxford.
Goulson, D. (2003) Conserving wild bees for crop pollination International *Journal of Food, Agriculture and the Environment* **1**, 142-144.
Goulson, D. (2006) The demise of the bumblebee in Britain. *The Biologist* **53**: 294-299.
Goulson, D. and Darvill, B. 2004) Niche overlap and diet breadth in bumblebees; are rare species more specialized in their choice of flowers? *Apidologie* **35**, 55-63.
Goulson, D., Hanley, M. E., Darvill, B., Ellis, J. S. and Knight, M. E. (2005) Causes of rarity in bumblebees. *Biological Conservation* **122**, 1-8.
Heard, M. S., Carvell, C., Carreck, N. L., Rothery, P., Osborne, J. l. and Bourke, A. F. G. (2007) Landscape context not patch size determines bumblebee density on flower mixtures sown for agri-environment schemes. *Biology Letters doi*: 10.1098/rsbl.2007.0425.
Kells, A. R., and Goulson, D. (2003) Preferred nesting sites of bumblebee queens (Hymenoptera: Apidae) in agroecosystems in the UK. *Biological Conservation* **109**, 165-174.
Kells, A. R., Holland, J. and Goulson, D. (2001) The value of uncropped field margins for foraging bumblebees. *Journal of Insect Conservation* **5**, 283-291.

Kleijn, D. & van der Voort, L.A.C. (1997) Conservation headlands for rare arable weeds: the effects of fertilizer application and light penetration on plant growth. *Biological Conservation*, **81**, 57-67.

Knight, M. E., Martin, A. P., Bishop, S., Osborne, J. L., Hale, R. J., Sanderson, R. A. and Goulson, D. (2005) An interspecific comparison of foraging range and nest density of four bumblebee (*Bombus*) species. *Molecular Entomology* **14**, 1811-1820.

Kwak. M. M., Velterop, O. and van Andel, J. 1998 Pollen and gene flow in fragmented habitats. *Applied Vegetation Science* **1**, 37-54.

Leeds-Harrison P.B., Quinton J.N., Walker M.J>, Harrison K.S., Tyrrel S.F., Morris J. & Harrod T. (1996). Buffer zones in headwater catchments. Maff/ English Nature Report no CSA 2285.

Malisauskas A., Haneklaus S. and Sileika AS. (2005). Nitrogen leaching from grassland in Lithuania. *Landbauforschung Volkenrode. Bundesforschungsanstalt fur Landwirtschaft* (FAL), Braunschweig, Germany: **55**: 71-78.

Meek, B., Loxton, D., sparks, T., Pywell, R., Pickett, H. and Nowakowski, M. (2002) The effect of arable field margin composition on invertebrate diversity. *Biological Conservation* **106**, 259-271.

Memmott, J., Waser, N. M. and Price, M. V.` (2004) Tolerance of pollination networks to species extinctions*. Proceedings of the Royal Society of London, Science* Series B **62**, 752-758.

Ockinger, E. and Smith, H. G. (2007) Semi-natural grasslands as population sources for pollinating insects in agricultural landscapes. *Journal of Applied Ecology* **44,** 50-59.

Osborne, J. L. and Corbet, S. A. (1994) Managing habitats for pollinators in farmland. *Aspects of Applied Biology* **40**, 36, 519-533.

Osborne, J. L., Martin, A. P., Shortall, C. R., Todd, A. D. Goulson, D., Knight, M. E., Hale, R. J. and Sanderson, R. A. (2007) Quantifying and comparing bumblebee nest densities in gardens and countryside habitats. *Journal of Applied Ecology* doi: 10.1111/j.1365-2664.2007.01359.x.

Osborne, J.L ., Clark, S.J., Morris, R.J., Williams, I.H., Riley, J.R., Smith, A.D., Reynolds, D.R. and Edwards, A.S. (1999) A landscape scale study of bumblebee foraging range and constancy, using harmonic radar. *Journal of Applied Ecology* **,** **36**, 519-533.

Osborne, J.L. & Williams, I.H. (2001) Site constancy of bumblebees in an experimentally-patchy habitat. *Agriculture, Ecosystems and Environment* , **83**, 129-141.

Parkinson, R. J., Griffiths, P., & Heathwaite, A. L. (2000), Transport of nitrogen in soil water following the application of animal manures to sloping grassland, *Hydrological Sciences Journal*, **45**, 61-73.

Petit, S., Howard, D.C., Smart, S.M., & Firbank, L.G. (2002). Biodiversity in British ecosystems: the changing regional landscape context. In: *The BCPC conference – Pests & Diseases 2002*, pp. 957-964. British Crop Protection Council, Farnham, UK.

Petit, S., Stuart, R.C., Gillespie, M.K., & Barr, C.J. (2003) Field boundaries in Great Britain: stock and change between 1984, 1990 and 1998. *Journal of Environmental Management*, **67**, 229-238.

Preston, C.D., Pearman, D.A., & Dines, T.D. (2002) *New Atlas of the British and Irish Flora.* Oxford University Press, Oxford

Pywell, R. F., Bullock, J. M., Hopkins, A., Walker, K. J., Sparks, T. H., Burke, M. J. W. and Peel, S. (2002) Restoration of species-rich grassland on arable land: assessing the limiting processes using a multi-site experiment. *Journal of Applied Ecology* **39**, 294-309.

Pywell, R. F., Bullock, J. M., Roy, D. B., Warman, E. A. and Rothery, P. (2003) Plant traits as predictors of performance in ecological restoration schemes. *Journal of Applied Ecology* **40**, 65-77.

Pywell, R. F., Warman, E. A., Carvell, C., Sparks, T. H., Dicks, L. V., Bennett, D., Wright, A., Critchley, C. N. R., and Sherwood, A. (2005) Providing foraging sources for bumblebees in intensively farmed landscapes*. Biological Conservation* **121**, 479-494.

Pywell, R. F., Warman, E. A., Hulmes, L., Hulmes, S., Nutall, P., Sparks, T. H., Critchley, C. N. R., and Sherwood, A. (2006) Effectiveness of new agri-environment schemes in providing foraging resources for bumblebees in intensively farmed landscapes. *Biological Conservation* **129**, 192-206.

Ramwell C.T., Smart R.P., Parry H. & Boatman N (2006). Scoping study to assess the possible effects of ES schemes on nutrient losses. Final report to Defra, project no. BD2301.

Rasmont, P. (1988) *Monographie ecologique et zoogeographique des bourdons de France et de Belgique (Hymenoptera, Apidae, Bombinae)* PhD thesis, Faculte des Sciences Agronomique del'Etat, Gembloux, Belgium.

Rich, T.C.G. & Woodruff, E.R. (1996). Changes in the vascular plant floras of England and Scotland between 1930-1960 and 1987-1988: the BSBI monitoring scheme. *Biological Conservation*, **75**, 217-229.

Saville, N. M., Dramstad, W. E., Fry, G. L. A. and Corbet, S. A. (1997) Bumblebee movement in a fragmented agricultural landscape. *Agriculture, Ecosystems and Environment* **61**, 145-154.

Shelly, T. E., Buchmann, S. L., Villalobos, E. M. and O'Rourke, M. K. (1991) Colony ergonomics for a desert-dwelling bumblebee species (Hymenoptera: Apidae). *Ecological Entomology* **16**, 361-370.

Still & Byfield, (2007). *New priorities for arable plant conservation*. Plantlife International, Salisbury.

Sutcliffe, O.L. & Kay, Q.O N. (2000). Changes in the arable flora of central southern England since the 1960s. *Biological Conservation,* **93**, 1-8.

Thomas, J. A. (1974). *The ecology of hairstreak butterflies.* PhD thesis, University of Leicester.

Thomas, J. A. (1991) Rare species conservation: case studies of European butterflies. In: *The scientific management of temperate communities for conservation*. 31st Symposium of the British Ecological Society, Southampton, 19989, Eds. Spellerberg, F. B., Goldsmith, F. B. and Morris, M. G., Blackwell Scientific Publications Ltd., Oxford, UK, pp149-198.

Thomas, J. A. and Emmet, A. M., (1989) The brown hairstreak. In: *The Moths and Butterflies of Great Britain and Ireland* Volume 7, Part 1 Hesperidae to Nymphalidae. Eds. Emmet, A. M. and Heath, J. Harley Books, Colchester Essex, UK. pp. 123-126.

U.K. Biodiversity Action Plan Bumblebee Working Group Report (1999). Unpublished report for the UKBAP bumblebee working group, Midhurst, UK.

U.K. Biodiversity Action Plan Bumblebee Working Group Report (2000). Unpublished report for the UKBAP bumblebee working group, Midhurst, UK.

U.K. Biodiversity Action Plan Bumblebee Working Group Report (2001). Unpublished report for the UKBAP bumblebee working group, Midhurst, UK.

Vickery, J., Chamberlain, D., Evans, A., Ewing, S., Boatman, N., Pietravalle S., Norris, K. & Butler, S. (2007). *Predicting the impact of future agricultural change and uptake of Environmental Stewardship on farmland birds*. Report to Defra and Natural England, November 2007.

Walker, K.J., Critchley, C.N.R., Sherwood, A.J., Large, R., Nuttall, P., Hulmes, S., Rose, R., & Mountford, J.O. (2007) The conservation of arable plants on cereal field margins: an assessment of new agri-environment scheme options in England, UK. *Biological Conservation*, 136, 260-270.

Walther-Hellwig, K. and Frankl, R. (2000) Foraging distances of *Bombus muscuorum*, *Bombus lapidarius* and *Bombus terrestris* (Hymenoptera, Apidae). *Journal of Insect Behaviour* **13**, 239-246.

Wigglesworth, T. (Ed.) (2005) Action for the Brown Hairstreak: Sharing good practice. In: *Proceedings from a Butterfly Conservation Seminar. January 2005*. Butterfly Conservation Report no. S05-04, 19 p.

Williams, I. H. and Christian, D. G. (1991) Observations on *Phacelia tanacetifolia* Bentham (Hydrophyllaceae) as a food plant for honey bees and bumble bees. *Journal of Apicultural Research* **21,** 236-245.

Williams, P. H. (1982) The distribution and decline of British bumble bees (*Bombus* Latr.). *Journal of Apicultural Research* **21**: 236-245.

Williams, P. H. (1986) Environmental change and the distributions of British bumblebees (Bombus Latr.). *Bee World* **67**: 50-61.

Williams, P. H. (2005) Does specialization explain rarity and decline among British bumblebees? A response to Goulson et al. *Biological Conservation* **122**, 33-43.

Wilson, P. & King, M. (2003). *Arable plants – a field guide*. Wildguides, Old Basing, Hampshire.

Wilson, P.J. & Aebischer, N.J. (1995) The distribution of dicotyledonous arable weeds in relation to distance from the field edge. *Journal of Applied Ecology*, 32, 295-310.

Wilson, P.J. (1990) *The ecology and conservation of rare arable weed species and communities*. Unpublished PhD thesis, University of Southampton.

Wilson, P.J. (1992). Britain's arable weeds. *British Wildlife* **3**, 149-161.

Annex A. Methodology for calculating indicator scores

This is a shortened version of the original methodology as set out in the earlier evaluation (Boatman et al., 2007), giving the key elements of the method as used in this project.

Overview

The aim of the modelling process was to provide an easily understood method of assessing the environmental impacts of ELS for key indicators in relation to agreed targets, based on expert scores. two pieces of information were required: a score indicating the potential of that option to contribute to the achievement of the target for the indicator if implemented optimally, and an estimate of how much of the option would be needed to gain maximum effect. Many of the experts canvassed in the original evaluation found themselves unable to give estimates of how much option would be required, and only gave scores for the option potential. Therefore, in this project, key options were identified, and estimates of amounts required derived, on the basis of literature review and consultation as described above (section 2.1).

The results gave a score for the potential value of the scheme on each farm for each indicator, which could also be related to a maximum potential score for the options chosen, if implemented optimally. The way in which the calculations were carried out means that the maximum potential score would always be ten, whether expressed at farm, JCA, region, national or any other level. A value of ten would indicate that the target for that indicator will be achieved in full. In practice this is accepted as being unlikely, but the scores would give an indication of the likely contribution of the scheme to achieving the target (within the limitations and assumptions inherent in the modelling process).

Calculation of indicator scores

To calculate the farm score for an indicator for a particular farm, the option score is multiplied by the ratio of the actual amount on the farm to the optimal amount up to a maximum value of 1, i.e.:

score value per option per farm for an individual option $S_i = s_i.\min[(\alpha_i/\theta_i); 1]$ (1)

where: s_i = expert score for option *i*
α_i = amount of option *i* per unit area on the farm;
θ_i = optimal amount of option *i* per unit area

For two equivalent options, the farm score for the indicator is calculated as the sum of the score values per option as in equation (1), i.e.:

Indicator score value per farm $S_{fe} = s_i.\min[(\alpha_i/\theta_i); 1] + s_j.\min[(\alpha_j/\theta_j); 1]$ (4)

In general, for up to *n* equivalent options,

$$S_{fe} = s_1.\min[(\alpha_1/\theta_1); 1] + \ldots + s_j.\min[(\alpha_j/\theta_j); 1] + \ldots\ldots s_n.\min[(\alpha_n/\theta_n); 1] \quad (5)$$

Worked examples

(a): Let us assume two options i, j,

For option *i*:

- expert score = 3,
- amount on farm = 17ha/km^2,
- expert estimate of optimum amount = 25ha/km^2

For option *j*:

- expert score = 7,

- amount on farm = 40ha/km^2,
- expert estimate of optimum amount = 70ha/km^2

calculation:

$S_{fe} = s_i.\min[(\alpha_i/\theta_i); 1] + s_j.\min[(\alpha_j/\theta_j); 1]$

$= (3x17/25) + (7x40/70)$

$= 2.04 + 4$

= **<u>6.04</u>**

(b): Three options *k, m, n* (all area options measured in hectares):

- expert scores = 3, 4, 7 respectively
- amounts on farm = 15, 300, 2 ha/km^2 respectively
- expert estimate of optimum amount = 50, 200, 10 ha/km^2 respectively

calculation:

$S_{fe} = s_k.\min[(\alpha_k/\theta_k); 1] + s_m.\min[(\alpha_m/\theta_m) + s_n.\min[(\alpha_n/\theta_n); 1]$

$= 3.\min[(15/50); 1] + 4.\min[(300/200); 1] + 7.\min[(2/10); 1]$

$= (3 \times 0.3) + (4 \times 1) + (7 \times 0.2)$

$= 0.9 + 4 + 1.4$

= **<u>6.4</u>**

Combining farm scores

The maximum score for an indicator on any farm is ten. Each farm is scored individually, and the scores can be averaged and weighted by farm area to give national scores. The maximum score for an indicator is still ten, but in practice it is almost certain to be less when scores are aggregated.

Annex B Methods of splitting options according to objectives

There is currently no entirely objective basis for deciding what proportion of the points target for a farm should reasonably be devoted to a specific objective on average (bearing in mind that variation between farms in this respect would be expected, and indeed is desirable in order to achieve spatial diversity of environmental benefits). In the absence of such a method, several possible approaches are outlined below.

(i) The average number of options per agreement is just over seven (Boatman *et al*., 2007). If each of these accounted for the same proportion of the points total, and on average one of the options were devoted to the objective in question, this would constitute 14% of the points for that farm.

(ii) points could be divided equally between resource protection, biodiversity, landscape and historic, and the biodiversity points between options targeted at birds, inverts, plants. This would give plants for example just over 8% for each, which could be increased where for example arable plants are the priority.

(iii) options could be divided into themes, and it might be considered reasonable to expect participants on average to divide their points between these themes. One such classification would give 11 categories (see table below); clearly a number of others are possible, which may give different numbers of categories. However, dividing the points between the 11 categories would suggest that 9% should be devoted to each theme.

All these approaches are relatively simplistic and have drawbacks, but it is likely that even a more complex analysis would be potentially open to criticism as there would inevitably be a subjective element. Nevertheless, all the approaches suggested above give similar outcomes in terms of proportions of points which might be devoted to a biodiversity objective or theme. The average percentage over the three approaches is 10%, and this could be justified in each case as follows:

- (i) Devoting a seventh of the points to one objective assumes that only seven (low level) objectives exist, which is probably too few.
- (ii) The allocation could be increased in areas where the objective is a priority.
- (iii) In most areas participants may not in fact have a choice of 11 themes because a sufficient range of options would not be available on their farm.

Table B.1 A possible classification of ELS options into 'themes'.

Option Code	Long Description	Theme no.	Theme
EM01	Soil management plan	1	resource prot
EM02	Nutrient management plan	1	resource prot
EM03	Manure management plan	1	resource prot
EM04	Crop protection management plan	1	resource prot
EF01	Field corner management	2	Buffers & field corners
EF02	Wild bird seed mixture	3	Bird seed
EF03	Wild bird seed mixture on set-aside land	3	Bird seed
EF04	Pollen & nectar flower mixture	4	Pollinators
EF05	Pollen & nectar flower mixture on set-aside land	4	Pollinators
EF06	Over-wintered stubbles	3	Bird seed
EF07	Beetle banks	5	inverts/summer bird habitat
EF08	Skylark plots	5	inverts/summer bird habitat
EF09	Conservation headlands in cereal fields	6	arable flora
EF10	Conservation headlands in cereal fields with no fertilisers/manure	6	arable flora
EF11	6m Uncropped, cultivated margins on arable land	6	arable flora
EB01	Hedgerow management (on both sides of hedge)	7	woody boundary
EB02	Hedgerow management (on one side of hedge)	7	woody boundary
EB03	Enhanced hedgerow management	7	woody boundary
EB04	Stone faced hedge bank management on both sides	7	woody boundary
EB05	Stone faced hedge bank management on one side	7	woody boundary
EB06	Ditch management	8	ditches
EB07	Half ditch management	8	ditches
EB08	Combined hedge and ditch management (incorporating EB1)	7+8	woody boundary + ditch
EB09	Combined hedge and ditch management (incorporating EB2)	7+8	woody boundary + ditch
EB10	Combined hedge and ditch management (incorporating EB3)	7+8	woody boundary + ditch
EB11	Stone wall protection and maintenance	2	Buffers & field corners
EE01	2m buffer strips on cultivated land	2	Buffers & field corners
EE02	4m buffer strips on cultivated land	2	Buffers & field corners
EE03	6m buffer strips on cultivated land	2	Buffers & field corners
EE04	2m buffer strips on intensive grassland	2	Buffers & field corners
EE05	4m buffer strips on intensive grassland	2	Buffers & field corners
EE06	6m buffer strips on intensive grassland	2	Buffers & field corners
EE07	Buffering in-field ponds in improved grassland	2	Buffers & field corners
EE08	Buffering in-field ponds in arable land	2	Buffers & field corners
ED01	Maintenance of traditional farm buildings	9	historic
ED02	Take archaeological features out of cultivation	9	historic
ED03	Reduce cultivation depth where there are archaeological features	9	historic
ED04	Management of scrub on archaeological sites	9	historic
ED05	Archaeological features on grassland	9	historic
EK01	Take field corners out of management	2	Buffers & field corners
EK02	Permanent grassland with low inputs	10	grassland
EK03	Permanent grassland with very low inputs	10	grassland
EK04	Management of rush pastures (outside of LFA)	10	grassland

Option Code	Long Description	Theme no.	Theme
EK05	Mixed stocking	10	grassland
EL01	Field corner management (LFA land)	2	Buffers & field corners
EL02	Manage permanent in-bye grassland with low inputs	10	grassland
EL03	Manage in-bye pasture and meadows with very low inputs	10	grassland
EL04	Management of rush pastures (LFA land)	10	grassland
EL05	Enclosed rough grazing	10	grassland
EL06	Moorland and rough Grazing	10	grassland
EC01	Protection of in-field trees (arable)	11	trees
EC02	Protection of in-field trees (grassland)	11	trees
EC03	Maintenance of woodland fences	7	woody boundary
EC04	Management of woodland edges	7	woody boundary
EG01	Under sown spring cereals	5	inverts/summer bird habitat
EG02	Wild bird seed mixture in grassland areas	3	Bird seed
EG03	Pollen and nectar seed mixtures in grassland areas	4	Pollinators
EG04	Cereals for whole crop silage followed by over-wintered stubbles	3	Bird seed
EG05	Brassica fodder crops followed by over-wintered stubbles	3	Bird seed
EJ01	Management of high erosion risk cultivated land	1	resource prot
EJ02	Management of maize crops to reduce soil erosion	1	resource prot

Annex C. List of JCAs selected for inclusion in uptake analysis for rare arable flora.[14]

JCA No.	JCA name	Total score
86	South Suffolk and North Essex Clayland	362
110	Chilterns	353
129	Thames Basin Heaths	335
106	Severn and Avon Vales	331
130	Hampshire Downs	330
87	East Anglian Chalk	328
88	Bedfordshire and Cambridgeshire Claylands	326
83	South Norfolk and High Suffolk Claylands	323
111	Northern Thames Basin	321
115	Thames Valley	321
108	Upper Thames Clay Vales	308
46	The Fens	305
109	Midvale Ridge	305
107	Cotswolds	298
120	Wealden Greensand	294
125	South Downs	292
116	Berkshire and Marlborough Downs	285
119	North Downs	278
121	Low Weald	277
132	Salisbury Plain and West Wiltshire Downs	276
134	Dorset Downs and Cranborne Chase	274
126	South Coast Plain	271
118	Bristol, Avon Valleys and Ridges	270
85	Breckland	268
84	Mid Norfolk	265
48	Trent and Belvoir Vales	264
140	Yeovil Scarplands	252
82	Suffolk Coast and Heaths	250
76	North West Norfolk	244
96	Dunsmore and Feldon	239
151	South Devon	233
104	South Herefordshire and Over Severn	223
152	Cornish Killas	223
75	Kesteven Uplands	219
114	Thames Basin Lowlands	218
39	Humberhead Levels	217
136	South Purbeck	217
127	Isle of Wight	216
142	Somerset Levels and Moors	213
44	Central Lincolnshire Vale	212
135	Dorset Heaths	207
145	Exmoor	204
146	Vale of Taunton and Quantock Fringes	203
143	Mid Somerset Hills	197

Continued….

[14] including all those with scores >75 using the system designed for identifying Important Arable Plant Areas (Still and Byfield, 2007), plus selected additions including BAP species or those with very restricted distributions.

JCA No.	JCA name	Total score
66	Mid Severn Sandstone Plateau	197
61	Shropshire, Cheshire and Staffordshire Plain	197
128	South Hampshire Lowlands	195
43	Lincolnshire Wolds	195
92	Rockingham Forest	194
131	New Forest	193
45	Northern Lincolnshire Edge with Coversands	189
47	Southern Lincolnshire Edge	188
117	Avon Vale	186
89	Northamptonshire Vales	183
133	Blackmoor Vale and the Vale of Wardour	181
113	North Kent Plain	181
147	Blackdowns	180
78	Central North Norfolk	178
30	Southern Magnesian Limestone	177
74	Leicestershire and Nottinghamshire Wolds	174
100	Herefordshire Lowlands	173
122	High Weald	169
38	Nottinghamshire, Derbyshire and Yorkshire Coalfield	168
80	The Broads	162
97	Arden	160
148	Devon Redlands	157
158	Isles of Scilly	139
27	Yorkshire Wolds	133
94	Leicestershire Vales	130
123	Romney Marshes	120
157	The Lizard	79
156	West Penwith	79
124	Pevensey Levels	68

Annex D. Favoured food plants for bumblebees, suggested field margin design and seed mixtures

Table D.1 Favoured food plant species of the six most common bumblebee species in England

Asteraceae
Centaurea scabiosa (Greater knapweed)
Centaurea nigra (Common knapweed)
Cirsium spp.

Boraginaceae
Echium vulgare (Vipers's buglos)
Symphytum officinalis (Comfrey)

Dipsacaceae
Dipsacus fullonum (Teasel)

Fabaceae
Anthyllis vulneraria (Kidney vetch)
Lathyrus pratensis (Meadow vetchling)
Lotus corniculatus (Bird's foot trefoil)
Onobrychis viciifolia (Sainfoin)
Trifolium pratense (Red clover)
T. repens (White clover)
Vicia cracca (Tufted vetch)
Vicia sepium (Bush vetch)

Lamiaceae
Ballota nigra (Black horehound)
Lamium album (White deadnettle)
Other genera include *Thymus* spp. (Thymes), *Mentha* spp. (Mints), *Stachys* (Woundworts and Bettony), *Ajuga* (Bugle)

Rosaceae
Rubus fructicosus (Bramble)

Salicaceae
Salix spp. (Willows)

Scophulariaceae
Digitalis purpureum (Foxglove)
Odonites vernus (Red bartsia)
Rhinanthus minor (Yellow rattle)
Other genera include *Linaria* spp. (Toadflaxes)

Suggested Field margin design for bumblebees

A suggested design for the ideal field margin which provides nesting and over-wintering sites and pollen and nectar sources throughout the bumblebee season.

Hedge Renewing and Planting

Salix caprea (Goat Willow) provides an early year food source for bumblebees. *Ligustrum vulgare* (Wild Privet) is a good mid season food source, whilst bramble *Rubus fruticosus* provides a food resources in the mid to late season.

A three-year hedge cutting rotation is ideal, with a third of the hedges on a farm cut each year. Cutting should be carried out in winter/autumn.

Hedge-side row

One seed drill width, unmown year round, with seed mixture dominated by grasses with tall perennials to provide a thick tussocky environment (Table D.2). This type of habitat provides nest building areas for *Bombus,* nesting sites for ground nesting birds e.g. grey partridge, cover and nesting sites for small mammals which in turn provide nesting sites for under ground and above ground nesting[15] *Bombus*, over-wintering sites for aphidiphagous parasitoids and predators, larval food plants for butterfly species and nectar sources for adult bumblebees, butterflies, aphidiphagous predators and parasitoids.

Field-side seed drill row

Dominated by perennials (Table D.3) with few grasses, unmown between April and September, this row is used to provide nectar sources for bumblebees, butterflies and aphidiphagous parasitoids and predators, and food. The increased range of species in this mixture will increase the diversity of associated insect fauna which will provide good feeding grounds for insectivorous birds.

Table D.2. Suggested tussocky grasses and perennials for the hege-side row.

Grasses	**Perennials**
Yorkshire-fog (*Holcus lanatus)*	*Echium vulgare* (Vipers's buglos)
Red Fescue (*Festuca rubra*)	*Symphytum officinalis* (Comfrey)
Sheep's-fescue *(F. ovina)*	*Lathyrus pratensis* (Meadow vetchling)
Cock's-foot (*Dactylis glomerata)*	*Onobrychis viciifolia* (Sainfoin)
False Brome (*Brachypodium sylvaticum)*	*Vicia cracca* (Tufted vetch)
Bents (*Agrostis capillaris* and spp.)	*Vicia sepium* (Bush vetch)
Meadow-grasses (*Poa* spp.)	*Centaurea scabiosa* (Greater knapweed)
	Centaurea nigra (Common knapweed)
	Melilotus altissimus (Tall Melilot)
	Dipsacus fullonum (Teasel)
	Digitalis purpureum (Foxglove)
	Ballota nigra (Black horehound)
	Heracleum sphondylium (Hogweed)
	Anthriscus sylvestris (Cow parsley)

[15] Above-ground summer vole nests are used by above-ground bumblebees

Table D.3. Suggested perennials in order of preference for the field-side row.

Trifolium pratense (Red clover) (key species for many of the rare long-tongued bees
T. repens (White clover)
Lotus corniculatus (Bird's foot trefoil),
Centaurea nigra (Common knapweed)
Centaurea scabiosa (Greater knapweed)
Odonites vernus (Red bartsia)
Vicia cracca (Tufted Vetch)
Vicia sepium (Bush vetch)
Rhinanthus minor (Yellow rattle)
Anthyllis vulneraria (Kidney vetch)
Thymus spp. (Thymes)
Lamium album (White deadnettle)
Lathyrus pratensis (Meadow vetchling)
Linaria spp. (Toadflaxes)
Mentha spp. (Mints)
Stachys (Woundworts and Bettony)
Ajuga (Bugle)

Annex E. Calculations of N and P loss under Soil, Nutrient and Manure Management Plans for arable, dairy and beef farms under low, medium and high scenarios.

Arable scenario:

Farm size = 300 ha; Baseline N loss = 50 kg/ha; Baseline P loss = 3.8 kg/ha. In the absence of ELS N loss = 15000 kg and P loss = 1140 kg.

Dairy scenario :

Farm size = 125 ha; Baseline N loss = 50 kg/ha; Baseline P loss = 2.2 kg/ha. In the absence of ELS N loss = 6250 kg and P loss = 275 kg.

Beef scenario:

Farm size = 100 ha; Baseline N loss = 20 kg/ha; P loss = 1.6 kg/ha. In the absence of ELS N loss = 2000 kg and P loss = 160 kg.

Table E.1 Calculation of N and P loss under the Soil, Nutrient and Manure Management Plan for Arable – high ELS uptake scenario

ARABLE - HIGH	Mean N loss	P loss (kg/ha)		Typology	% of land in ELS	Area of land (ha) in		Total loss	% reduction		Total loss	% reduction	
Equivalent mitigation method	(kg/ha)	pre-ELS	post-ELS			ELS	Non-ELS	kg/N		Max	kg/P		Max
Convert high risk land	20	3.5	2.2	landuse	2.7	8	292	14760	1.6	1.6	1039.6	0.99	0.99
Establish cover crops in autumn	40	3.9	2.78	soil	75	225	75	12750	15		918	21.54	
Cultivate land spring	40	3.82	2.71	soil	75	225	75	12750	15		896.25	21.79	
Adopt minimal cultivation systems	47.5	3.83	2.71	soil	75	225	75	14438	3.75		897	21.93	
Cultivate and drill across slope	50	3.83	2.72	soil	75	225	75	15000	0		899.25	21.74	
Leave autumn seedbeds rough	50	3.83	2.72	soil	75	225	75	15000	0	15	899.25	21.74	21.93
Avoid tramlines over winter	50	3.83	2.72	tramline	25	75	225	15000	0	0	1065.75	7.25	7.25
In-field grass buffers/strip contour	47	2.71	0.54	runoff	25	75	225	14775	1.5		650.25	20.02	
Install hedges	50	2.71	2.03	runoff	25	75	225	15000	0		762	6.27	
Move gateways	50	2.71	1.89	runoff	10	30	270	15000	0	1.5	788.4	3.03	20.02
					Soil Management Plan % reduction:				**Total N**	**18.1**		**Total P**	**50.19**
Fertiliser recommendation system	45	3.83	3.74	fertiliser	75	225	75	13875	7.5		1128.75	1.76	
Integrate fertiliser & manure	42.5	2.19	2.10	fertiliser	75	225	75	13313	11.25		636.75	3.08	
Do not apply P to high index soil	-	4.22	4.16	fertiliser	75	225	75	-	-		1252.5	1.07	
Time N	37.5	2.45	2.31	fertiliser	75	225	75	12188	18.75	18.75	703.5	4.29	4.29
Incorporate P	-	3.76	3.73	incorporate	75	225	75	-	-		1121.25	0.60	0.60
calibrate spreader - cereal	46.5	3.82	3.73	calibrate	100	300	0	13950	7	7	1119	2.36	2.36
					Nutrient Management Plan % reduction:				**Total N**	**25.75**		**Total P**	**7.24**
Do not apply slurry high risk times	30	2.19	2.03	fertiliser	75	225	75	10500	30	30	621	5.48	5.48
Identify no spread areas*													
*Negligible according to Cuttle					**Manure Management Plan % reduction:**				**Total N**	**30**		**Total P**	**5.48**

Table E.2 Calculation of N and P loss under the Soil, Nutrient and Manure Management Plan for Arable – medium ELS uptake scenario

ARABLE - MEDIUM	Mean N loss	P loss (kg/ha)		Typology	% of land in	Area of land (ha) in		Total loss	% reduction		Total loss	% reduction	
Equivalent mitigation method	(kg/ha)	pre-ELS	post-ELS		ELS	ELS	Non-ELS	kg/N		Max	kg/P		Max
Convert high risk land	20	3.5	2.2	landuse	1	3	297	14910	0.6	0.6	1046	0.37	0.37
Establish cover crops in autumn	40	3.9	2.78	soil	50	150	150	13500	10		1002	14.36	
Cultivate land spring	40	3.82	2.71	soil	50	150	150	13500	10		980	14.53	
Adopt minimal cultivation systems	47.5	3.83	2.71	soil	50	150	150	14625	2.5		981	14.62	
Cultivate and drill across slope	50	3.83	2.72	soil	50	150	150	15000	0		983	14.49	
Leave autumn seedbeds rough	50	3.83	2.72	soil	50	150	150	15000	0	10	983	14.49	14.62
Avoid tramlines over winter	50	3.83	2.72	tramline	10	30	270	15000	0	0	1116	2.90	2.90
In-field grass buffers/strip contour	47	2.71	0.54	runoff	10	30	270	14910	0.6		748	8.01	
Install hedges	50	2.71	2.03	runoff	10	30	270	15000	0		793	2.51	
Move gateways	50	2.71	1.89	runoff	5	15	285	15000	0	0.6	801	1.51	8.01
					Soil Management Plan % reduction:				**Total N**	**11.2**		**Total P**	**25.9**
Fertiliser recommendation system	45	3.83	3.74	fertiliser	50	50	150	150	14250	5		1136	1.17
Integrate fertiliser & manure	42.5	2.19	2.10	fertiliser	50	50	150	150	13875	7.5		644	2.05
Do not apply P to high index soil	-	4.22	4.16	fertiliser	50	50	150	150				1257	0.71
Time N	37.5	2.45	2.31	fertiliser	50	50	150	150	13125	12.5	12.5	714	2.86
Incorporate P	-	3.76	3.73	incorporate	50	50	150	150	7500		0	1124	0.40
calibrate spreader - cereal	46.5	3.82	3.73	calibrate	100	100	300	0	13950	7	7	1119	2.36
					Nutrient Management Plan % reduction:				**Total N**	**19.5**		**Total P**	**5.61**
Do not apply slurry high risk times	30	2.19	2.03	fertiliser	50	150	150	12000	20	20	633	3.65	3.65
Identify no spread areas*													
*Negligible according to Cuttle					**Manure Management Plan % reduction:**				**Total N**	**20**		**Total P**	**3.65**

Table E.3 Calculation of N and P loss under the Soil, Nutrient and Manure Management Plan for Arable – low ELS uptake scenario

ARABLE - LOW	Mean N loss	P loss (kg/ha)		Typology	% of land in	Area of land (ha) in		Total loss	% reduction		Total loss	% reduction	
Equivalent mitigation method	(kg/ha)	pre-ELS	post-ELS		ELS	ELS	Non-ELS	kg/N		Max	kg/P		Max
Convert high risk land	20	3.5	2.2	landuse	0	0	300	15000	0	0	1050	0.00	0.00
Establish cover crops in autumn	40	3.9	2.78	soil	25	75	225	14250	5		1086	7.18	
Cultivate land spring	40	3.82	2.71	soil	25	75	225	14250	5		1063	7.26	
Adopt minimal cultivation systems	47.5	3.83	2.71	soil	25	75	225	14813	1.25		1065	7.31	
Cultivate and drill across slope	50	3.83	2.72	soil	25	75	225	15000	0		1066	7.25	
Leave autumn seedbeds rough	50	3.83	2.72	soil	25	75	225	15000	0	5	1066	7.25	7.31
Avoid tramlines over winter	50	3.83	2.72	tramline	0	0	300	15000	0	0	1149	0.00	0.00
In-field grass buffers/strip contour	47	2.71	0.54	runoff	0	0	300	15000	0		813	0.00	
Install hedges	50	2.71	2.03	runoff	0	0	300	15000	0		813	0.00	
Move gateways	50	2.71	1.89	runoff	0	0	300	15000	0	0	813	0.00	0.00
					Soil Management Plan % reduction:				**Total N**	**5**		**Total P**	**7.31**
Fertiliser recommendation system	45	3.83	3.74	fertiliser	25	75	225	14625	2.5		1142	0.59	
Integrate fertiliser & manure	42.5	2.19	2.10	fertiliser	25	75	225	14438	3.75		650	1.03	
Do not apply P to high index soil	-	4.22	4.16	fertiliser	25	75	225	11250			1262	0.36	
Time N	37.5	2.45	2.31	fertiliser	25	75	225	14063	6.25	6.25	725	1.43	1.43
Incorporate P	-	3.76	3.73	incorporate	25	75	225	11250		0	1126	0.20	0.20
calibrate spreader - cereal	46.5	3.82	3.73	calibrate	0	0	300	15000	0	0	1146	0.00	0.00
				Nutrient Management Plan % reduction:					**Total N**	**6.25**		**Total P**	**1.63**
Do not apply slurry high risk times	30	2.19	2.03	fertiliser	25	75	225	13500	10	10	645	1.83	1.83
Identify no spread areas*													
*Negligible according to Cuttle				**Manure Management Plan % reduction:**					**Total N**	**10**		**Total P**	**1.83**

Table E.4 Calculation of N and P loss under the Soil, Nutrient and Manure Management Plan for Dairy – high ELS uptake scenario

DAIRY - HIGH Equivalent mitigation method	Mean N loss (kg/ha)	P loss (kg/ha) pre-ELS	post-ELS	Typology	% of land in ELS	Area of land (ha) in ELS	Non-ELS	Total loss kg/N	% reduction	Max	Total loss kg/P	% reduction	Max
Establish in-field buffers	47	2.71	0.54	runoff	25	31.25	93.75	6156	1.50		271	20.02	
Move gateways	50	2.71	1.89	runoff	10	12.5	112.5	6250	0.00	1.50	329	3.03	20.02
Reduce stocking rates when wet	49.5	2.19	1.91	stock	75	93.75	31.25	6203	0.75		248	9.59	
Reduce length of grazing day	38	2.19	1.91	stock	75	93.75	31.25	5125	18.00		248	9.59	
Move feed & water troughs regularly	49.5	2.19	1.91	stock	75	93.75	31.25	6203	0.75		248	9.59	
Loosen compacted soils grass	50	2.19	1.91	stock	25	31.25	93.75	6250	0.00	18.00	265	3.20	9.59
Fence off river banks etc	49.5	2.19	1.91	fence	25	31.25	93.75	6234	0.25		265	3.20	
Construct bridges	49.5	2.19	1.91	fence	25	31.25	93.75	6234	0.25	0.25	265	3.20	3.20
					Soil Management Plan % reduction:				**Total N**	**19.75**		**Total P**	**32.8**
Fertiliser recommendation system	47	-	-	fertiliser	75	93.75	31.25	5969	4.50				
Integrate fertiliser & manure	42.5	2.19	2.10	fertiliser	75	93.75	31.25	5547	11.25		265	3.08	
Time N	42.5	2.71	2.58	fertiliser	75	93.75	31.25	5547	11.25		327	3.60	
Do not apply P to high index soil	-	2.6	2.51	fertiliser	75	93.75	31.25	-	-	11.25	317	2.60	3.60
Incorporate P	50	3.76	3.73	incorporate	75	93.75	31.25	6250	0.00	0.00	467	0.60	0.60
					Nutrient Management Plan % reduction:				**Total N**	**11.25**		**Total P**	**4.2**
Identify high risk areas	49.5	3.83	3.66	no spread	10	12.5	112.5	6244	0.10	0.10	477	0.44	
Increase capacity slurry stores	46.5	2.19	2.03	fertiliser	75	93.75	31.25	5922	5.25		259	5.48	
Do not apply FYM at high risk times	44	2.19	2.03	fertiliser	75	93.75	31.25	5688	9.00		259	5.48	
Do not apply slurry at high risk times	48	2.19	2.03	fertiliser	75	93.75	31.25	6063	3.00		259	5.48	
Minimise dirty water	49.5	1.78	1.75	fertiliser	75	93.75	31.25	6203	0.75		220	1.26	
Composting can reduce volume	46	2.19	2.19	fertiliser	75	93.75	31.25	5875	6.00	9.00	274	0.00	5.48
Collect effluent - manure stores	49.5	2.19	2.03	storage	75	93.75	31.25	6203	0.75		259	5.48	
Site manure heaps away from water	49.5	2.19	2.03	storage	75	93.75	31.25	6203	0.75	0.75	259	5.48	5.48
					Manure Management Plan % reduction:				**Total N**	**9.85**		**Total P**	**10.96**

Table E.5 Calculation of N and P loss under the Soil, Nutrient and Manure Management Plan for Dairy – medium ELS uptake scenario

DAIRY - MEDIUM	Mean N loss	P loss (kg/ha)		Typology	% of land in	Area of land (ha) in		Total loss	% reduction		Total loss	% reduction	
Equivalent mitigation method	(kg/ha)	pre-ELS	post-ELS		ELS	ELS	Non-ELS	kg/N		Max	kg/P		Max
Establish in-field buffers	47	2.71	0.54	runoff	10	12.5	112.5	6213	0.60		312	8.01	
Move gateways	50	2.71	1.89	runoff	5	6.25	118.75	6250	0.00	0.60	334	1.51	8.01
Reduce stocking rates when wet	49.5	2.19	1.91	stock	50	62.5	62.5	6219	0.50		256	6.39	
Reduce length of grazing day	38	2.19	1.91	stock	50	62.5	62.5	5500	12.00		256	6.39	
Move feed & water troughs regularly	49.5	2.19	1.91	stock	50	62.5	62.5	6219	0.50		256	6.39	
Loosen compacted soils grass	50	2.19	1.91	stock	10	62.5	62.5	6250	0.00	12.00	256	6.39	6.39
Fence off river banks etc	49.5	2.19	1.91	fence	10	12.5	112.5	6244	0.10		270	1.28	
Construct bridges	49.5	2.19	1.91	fence	10	12.5	112.5	6244	0.10	0.10	270	1.28	1.28
					Soil Management Plan % reduction:				**Total N**	**12.70**		**Total P**	**15.68**
Fertiliser recommendation system	47	-	-	fertiliser	50	62.5	62.5	6063	3.00				
Integrate fertiliser & manure	42.5	2.19	2.10	fertiliser	50	62.5	62.5	5781	7.50		268	2.05	
Time N	42.5	2.71	2.58	fertiliser	50	62.5	62.5	5781	7.50		331	2.40	
Do not apply P to high index soil	-	2.6	2.51	fertiliser	50	62.5	62.5	-	-	7.50	319	1.73	2.40
Incorporate P	50	3.76	3.73	incorporate	50	62.5	62.5	6250	0.00	0.00	468	0.40	0.40
					Nutrient Management Plan % reduction:				**Total N**	**7.50**		**Total P**	**2.80**
Identify high risk areas	49.5	3.83	3.66	no spread	50	62.5	62.5	6219	0.50	0.50	468	2.22	
Increase capacity slurry stores	46.5	2.19	2.03	fertiliser	50	62.5	62.5	6031	3.50		264	3.65	
Do not apply FYM at high risk times	44	2.19	2.03	fertiliser	50	62.5	62.5	5875	6.00		264	3.65	
Do not apply slurry at high risk times	48	2.19	2.03	fertiliser	50	62.5	62.5	6125	2.00		264	3.65	
Minimise dirty water	49.5	1.78	1.75	fertiliser	50	62.5	62.5	6219	0.50		221	0.84	
Composting can reduce volume	46	2.19	2.19	fertiliser	50	62.5	62.5	6000	4.00	6.00	274	0.00	3.65
Collect effluent - manure stores	49.5	2.19	2.03	storage	50	62.5	62.5	6219	0.50		264	3.65	
Site manure heaps away from water	49.5	2.19	2.03	storage	50	62.5	62.5	6219	0.50	0.50	264	3.65	3.65
					Manure Management Plan % reduction:				**Total N**	**7.00**		**Total P**	**7.30**

Table E.6 Calculation of N and P loss under the Soil, Nutrient and Manure Management Plan for Dairy – low ELS uptake scenario

DAIRY - LOW	Mean N loss	P loss (kg/ha)		Typology	% of land in	Area of land (ha) in		Total loss	% reduction		Total loss	% reduction	
Equivalent mitigation method	(kg/ha)	pre-ELS	post-ELS		ELS	ELS	Non-ELS	kg/N		Max	kg/P		Max
Establish in-field buffers	47	2.71	0.54	runoff	0	0	125	6250	0.00		339	0.00	
Move gateways	50	2.71	1.89	runoff	0	0	125	6250	0.00	0.00	339	0.00	0.00
Reduce stocking rates when wet	49.5	2.19	1.91	stock	25	31.25	93.75	6234	0.25		265	3.20	
Reduce length of grazing day	38	2.19	1.91	stock	25	31.25	93.75	5875	6.00		265	3.20	
Move feed & water troughs regularly	49.5	2.19	1.91	stock	25	31.25	93.75	6234	0.25		265	3.20	
Loosen compacted soils grass	50	2.19	1.91	stock	0	0	125	6250	0.00	6.00	274	0.00	3.20
Fence off river banks etc	49.5	2.19	1.91	fence	0	0	125	6250	0.00		274	0.00	
Construct bridges	49.5	2.19	1.91	fence	0	0	125	6250	0.00	0.00	274	0.00	0.00
					Soil Management Plan % reduction:				**Total N**	**6.00**		**Total P**	**3.20**
Fertiliser recommendation system	47	-	-	fertiliser	25								
Integrate fertiliser & manure	42.5	2.19	2.10	fertiliser	25	31.25	93.75	6016	3.75		271	1.03	
Time N	42.5	2.71	2.58	fertiliser	25	31.25	93.75	6016	3.75		335	1.20	
Do not apply P to high index soil	-	2.6	2.51	fertiliser	25	31.25	93.75	-	-	3.75	322	0.87	1.20
Incorporate P	50	3.76	3.73	incorporate	25	31.25	93.75	6250	0.00	0.00	469	0.20	0.20
					Nutrient Management Plan % reduction:				**Total N**	**3.75**		**Total P**	**1.40**
Identify high risk areas	49.5	3.83	3.66	no spread	0	31.25	93.75	6234	0.25	0.25	473	1.11	
Increase capacity slurry stores	46.5	2.19	2.03	fertiliser	25	31.25	93.75	6141	1.75		269	1.83	
Do not apply FYM at high risk times	44	2.19	2.03	fertiliser	25	31.25	93.75	6063	3.00		269	1.83	
Do not apply slurry at high risk times	48	2.19	2.03	fertiliser	25	31.25	93.75	6188	1.00		269	1.83	
Minimise dirty water	49.5	1.78	1.75	fertiliser	25	31.25	93.75	6234	0.25		222	0.42	
Composting can reduce volume	46	2.19	2.19	fertiliser	25	31.25	93.75	6125	2.00	3.00	274	0.00	1.83
Collect effluent - manure stores	49.5	2.19	2.03	storage	25	31.25	93.75	6234	0.25		269	1.83	
Site manure heaps away from water	49.5	2.19	2.03	storage	25	31.25	93.75	6234	0.25	0.25	269	1.83	1.83
					Manure Management Plan % reduction:				**Total N**	**3.50**		**Total P**	**3.65**

Table E.7 Calculation of N and P loss under the Soil, Nutrient and Manure Management Plan for Beef – high ELS uptake scenario

BEEF - HIGH	Mean N loss (kg/ha)	P loss (kg/ha)		Typology	% of land in ELS	Area of land (ha) in		Total loss	% reduction		Total loss	% reduction	
Equivalent mitigation method		**pre-ELS**	**post-ELS**			**ELS**	**Non-ELS**	**kg/N**		**Max**	**kg/P**		**Max**
Establish in-field buffers	47	2.71	0.54	runoff	25	25	75	1925	3.75		217	20.02	
Move gateways	50	2.71	1.89	runoff	10	10	90	2000	0.00	3.75	263	3.03	20.02
Reduce stocking rates when wet	49.5	2.19	1.91	stock	75	75	25	1963	1.88		198	9.59	
Reduce length of grazing day	38	2.19	1.91	stock	75	75	25	1100	45.00		198	9.59	
Move feed & water troughs regularly	49.5	2.19	1.91	stock	75	75	25	1963	1.88		198	9.59	
Loosen compacted soils grass	50	2.19	1.91	stock	25	25	75	2000	0.00	45.00	212	3.20	9.59
Fence off river banks etc	49.5	2.19	1.91	fence	25	25	75	1988	0.63		212	3.20	
Construct bridges	49.5	2.19	1.91	fence	25	25	75	1988	0.63	0.63	212	3.20	3.20
					Soil Management Plan % reduction:				**Total N**	**49.38**		**Total P**	**32.80**
Fertiliser recommendation system	47	-	-	fertiliser	75	75	25	1850	7.50				
Integrate fertiliser & manure	42.5	2.19	2.10	fertiliser	75	75	25	1850	7.50		212	3.08	
Time N	42.5	2.71	2.58	fertiliser	75	75	25	1438	28.13		261	3.60	
Do not apply P to high index soil	-	2.6	2.51	fertiliser	75	75	25	-	-	28.13	253	2.60	3.60
Incorporate P	50	3.76	3.73	incorporate	75	75	25	2000	0.00	0.00	374	0.60	0.60
					Nutrient Management Plan % reduction:				**Total N**	**28.13**		**Total P**	**4.20**
Identify high risk areas	49.5	3.83	3.66	no spread	75	75	25	1963	1.88	1.88	370	3.33	
Increase capacity slurry stores	46.5	2.19	2.03	fertiliser	75	75	25	1925	3.75		207	5.48	
Do not apply FYM at high risk times	44	2.19	2.03	fertiliser	75	75	25	1550	22.50		207	5.48	
Do not apply slurry at high risk times	48	2.19	2.03	fertiliser	75	75	25	1925	3.75		207	5.48	
Minimise dirty water	49.5	1.78	1.75	fertiliser	75	75	25	1963	1.88		176	1.26	
Composting can reduce volume	46	2.19	2.19	fertiliser	75	75	25	1700	15.00	22.50	219	0.00	5.48
Collect effluent - manure stores	49.5	2.19	2.03	storage	75	75	25	1963	1.88		207	5.48	
Site manure heaps away from water	49.5	2.19	2.03	storage	75	75	25	1963	1.88	1.88	207	5.48	5.48
					Manure Management Plan % reduction:				**Total N**	**26.25**		**Total P**	**10.96**

Table E.8 Calculation of N and P loss under the Soil, Nutrient and Manure Management Plan for Beef – medium ELS uptake scenario

BEEF - MEDIUM	Mean N loss	P loss (kg/ha)		Typology	% of land in ELS	Area of land (ha) in		Total loss	% reduction		Total loss	% reduction	
Equivalent mitigation method	(kg/ha)	pre-ELS	post-ELS			ELS	Non-ELS	kg/N		Max	kg/P		Max
Establish in-field buffers	47	2.71	0.54	runoff	10	10	90	1970	1.50		249.3	8.01	
Move gateways	50	2.71	1.89	runoff	5	5	95	2000	0.00	1.50	266.9	1.51	8.01
Reduce stocking rates when wet	49.5	2.19	1.91	stock	50	50	50	1975	1.25		205	6.39	
Reduce length of grazing day	38	2.19	1.91	stock	50	50	50	1400	30.00		205	6.39	
Move feed & water troughs regularly	49.5	2.19	1.91	stock	50	50	50	1975	1.25		205	6.39	
Loosen compacted soils grass	50	2.19	1.91	stock	10	10	90	2000	0.00	30.00	216.2	1.28	6.39
Fence off river banks etc	49.5	2.19	1.91	fence	10	10	90	1995	0.25		216.2	1.28	
Construct bridges	49.5	2.19	1.91	fence	10	10	90	1995	0.25	0.25	216.2	1.28	1.28
					Soil Management Plan % reduction:				**Total N**	**31.75**		**Total P**	**15.68**
Fertiliser recommendation system	47	-	-	fertiliser	50	50	50	1900	5.00				
Integrate fertiliser & manure	42.5	2.19	2.10	fertiliser	50	50	50	1900	5.00		214.5	2.05	
Time N	42.5	2.71	2.58	fertiliser	50	50	50	1625	18.75		264.5	2.40	
Do not apply P to high index soil	-	2.6	2.51	fertiliser	50	50	50	-	-	18.75	255.5	1.73	2.40
Incorporate P	50	3.76	3.73	incorporate	50	50	50	2000	0.00	0.00	374.5	0.40	0.40
					Nutrient Management Plan % reduction:				**Total N**	**18.75**		**Total P**	**2.80**
Identify high risk areas	49.5	3.83	3.66	no spread	5	50	50	1975	1.25	1.25	374.5	2.22	50
Increase capacity slurry stores	46.5	2.19	2.03	fertiliser	50	50	50	1950	2.50		211	3.65	50
Do not apply FYM at high risk times	44	2.19	2.03	fertiliser	50	50	50	1700	15.00		211	3.65	50
Do not apply slurry at high risk times	48	2.19	2.03	fertiliser	50	50	50	1950	2.50		211	3.65	50
Minimise dirty water	49.5	1.78	1.75	fertiliser	50	50	50	1975	1.25		176.5	0.84	50
Composting can reduce volume	46	2.19	2.19	fertiliser	50	50	50	1800	10.00	15.00	219	0.00	50
Collect effluent - manure stores	49.5	2.19	2.03	storage	50	50	50	1975	1.25		211	3.65	50
Site manure heaps away from water	49.5	2.19	2.03	storage	50	50	50	1975	1.25	1.25	211	3.65	50
					Manure Management Plan % reduction:				**Total N**	**17.50**		**Total P**	**7.30**

Table E.9 Calculation of N and P loss under the Soil, Nutrient and Manure Management Plan for Beef – low ELS uptake scenario

BEEF - LOW	Mean N loss	P loss (kg/ha)		Typology	% of land in	Area of land (ha) in		Total loss	% reduction		Total loss	% reduction	
Equivalent mitigation method	(kg/ha)	pre-ELS	post-ELS		ELS	ELS	Non-ELS	kg/N		Max	kg/P		Max
Establish in-field buffers	47	2.71	0.54	runoff	0	0	100	2000	0.00		271	0.00	
Move gateways	50	2.71	1.89	runoff	0	0	100	2000	0.00	0.00	271	0.00	0.00
Reduce stocking rates when wet	49.5	2.19	1.91	stock	25	25	75	1987.5	0.63		212	3.20	
Reduce length of grazing day	38	2.19	1.91	stock	25	25	75	1700	15.00		212	3.20	
Move feed & water troughs regularly	49.5	2.19	1.91	stock	25	25	75	1987.5	0.63		212	3.20	
Loosen compacted soils grass	50	2.19	1.91	stock	0	0	100	2000	0.00	15.00	219	0.00	3.20
Fence off river banks etc	49.5	2.19	1.91	fence	0	0	100	2000	0.00		219	0.00	
Construct bridges	49.5	2.19	1.91	fence	0	0	100	2000	0.00	0.00	219	0.00	0.00
Soil Management Plan % reduction:									**Total N**	**15.00**		**Total P**	**3.20**
Fertiliser recommendation system	47	-	-	fertiliser	25	25	75	1950	2.50				
Integrate fertiliser & manure	42.5	2.19	2.10	fertiliser	25	25	75	1950	2.50		216.75	1.03	
Time N	42.5	2.71	2.58	fertiliser	25	25	75	1812.5	9.38		267.75	1.20	
Do not apply P to high index soil	-	2.6	2.51	fertiliser	25	25	75			9.38	257.75	0.87	1.20
Incorporate P	50	3.76	3.73	incorporate	25	25	75	2000	0.00	0.00	375.25	0.20	0.20
Nutrient Management Plan % reduction:									**Total N**	**9.38**		**Total P**	**1.40**
Identify high risk areas	49.5	3.83	3.66	no spread	0	25	75	1987.5	0.63	0.63	378.75	1.11	
Increase capacity slurry stores	46.5	2.19	2.03	fertiliser	25	25	75	1975	1.25		215	1.83	
Do not apply FYM at high risk times	44	2.19	2.03	fertiliser	25	25	75	1850	7.50		215	1.83	
Do not apply slurry at high risk times	48	2.19	2.03	fertiliser	25	25	75	1975	1.25		215	1.83	
Minimise dirty water	49.5	1.78	1.75	fertiliser	25	25	75	1987.5	0.63		177.25	0.42	
Composting can reduce volume	46	2.19	2.19	fertiliser	25	25	75	1900	5.00	7.50	219	0.00	1.83
Collect effluent - manure stores	49.5	2.19	2.03	storage	25	25	75	1987.5	0.63		215	1.83	
Site manure heaps away from water	49.5	2.19	2.03	storage	25	25	75	1987.5	0.63	0.63	215	1.83	1.83
Manure Management Plan % reduction:									**Total N**	**8.75**		**Total P**	**3.65**