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GLASTIR MONITORING & EVALUATION PROGRAMME

FINAL REPORT – Annex 5

Glastir Impact Modelling

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Abstract

The Glastir Monitoring and Evaluation Programme (GMEP) led by the Centre for Ecology and Hydrology (CEH) is an integrated programme of whole ecosystem monitoring and modelling for robust analysis of the outcomes of the Welsh Government's Glastir agri-environment scheme (Emmett et al., 2014). This report describes a computer-modelling based approach to assessing the impacts of current uptake of Glastir upon losses of nitrate, phosphorus and sediment from agricultural land, and any associated impacts on the greenhouse gases nitrous oxide and methane. The approach uses an existing model of agricultural pollution (Farmscoper; Gooday et al. 2014), incorporating results from both the Second Welsh Farm Practice Survey (Anthony et al. 2016b) and information from Glastir Scheme agreements to determine changes in farm practices or land management. The net impacts of Glastir, on pollutant losses from all agricultural land (i.e. including land not in Glastir) are calculated to be reductions of up to 1%. Reductions are approximately double on the land managed by farms in Glastir, with greater reductions possible at more localised scales. The major cause of reductions in pollutant losses are reductions in livestock numbers and fertiliser use.

1. Introduction

The Glastir agri-environment scheme was introduced in 2009 and became the single operational agri-environment scheme in Wales from 2013. The scheme objectives reflect the government's environmental objectives and a reframing of support to farmers as payments for ecosystem goods and services, including improving water quality and reducing surface run-off.

Glastir is composed of an Entry level element that is accessible to all farmers in Wales, an upper level Advanced element which spatially targets issues of concern in pre-defined priority areas (addressing soil carbon management, water quality, water quantity, biodiversity, the historic environment, and improved access), a Commons element, the Efficiency capital grant element, an Organic farming element, and a stand-alone Woodland element (Rose, 2011). Farms participating in Glastir are required to adhere to a Whole Farm Code that concerns record keeping and habitat protection, and prohibits some practices such as application of livestock manures when soils are waterlogged. There are currently 4,600 participants in the Entry level scheme, including 1,400 in the Advanced level, managing 35% of the total utilised agricultural area in Wales. Figure 1.1 shows the proportion of agricultural land (not accounting for Commons land) within each Water Framework Directive (WFD) waterbody that is managed by a farm in Glastir Entry and Glastir Advanced. Figure 1.2 (agricultural pollutant losses by WFD waterbody, from Anthony et al., 2012) shows that the areas where Glastir agreements cover the majority of the managed land (e.g. upland areas) do not correlate with areas where losses of nutrients, particularly nitrate, are most intensive (e.g. Pembrokeshire, Anglesey).

The objective of this report is to quantify the impacts of Glastir on agricultural emissions of nitrate, phosphorus and sediment (thereby assessing the impact of the scheme on water quality) and also to determine whether there have been any additional consequences for the greenhouse gases methane and nitrous oxide as a result of Glastir. The report only considers impacts due to the Glastir Entry and Advanced elements.

The assessment of Glastir was achieved using a computer model (Farmscoper; Gooday et al., 2014) which is briefly described in Section 2, incorporating results from both the Second Welsh Farm Practice Survey (Anthony et al. 2016b; see Section 3) and information from Glastir Scheme agreements (see Section 4) to determine changes in farm practices or land management. Such an approach allows for an assessment of long-term outcomes at landscape scale, which would be difficult to measure directly for reasons of scale or cost. A model-based approach also provides the ability to apportion impacts between the many changes in land management associated with a scheme.

The Farmscoper tool was applied at Water Management Catchment (WMC) scale (Figure 1.3) in order to capture some of the spatial variation in scheme entry shown in Figure 1.1 whilst retaining a resolution at which uncertainties in the assessment of scheme implementation, farm management practices and the outputs of pollutant models could be considered commensurate. Note that where a WMC extended from Wales into England, only the Welsh part was considered.

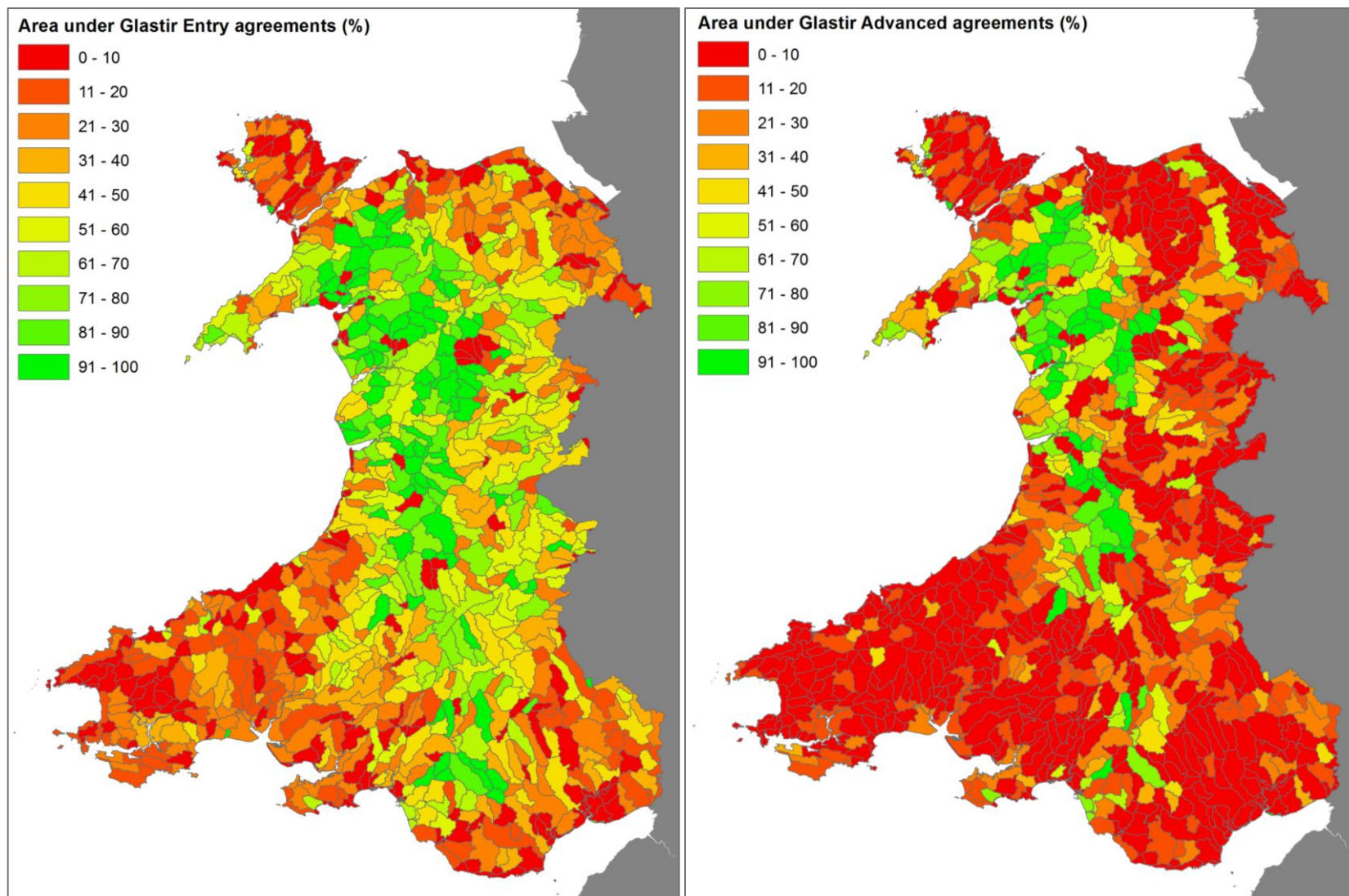


Figure 1.1 Percentage of the farmed area (excluding commons land) within each WFD waterbody that is managed by a farm in Glastir Entry or Advanced

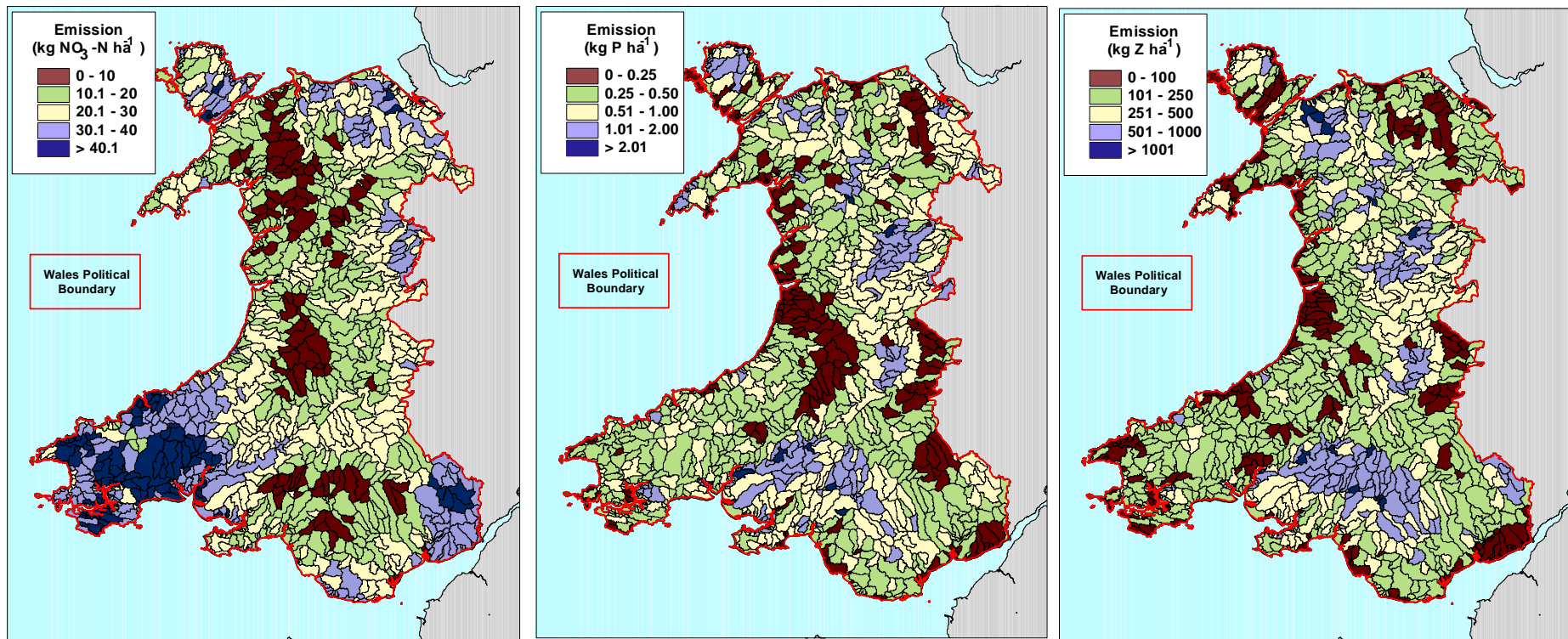


Figure 1.2 Modelled baseline annual average a) nitrate; b) phosphorus; and c) sediment emissions from agricultural land in Wales, based on agricultural census and farm activity data for the year 2004. Baseline emissions include the effects of soil compaction and poaching, but exclude the impact of any mitigation methods or changes in livestock numbers and fertiliser use due to participation in the Wales agri-environment schemes. The pollutant loads are averaged over the total agricultural land area including common land. From Anthony et al., 2012.

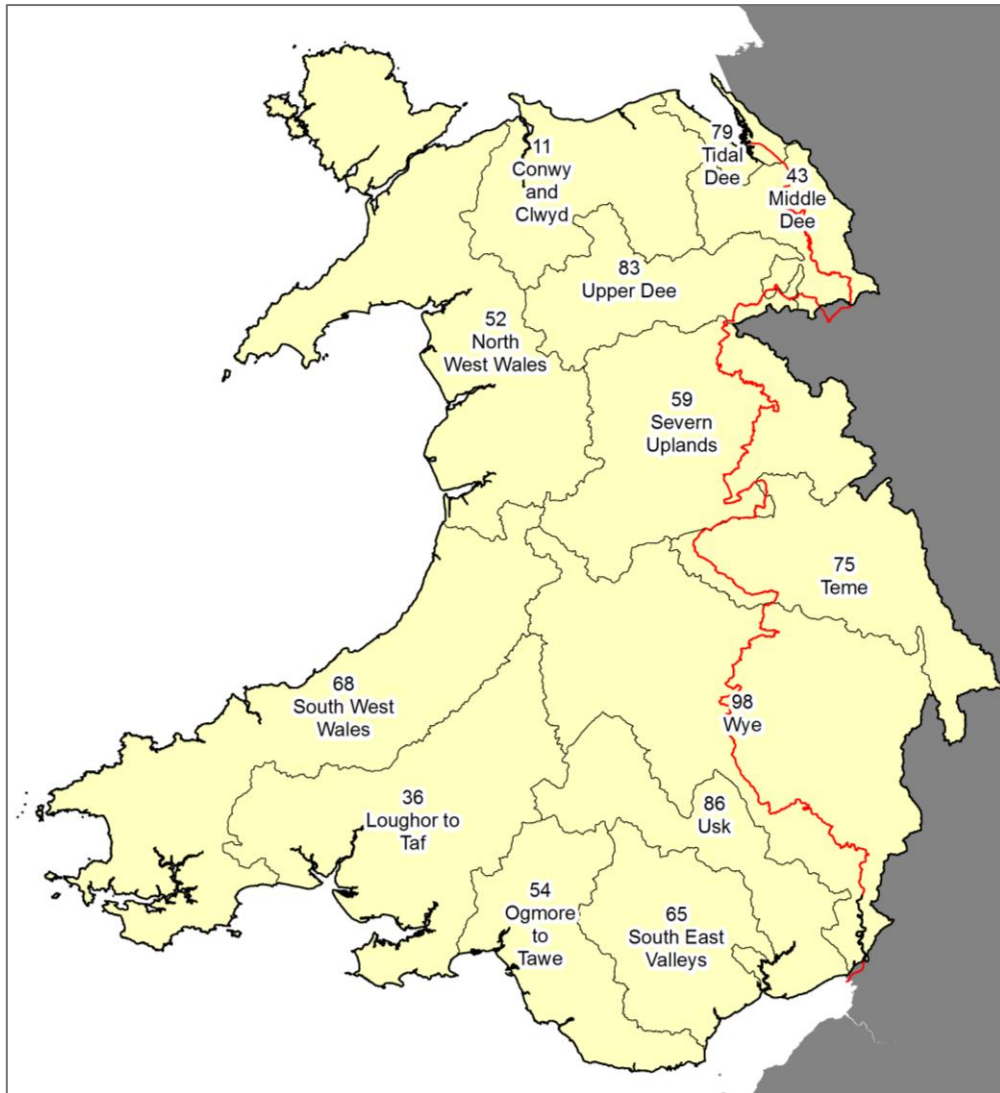


Figure 1.3 Water Management Catchments that are wholly or partially within Wales

2. Modelling Approach

This work has used the Farmscoper model (Gooday et al, 2014) to determine the agricultural pollution loads across Wales in the absence of Glastir and the impacts of Glastir on these loads.

Farmscoper was initially developed as a farm-scale decision support tool able to predict the emissions of multiple pollutants, to quantify the effect of implementation of one or more mitigation measures on those pollutant emissions and to estimate the cost of measure implementation. Pollutant losses within Farmscoper are based on a complex set of export coefficients derived from more process-based models that have been used for policy support in the UK (e.g. PSYCHIC, Davison et al., 2008; NEAPN, Lord and Anthony 2000; NitCat, Lord 1991; IPCC, Baggott et al., 2006). Farmscoper contains a library of over 100 mitigation methods, based around those in the Mitigation Method User Guide (Newell-Price et al, 2011) and certain Environmental Stewardship options. The most recent version of Farmscoper (v3; Gooday et al, 2015), allows for a catchment scale assessment of pollution losses and mitigation impacts through the automated creation of multiple farms representative of the farming within a catchment.

Farmscoper recognises three different soil types, which are designed to reflect the different dominant flow pathways, i.e. free draining soils, where nearly all water travels vertically through the soil profile, and impermeable soils, where artificial drainage leads to substantial lateral flow through drains. The modelling used to calculate the pollutant loss coefficients in Farmscoper was done nationally at 1 km², and the results summarised by the three soil types and six climate zones in Farmscoper. Thus the results for a particular climate and soil type reflect all land in England and Wales that has that particular climate and soil. The pollutant loss coefficients are then multiplied by local data on fertiliser use, stock numbers and crop areas to produce pollutant loads. This approach has been shown to allow Farmscoper to reproduce catchment pollutant loads that are comparable to the source input models used in the initial construction of Farmscoper (Gooday et al, 2015) and to produce totals comparable to long term monitoring data (Collins et al., 2016).

2.1. Input data

The catchment-scale version of Farmscoper requires knowledge of the number of livestock and area of cropping within a catchment for a range of different categories. The input data for each WMC in Wales was obtained through analysis of the holding level data for all farms in Wales from the 2014 June Agricultural Survey (JAS), using the reporting address of each holding to locate it within a WMC. Farmscoper also requires the count of the different farm types within the catchment by the soil and climate zones recognised, which were also derived from the holding level census data. Farmscoper uses the Robust Farm Types used for government reporting (Defra, 2010):

- Cereals
- General Cropping
- Horticulture
- Specialist Pig
- Specialist Poultry
- Dairy
- Cattle and Sheep – Lowland
- Cattle and Sheep – Less Favoured Area (LFA)
- Mixed Livestock

Farmscoper uses assumptions on typical farm management and stocking density constraints to apportion the livestock and cropping between the different farms. It also requires the fertiliser rates to be specified by crop type for each farm type, along with the proportion of each livestock type managed on solid manure or slurry systems and a preference table for which crops receive which manure type. The fertiliser rates in Farmscoper used for this project were taken from the British Survey of Fertiliser Practice for 2015 (BSFP), using the values for Great Britain as they provided the farm type differentiation. The Welsh Farm Practice Survey (see Section 3) was used to determine livestock management.

The majority of the other assumptions on farm management that are used to model pollutant losses are set by default within Farmscoper, as they are contained within the existing database of modelled loss coefficients (derived from previous model runs for England and Wales). These other assumptions include timing of fertiliser and manure applications, duration of grazing and soil phosphorus status. They are based upon national survey data (such as the BSFP and Defra Farm Practice Surveys) and are therefore representative of the average management across a catchment rather than the management on any one particular farm.

The majority of pig and poultry holdings are relatively small in terms of the land area farmed and they export the majority of the manure they produce to neighbouring farms. However, rather than attempt to calculate this export of manure, the catchment version of Farmscoper effectively imports land from other farm types within the catchment until it has sufficient land to spread all of the manure it produces at an appropriate rate. Thus the results for the pig and poultry farms produced by

Farmscoper are the effective results for the pig and poultry farm itself and the land that receives the manure by that farm, although that land may actually be managed by a neighbouring farm.

Farmscoper also requires an estimate of the current level of implementation of each mitigation method within its method library, which ensures that any scenario-based assessment of alternative farm practice has an appropriate baseline. As part of the creation of v3 of Farmscoper (Gooday et al, 2015), these implementation rates were revised based upon the best available survey data for England and Wales. Section 3.1 of this report describes how Welsh specific data was used to verify and revise these current implementation rates.

The impacts of Glastir were represented by determining increases in the implementation rates of the mitigation methods within the Farmscoper method library and by manipulation of the input JAS data and fertiliser usage data, as described in the next two Sections.

3. Survey Analysis

A Survey investigating the changes in farm practices attributable to participation in the Glastir and preceding Tir Cynnal and Tir Gofal agri-environment schemes (Anthony et al., 2016a) was commissioned by the Welsh Government as part of the Glastir Monitoring and Evaluation Programme.

All farms surveyed were active businesses and were claiming under the Single Payment Scheme. Stratification for analysis was by Robust Farm Type and level of participation in the Glastir, Tir Cynnal and Tir Gofal agri-environment schemes. Stratification for inclusion in the survey also considered farm size and agricultural region. In total 601 farms were surveyed. Of the 280 farms in Glastir that were surveyed, 125 were in Glastir Advanced and 155 were in Glastir Entry. Of the Glastir farms surveyed, 18% were dairy farms, 45% were cattle and sheep in Severely Disadvantaged Areas (SDA) and 37% were either lowland cattle and sheep or cattle and sheep in Disadvantaged Areas (DA).

The survey was structured by areas of farm management (fertiliser, soil, manure and livestock), supported by introductory segments to collect background information on current scheme participation (to validate the targeting of the survey), and on land use and soils (to better interpret the management information).

The results of the survey are reported in detail in Anthony et al., 2016b and Stopps et al., 2017.

The survey allows for the implementation rates of a number of Farmscoper mitigation methods on non-Glastir farms to be determined, allowing the creation of a baseline which more accurately reflects current practice, including any legacy impacts of the preceding Tir Cynnal and Tir Gofal schemes (see Section 3.1). The impacts of Glastir can then be assessed relative to this baseline. The survey also allows for an assessment of any impact of Glastir on these same mitigation methods (see Section 3.2). Some of these mitigation methods covered by the survey are directly influenced by Glastir scheme options (e.g. use of buffer strips), whilst some represent methods that farmers are encouraged to do as part of the Glastir Whole Farm Code. Finally, the survey also provided data on changes in livestock numbers and fertiliser use attributed to Glastir (see Section 3.3), which could be used to determine the impacts of a large number of Glastir options that place restrictions on field stocking densities and fertiliser use.

The combined representation of the changes in farm practice associated with Glastir derived through the survey (Sections 3.2 and 3.3) and through analysis of scheme option data (see Section 4) are discussed in Section 4.3.

3.1. Current farm practice (pre-Glastir)

A number of the survey questions could be used to verify or revise the assumptions on current mitigation method implementation in Farmscoper, which forms the baseline from which the impacts

of Glastir are assessed. For each of these methods, the survey results for the percentage of farmers implementing the method (stratified by farm type and history of scheme participation) were compared with the table used to score baseline implementation in Farmscoper (Table 3.1), which uses an average value from an associated range to account for the uncertainty in the scoring. The results of this analysis are shown in Table 3.2. There were several changes to the default assumptions in Farmscoper, which had been derived from analysis of available survey data for England and Wales (Gooday et al., 2015), with the notable changes being for ‘Loosen compacted soil layers in grassland fields’ (increase from C to F), ‘Reduce the length of the grazing day/grazing season’ (increase from C to E) and ‘Site solid manure heaps away from watercourses/field drains’ (decrease from F to D).

The survey determined the proportion of respondents implementing an action, not the proportion of their farm land on which it was implemented. Thus for some methods, the survey answer provides an upper estimate of implementation, as it is unlikely the method would be implemented on all potential applicable land (e.g. riparian buffers).

Note that the survey asked farmers about testing fields for pH and liming, which aligns with the Farmscoper method “Monitor and amend soil pH status for grassland”. The results of the Welsh Farm Practice Survey were comparable to those of the Defra Farm Practice Survey (2012; 70% of farms tested the pH of soil at least every five years, and 22% of farms more than every three years), which is assumed to be captured as part of the baseline model predictions. This survey question / Farmscoper method was thus not included in Table 3.2.

Table 3.1 Ranges and average values used in for scoring the baseline implementation of Farmscoper mitigation methods. Scoring is based upon the range in which an answer lies, but it is the average value used in the modelling work.

Score	Average Value	Range
A	0	-
B	2	0 - 10
C	10	2 - 25
D	25	10 - 50
E	50	25 - 80
F	80	50 - 100
G	100	-

Table 3.2 Farmscoper mitigation methods with corresponding original and revised baseline implementation rates (using the scale from Table 3.1) and modifiers to those rates on grazing livestock farms, plus the survey results (Anthony et al., 2016b) from which the revised values are derived.

Farmscoper Method		Original Value	Revised Wales Value	Intensive Grazing	Extensive Grazing	Survey Table	Scheme History	DAIRY	CS-DA+ CS-LOW	CS-SDA
4	Establish cover crops in the autumn	C*	C*†			8.12	None TC or TG	33 38	52 36	20 17
5	Early harvesting and establishment of crops in the autumn	E	E			8.10	None TC or TG	27 31	24 46	10 0
6	Cultivate land for crops in spring rather than autumn	F*	F*			8.18	None TC or TG	73 63	57 73	20 67
7	Adopt reduced cultivation systems	C**	C**		+1	8.14	None TC or TG	13 44	33 46	50 83
8	Cultivate compacted tillage soils	D	D			8.15	None TC or TG	40 31	38 27	30 17
9	Cultivate and drill across the slope	D*	D*			8.20	None TC or TG	20 31	24 55	0 33
10	Leave autumn seedbeds rough	D	D		-1	8.19	None TC or TG	33 19	19 27	0 17
13	Establish in-field grass buffer strips	B	C†		-1	8.21	None TC or TG	33 25	10 18	0 0
14	Establish riparian buffer strips	D	C†		-1	8.21	None TC or TG	33 25	10 18	0 0
15	Loosen compacted soil layers in grassland fields	C	F		-1	8.30	None TC or TG	81 74	53 61	32 61
21	Fertiliser spreader calibration	E	F		-1	6.9	None TC or TG	74 68	40 47	38 42
22	Use a fertiliser recommendation system	F	E			6.11	None TC or TG	59 58	34 36	31 58
26	Avoid spreading manufactured fertiliser to fields at high-risk times	A	A			6.13	None TC or TG	65 71	77 67	50 58
35	Reduce the length of the grazing day/grazing season	C	E			8.28	None TC or TG	56 36	53 40	32 26
37	Reduce field stocking rates when soils are wet	E	E			8.27	None TC or TG	69 65	64 51	59 66

Farmscoper Method		Original Value	Revised Wales Value	Intensive Grazing	Extensive Grazing	Survey Table	Scheme History	DAIRY	CS-DA+ CS-LOW	CS-SDA
38	Move feeders at regular intervals	E	E			8.33	None TC or TG	56 45	60 54	59 74
52	Increase the capacity of farm slurry stores to improve timing of slurry applications	A	C		-2	7.9	None TC or TG	20 23	5 2	0 2
570	Minimise the volume of dirty water produced	D	E		-1	7.13	None TC or TG	63 57	31 26	30 29
60	Site solid manure heaps away from watercourses/field drains	F*	D*			7.16	None TC or TG	49 29	27 26	26 31
62	Cover solid manure stores with sheeting	B	C			7.15	None TC or TG	7 6	3 9	9 9
67	Manure Spreader Calibration	D	D		-1	7.17	None TC or TG	34 20	20 15	7 16
69	Do not spread slurry or poultry manure at high-risk times	A	A			7.18	None TC or TG	39 69	32 30	28 38
72	Do not spread FYM to fields at high-risk times	A	A			7.18	None TC or TG	39 69	32 30	28 38
76	Fence off rivers and streams from livestock	E	E [†]		-1	8.31	None TC or TG	58 52	38 35	12 42
115	Leave over winter stubbles	F	F*		-1	8.11	None TC or TG	67 44	52 46	10 17

* Values are lower on drained soils

** Values are higher on drained soils

[†] The survey determined the proportion of respondents implementing an action, not the proportion of their farm land on which it was implemented. For these methods, it was felt that the method would not be implemented on all potential land and so the implementation rate was left as per the default Farmscoper rate.

3.2. Scheme impacts

For each question in the survey, the effects of key variables (e.g. farm type, scheme participation) on survey responses were modelled. The marginal effect due to being in Glastir was identified for each Farmscoper mitigation method where applicable (Table 3.3). No effect of farm type on top of the marginal effect of Glastir was found for any method. As described in the previous Section, the survey determined the proportion of respondents implementing an action, not the proportion of their farm land on which it was implemented. Thus for some methods, the survey answer provides an upper estimate of implementation, as it is unlikely the method would be implemented on all potential applicable land (e.g. riparian buffers).

Some of these mitigation methods are directly influenced by Glastir scheme options (e.g. use of buffer strips), and so the increase in implementation rate calculated from the survey overlaps with the implementation rate calculated from the scheme option data (see Section 4.1). Where this is the case, only the rate derived from the option data is used.

Table 3.3 Farmscoper mitigation methods and the increase in implementation above the baseline rate due to Glastir, as determined by the Welsh Farm Practice Survey (note that all methods that could be linked to the survey are included in the table, as per Table 3.2, but Glastir was not found to have an impact for all methods). Methods that directly relate to Glastir Scheme options are identified - for these methods, it is the rate derived from the option data that is used in the modelling.

Farmscoper Method		Rate Increase (%)	Related to Glastir Option
4	Establish cover crops in the autumn	0.0 [†]	Y
5	Early harvesting and establishment of crops in the autumn	0.0	-
6	Cultivate land for crops in spring rather than autumn	0.0	-
7	Adopt reduced cultivation systems	0.0	-
8	Cultivate compacted tillage soils	0.0	-
9	Cultivate and drill across the slope	0.0	-
10	Leave autumn seedbeds rough	0.0	-
13	Establish in-field grass buffer strips	25.7 [†]	Y
14	Establish riparian buffer strips	25.7 [†]	Y
15	Loosen compacted soil layers in grassland fields	0.0	-
21	Fertiliser spreader calibration	12.9	-
22	Use a fertiliser recommendation system	0.0	-
26	Avoid spreading manufactured fertiliser to fields at high-risk times	13.3	-
35	Reduce the length of the grazing day/grazing season	0.0	-
37	Reduce field stocking rates when soils are wet	0.0	-
38	Move feeders at regular intervals	16.2	-
52	Increase capacity of farm slurry stores to improve timing of slurry applications	6.8	-
570	Minimise the volume of dirty water produced	0.0	-
60	Site solid manure heaps away from watercourses/field drains	0.0	-
62	Cover solid manure stores with sheeting	7.3	-
67	Manure Spreader Calibration	8.0	-
69	Do not spread slurry or poultry manure at high-risk times	0.0	-
72	Do not spread FYM to fields at high-risk times	0.0	-
76	Fence off rivers and streams from livestock	29.4 [†]	Y
115	Leave over winter stubbles	25.4	Y

[†] The survey determined the proportion of respondents implementing an action, not the proportion of their farm land on which it was implemented. For these methods, the survey is likely to be an over-estimate of implementation. However, scheme option data - which does not have the same problem - was available for each of these methods (see Section 4.1).

3.3. Changes in fertiliser use and livestock numbers

A number of Glastir options place restrictions on stocking rates or fertiliser rates on improved land (e.g. Option 15: Grazed permanent pasture with low inputs) or habitat land (e.g. Option 41 grazing management of open country). The survey asked respondents in Glastir to report any change in stock numbers or fertiliser use that was a result of the current scheme agreement. Any change reported should capture the overall impacts of the various Glastir options, but also any change which may not necessarily be a direct result of a scheme option, and could be a result of a change in farm business strategy that took account of the management requirements and income generated by scheme participation.

The changes in fertiliser rate to grassland and livestock numbers from the survey were used irrespective of the level of significance.

For those farms participating in the Glastir Scheme there was a statistically significant net decrease in the use of manufactured phosphate fertilisers on grassland fields and the use of manufactured nitrogen fertilisers on grassland fields (Table 3.4). There was a net decrease of 13.7% in the use of manufactured phosphate fertilisers on grassland fields for dairy farms and 12.2% in the use of manufactured phosphate fertilisers on grassland fields for Cattle and Sheep (DA and Lowland).

Table 3.4 Net reduction (%) in fertiliser rate attributed to Glastir (Anthony et al., 2016b)

Reductions in fertiliser (%) due to Glastir		Dairy	Cattle & Sheep (DA & Lowland)	Cattle & Sheep (SDA)
Grassland	N	8.8	12.2	4.5
	P	13.7	9.4	6.5

For farms participating in the Glastir Scheme, Table 3.5 shows a statistically significant 3.9% net decrease in breeding ewe numbers, and smaller statistically insignificant changes in the numbers of beef sucklers, beef finishers or dairy cows (with the changes for finishers and dairy animals being small increases in stock numbers).

Table 3.5 Net reduction (%) in livestock numbers attributed to Glastir (Anthony et al., 2016b)

Sheep	Beef Suckler	Beef Finisher	Dairy
3.9	1.7	+1.5	+0.8

There are no Glastir options for arable land with explicit restrictions on fertiliser rates, although a number of options require land to be taken out of production (e.g. buffer strips) and so should reduce overall fertiliser usage - the implementation of such options is described in Section 4.1. Therefore, although the survey found reductions in fertiliser use on arable land which respondents attributed to Glastir (a statistically significant 7.3% decrease in the use of phosphate fertilisers on arable fields and an insignificant 2.7% decrease in the use of nitrogen fertilisers), these changes were not included within the modelling.

4. Scheme Option Data

The Glastir dataset provided for this work (from agreements up to September 2015) contained approximately 66,000 instances of Glastir Entry options being implemented, from a total of 63 different Glastir options and 36,000 instances of Glastir Advanced options being implemented, from a total of 152 different Glastir Advanced options. The options were separated in to those which relate to Farmscoper mitigation methods and the level of uptake would result in an impact on pollutant losses at the scale modelled in this project (see Section 4.1), those that require field or farm level changes to livestock numbers and/or fertiliser use (see Section 4.2) and other options which were excluded from further analysis (see paragraph below). Table 4.1 shows that the majority of options (60% for Glastir Entry, 73% for Glastir Advanced) involve field-level restrictions on fertiliser or livestock numbers (e.g. Option 15 Grazed permanent pasture with no inputs; Option 41a Grazing management of open country), whilst only a small proportion were found to be comparable to Farmscoper mitigation methods (and have high levels of uptake).

The remaining 30% of Glastir options classified as 'Other' in Table 4.1 can be classified as: i) not relevant to the control of diffuse pollution; ii) have very limited or uncertain impact on diffuse pollution or iii) a potentially significant impact but very low uptake. Table 4.2 shows that almost half of these 'Other' options involve management of restoration of existing hedgerows – as these hedgerows already exist, there will be no significant areas of additional land taken out of production and no further disruption of the landscape and thus reduction in connectivity for surface pollutant transport. There were just over 800 occurrences of options requiring management of arable land or grassland that may have had an impact on diffuse pollution, but where uptake was so small (under 0.2% of fields) and/or impact per occurrence is so small that they would have no impact in an analysis at the scale undertaken in this report – these options may be locally significant, particularly if clustered within a small area. These include: GA Option 156 (Buffer to prevent erosion to ditches; 333 occurrences); GA option 159 (Grass with no inputs 15 Oct – 31 Jan; 289 occurrences) and GA Option 153 (Red Clover; 48 occurrences).

Table 4.1 Number of different Glastir options in the different categories used for representation within the modelling, and the count of the occurrences of each option. Note that the same option may be included in both Glastir Entry and Glastir Advanced.

Categorised Glastir Option	Glastir Entry		Glastir Advanced	
	No. of different options	Occurrences of options	No. of different options	Occurrences of options
Comparable to Farmscoper mitigation method	17	3,386	9	985
Explicit restriction on fertiliser rates	4	28,118	4	8,707
Land use change / livestock restrictions	15	11,877	50	17,372
Other	26	22,609	89	8,843
Total	62	65,990	152	35,907

Table 4.2 Count of occurrences for different Glastir options, by category, for those Glastir options excluded from further analysis for impacts on diffuse pollution.

Categorised Glastir Option	Glastir Entry	Glastir Advanced
Management of hedgerows	12,122	350
Management of existing streamside corridors	3,178	0
Reduced pesticide usage	2,695	379
Restoration of hedgerows	2,032	0
Management of planting of trees & orchards	1,328	1,254
Management or creation of buildings, pathways etc.	598	1,019
Management of bracken, scrub, heather	411	3,306
Creation of new ponds	232	433
Management of grass for specific wildlife species	0	354
Management of livestock	0	948
Management of arable / grassland	13	800
Total	22,609	8,843

4.1. Glastir options that relate to Farmscoper mitigation methods

Farmscoper contains a library of over 100 mitigation methods, primarily taken from the Mitigation Method User Guide (Newell-Price et al., 2011). The options within Glastir were assessed to see if they were comparable to the Farmscoper methods, with 11 different methods identified that matched 23 different Glastir options (Table 4.3). A number of other options matched to Farmscoper methods, but the number of occurrences were so small that calculated implementation rates would be negligible and they were thus excluded from analysis (as per Table 4.1).

Table 4.3 Mitigation methods from the Farmscoper method library, and the Glastir options that were deemed to be comparable

Farmscoper Method	Glastir Options
4 Establish cover crops in the autumn	33
13 Establish in-field grass buffer strips	158, 174, 1, 1b
14 Establish riparian buffer strips	7a, 7b, 9a, 9b
76 Fence off rivers and streams from livestock	173
79 Farm track management	526, 527, 528
102 Management of woodland edges	24
107 Beetle banks	2, 3, 2b
108 Uncropped cultivated margins	26, 27, 26b
113 Undersown spring cereals	29
114 Management of grassland field corners	23
115 Leave over winter stubbles	28

For each of these Farmscoper methods, the total area or length (as appropriate for each method) from the Glastir option data was totalled by WMC and farm type, using the farm type and holding location from the Welsh JAS. These totals were then scaled to account for the proportion of a field that a method occupied and then divided by the total area of relevant land (of scheme farms, by farm type within a WMC) to determine the percentage implementation rate of each method.

The calculations assumed average arable and grassland field sizes of 3.6 ha and 2.5 ha respectively, based upon an analysis of the LPIS field parcel data for Wales. Assuming square fields, this gives average field lengths of 190 m and 160 m for arable and grass fields. For method 13 (in-field buffer

strips) the average width of the Glastir options as calculated from the provided agreement data was 2.5 m – the total area of options associated with method 13 was thus divided by 2.5 to determine the length of buffer and multiplied by the average arable field length to give a total field area affected by method 13, this total was then divided by the total arable area to produce a percentage implementation. For method 4 (establish cover crops), the option data recorded the total field area, but the method is only relevant to spring sown crops, so the total area of the method was divided by the area of appropriate spring sown crops to determine the implementation rate. Similar calculations were performed for the other methods as required. The resulting implementation rates, aggregated by WMC and for all Wales, are shown in Table 4.4 and Table 4.5 for Glastir Entry and Glastir Advanced respectively. Note that nearly all farms in Glastir Advanced were also in Glastir Entry, so farms in Glastir Advanced would be doing the sum of both Table 4.4 and Table 4.5. Average national implementation rates for nearly all methods are below 10%, sometimes as low as 1%. The highest implementation rates are for method 13 (in-field buffers), which represents a number of different Glastir options about non-riparian buffers. Implementation rates in certain catchments are over 20% - for example, in catchment 54, method 108 (uncropped cultivated margins) has an implementation rate of almost 50%. This is because there were 15 ha of margin in only 1300 ha of arable land. With an average margin width of about 4.5 m, a margin on one side of a field occupies 0.09 ha, for a total of 175 margins out of a total of 360 fields (assuming an average field size of 3.6 ha). A single field may have an uncultivated margin along more than one edge, so this estimate of implementation will overestimate any impacts of the margin in terms of intercepting runoff (and takes no account of whether the margin is on the top or bottom of the slope), but will still correctly account for the impacts of taking land out of production.

Table 3.3 shows that 26% of farmers surveyed claimed to have used in-field buffers (inc. grass margins) or riparian buffers to reduce diffuse pollution, whilst Table 4.4 and Table 4.5 based upon the Glastir scheme option data show a much smaller figure for implementation on the appropriate land (only 1.3% for riparian buffer strips, but a total of 18% for buffers). This difference highlights how a farmer implementing a mitigation method may not do so on all the appropriate land on his farm. Thus, where implementation rates derived from both scheme option data and survey data are available, those from the scheme option data are used.

Table 4.4 The percentage implementation, on scheme farms, of Farmscoper methods due to Glastir Entry, summarised nationally and by catchment

			Water Management Catchment												
Farmscoper Method		Total	11	36	43	52	54	59	65	68	75	79	83	86	98
4	Establish cover crops in the autumn	1.6	3.6	0.7	0.7	3.3	1.2	0.8	0.0	1.9	0.0	0.0	6.5	1.0	0.7
13	Establish in-field grass buffer strips	6.4	2.1	10.2	2.7	17.1	5.5	8.3	9.9	3.9	5.1	0.0	13.9	5.7	4.7
14	Establish riparian buffer strips	1.3	1.8	1.2	3.0	1.0	2.2	1.3	0.4	1.0	3.7	0.0	1.2	1.8	1.5
76	Fence off rivers and streams from livestock	1.3	1.8	1.2	3.0	1.0	2.2	1.3	0.4	1.0	3.7	0.0	1.2	1.8	1.5
102	Management of woodland edges	0.6	0.2	0.8	0.0	0.0	0.7	0.6	1.7	1.3	0.0	0.0	0.0	1.6	0.5
107	Beetle banks	4.5	5.7	5.3	4.4	8.6	6.2	3.9	9.9	2.7	0.0	4.5	10.7	3.0	3.1
108	Uncropped cultivated margins	7.6	0.2	0.9	10.2	1.7	49.1	1.2	27.9	1.3	0.0	0.0	6.7	13.0	7.8
113	Undersown spring cereals	0.6	0.5	2.7	0.0	0.2	0.0	1.6	2.1	0.3	0.0	0.0	0.6	1.0	0.0
114	Management of grassland field corners	2.6	2.6	9.1	1.5	2.2	1.1	4.6	2.7	1.7	0.0	2.9	6.4	2.1	1.0
115	Leave over winter stubbles	7.6	1.8	4.0	4.3	3.6	15.1	2.9	7.9	12.4	4.6	0.0	14.1	11.6	8.2

Table 4.5 The percentage implementation, on scheme farms, of Farmscoper methods due to Glastir Advanced, summarised nationally and by catchment

			Water Management Catchment												
Farmscoper Method		Total	11	36	43	52	54	59	65	68	75	79	83	86	98
4	Establish cover crops in the autumn	1.3	2.2	2.0	0.0	1.9	1.3	0.0	15.3	0.3	0.0	0.0	3.3	3.0	0.5
13	Establish in-field grass buffer strips	11.7	0.0	29.3	1.0	21.6	0.0	5.5	0.0	10.0	0.0	0.0	0.0	8.6	22.0
76	Fence off rivers and streams from livestock	2.8	2.8	4.6	3.2	2.5	0.2	2.2	0.1	3.9	0.0	0.0	1.2	4.5	3.9
79	Farm track management	0.1	0.0	0.2	0.0	0.1	0.2	0.0	0.1	0.3	0.0	0.0	0.1	0.1	0.2
108	Uncropped cultivated margins	1.9	0.4	0.9	0.0	0.3	7.5	0.0	29.2	1.3	0.0	0.0	0.0	6.0	0.6
115	Leave over winter stubbles	2.2	0.0	0.0	0.0	0.0	9.4	0.0	0.0	4.3	0.0	0.0	0.0	5.2	1.7

For each Glastir Entry and Glastir Advanced option mapped to Farmscoper mitigation methods, the number of farms taking up the Farmscoper method and the average occurrences of that Farmscoper method on the farm have been calculated (Table 4.6). The method associated with Glastir Entry that was implemented on the most farms was method 14 (Riparian buffers strips; 363 farms implementing the method). The most frequent occurrence of a mitigation method associated with Glastir Entry is 108 (Uncropped cultivated margin) with an average of 10.5 occurrences on each farm selecting the method (note that this mitigation method is linked to three Glastir options; Table 4.3). The method associated with Glastir Advanced that was implemented on the most farms was method 76 (Fencing off watercourses from livestock; 227 farms implementing the method). The most frequent occurrence of a method associated with Glastir Advanced is 115 (Retain over winter stubbles) with 3.43 occurrences for each farm selecting the method.

Table 4.6 helps explain the low implementation rates shown in Table 4.5. The scheme data provided were for the 4,600 farms in Glastir Entry and 1,900 in Glastir Advanced. The identified methods were always implemented on less than 10% of farms, and even allowing for multiple occurrences on a farm, probably would not be implemented on all appropriate land on each farm.

Table 4.6 Uptake of Farmscoper methods that map to Glastir Entry and Glastir Advanced options.

Farmscoper Method	Glastir Entry		Glastir Advanced	
	Number of farms implementing method	Occurrences of method per farm	Number of farms implementing method	Occurrences of method per farm
4	106	2.23	33	1.55
13	287	1.94	20	3.40
14	363	2.28	-	-
76	-	-	227	2.98
79	-	-	47	1.55
102	20	1.45	-	-
107	235	1.92	-	-
108	24	10.54	11	2.55
113	20	1.60	-	-
114	196	1.99	-	-
115	93	2.03	7	3.43

4.2. Glastir options that restrict livestock numbers or fertiliser use, or that require land use change

As shown in Table 4.1, there are four options with explicit restrictions on fertiliser rates, and a large number of Glastir options which also restrict fertiliser use or livestock numbers, which could have a significant impact on diffuse pollution.

The Farm Practice Survey identified changes in fertiliser use and livestock numbers that were attributed to Glastir (Table 3.4 and Table 3.5), but it is also possible to estimate the impacts of the scheme options on livestock and fertiliser use using the scheme agreement data and the option prescriptions and then compare these with the results of the survey.

Glastir options 15a and 15c (Grazed Permanent Pasture with No Inputs) require that no nitrogen fertiliser is applied, whilst options 15b and 15d (Grazed Permanent Pasture with Low Inputs) restrict applications to 50 kg ha⁻¹ per year. Table 4.7 shows the areas under these options, stratified by farm type, with a total area of 94,000 hectares across Wales, which is approximately a quarter of the area of permanent pasture found on scheme farms.

The potential impacts of these four options can be found by integrating the areas impacted with data on fertiliser use by farm type for Great Britain taken from the British Survey of Fertiliser Practice (Table 4.8), with scheme data grouped by dairy farms, cattle and sheep (both LFA and lowland) and all other farms. This table shows that on dairy farms, 15% of pasture does not receive any nitrogen fertiliser, whilst for non-dairy farms, 40% to 50% of pasture receives no nitrogen fertiliser. For these non-dairy farms (which have the majority of land under Option 15), the percentage of permanent pasture not receiving any nitrogen fertiliser is greater than the c. 20% of pasture under Option 15, so theoretically there may be no impact of these options (although farmers applying for Glastir Advanced have to agree their options with an advisor associated with Glastir, so this is less likely on those farms). A maximum impact can be found by reducing the nitrogen fertiliser rate to the option requirement (50 or 0 kg N ha⁻¹) assuming all fields under Option 15 were originally receiving fertiliser. This works out as an overall 5% reduction in nitrogen fertiliser to permanent pasture on dairy farms and a 25% reduction on non-dairy farms. A more conservative answer may be found by reducing from the average rate across all permanent pasture (including fields receiving and not receiving fertiliser), which results in an overall 5% reduction for dairy farms and an c. 10% reduction for non-dairy farms. These reductions are comparable to those derived from the Farm Practice Survey of 9% for dairy farms and 12% and 5% for non-dairy farms (Table 3.4). Only the survey values were used in the final modelling, as they account for all changes in livestock numbers from all the different options, including those other than 15a-15d.

Analysis of changes in fertiliser rate on grassland productivity using the N-Cycle model (Scholefield et al., 1991) suggest that reductions in fertiliser use of 5-10% reduce dry matter production – and thus the amount of livestock that can be supported – by 2-5%. Such a reduction in livestock numbers associated with the changes in fertiliser use is comparable to the 4% reduction in sheep numbers found in the Farm Practice Survey (Table 3.5) but greater than changes in other grazing livestock.

Table 4.7 Areas under Glastir options 15a, 15b, 15c and 15d, which restrict the rate of nitrogen fertiliser on improved grassland fields.

	Option	Area (ha)			
		Dairy	Cattle & Sheep	Other	Total
Glastir Entry	15a	1,040	28,880	1,110	33,790
	15b	1,090	27,150	850	32,090
	15c	110	3,600	90	4,090
	15d	270	6,200	150	6,930
Glastir Advanced	15a	220	9,010	270	10,400
	15b	190	5,370	100	5,870
	15c	0	520	10	550
	15d	110	940	0	1,080
Total option area in Glastir		3,030	81,660	2,570	94,800
Total permanent pasture in Glastir		55,570	478,560	13,740	547,870
Percent of pasture affected		5	17	19	17

Table 4.8 Area receiving nitrogen fertiliser applications, and nitrogen fertiliser application rates to permanent pasture (taken from the British Survey of Fertiliser Practice, 2015)

Fertiliser Application	Dairy	Cattle & Sheep	Other
Area receiving dressing (%)	85	51	59
Average rate across all grass (kg ha ⁻¹)	113	34	48
Average rate on grass fields receiving N fertiliser (kg ha ⁻¹)	132	67	82

Table 4.9 Calculated percentage reductions in average nitrogen fertiliser rate across all permanent pasture due to Glastir options 15a, 15b, 15c and 15d.

Glastir option distribution	Dairy	Cattle & Sheep	Other
Across all grass fields	4.5	9.6	11.8
Only on grass fields receiving N fertiliser	5.4	23.5	25.9

Table 4.1 shows that a large proportion of Glastir options (other than Option 15 a – 15d) involve restrictions on livestock numbers or fertiliser use / manure use, or require land use change. Table 4.10 lists the different options, and the land use to which they are relevant. The vast majority of options are relevant to rough grazing (unimproved land or habitat land) with the most common options shown in Table 4.13. The most common option is 41a (Grazed Open Country), which accounts for 65% of land area under these options. The livestock restrictions can be very varied, e.g. “grazing levels should not exceed 0.4 Livestock Units / Hectare at any time between 1 March and 15 July” (Option 21) or “A forward stocking schedule must be agreed which will state the minimum and maximum number of LUs that will be on the contract land on any given day of the year” (Option 41a). Anthony (2013) assessed the potential impact of grazing open country, based upon sustainable and typical stocking rates for different habitats provided by Welsh Government, and derived a net impact of 0.2 livestock units per ha (which is approximately two ewes). The 105,000 hectare total area of grazing open country (Table 4.13) thus equates to a reduction in sheep numbers of approximately 210,000, which is a reduction of approximately 8% in sheep numbers on farms in Glastir. The impacts of Options 100 (Woodland Stock Exclusion) and 176 (Woodland – Light Grazing) were assumed by Welsh Government to be a reduction in ewe numbers of 2 and 1.3 ewes per hectare, which equates to a total reduction of almost 14,000 ewes when integrated with the 7,000 hectares under these options. The combined impacts of all the options changing stock numbers would thus be more than twice the 4.8% reduction in sheep numbers taken from the Farm Practice Survey (Table 3.5), but it is the change from the survey that was applied in the modelling, as this was assumed to more accurately reflect the net impact of the scheme options, given the uncertainty in stocking practices before Glastir the changes actually required given the possibility that the displaced livestock could be accommodated elsewhere on farm. The total area of arable reversion (option 131) is only 80 hectares so will have a negligible impact on pollutant losses at WMC scale.

Table 4.10 Glastir options that involve field level restrictions on fertiliser use, manure use or livestock numbers, other than options 15a – 15d, grouped by the land use to which they are relevant.

Management Restrictions	Glastir Options
Grassland	22, 104, 132,
Arable reversion	131
Rough grazing	16, 17, 18, 19, 19b, 20, 20b, 21, 21b, 25, 25b, 41a, 41b, 103, 109, 115, 116, 117, 118, 119, 120, 121, 122, 123, 124, 125, 126, 128, 129, 130, 133, 134, 139, 140, 141, 142, 143, 144, 145, 146, 147, 148, 149, 150, 151, 175
Woodland	100, 176

Table 4.11 Percent of relevant land area under Glastir Entry options that restrict fertiliser use, manure use or livestock numbers

		Water Management Catchment												
Management Restrictions	Total	11	36	43	52	54	59	65	68	75	79	83	86	98
Grass	1.2	0.5	0.9	1.2	0.5	1.6	0.7	3.9	1.3	2.1	2.8	1.1	3.0	1.8
Rough	69.6	55.1	99.9	30.9	66.4	46.9	52.9	55.7	69.2	33.4	0.0	78.3	70.0	36.8

Table 4.12 Percent of relevant land area under Glastir Advanced options that restrict fertiliser use, manure use or livestock numbers

		Water Management Catchment												
Management Restrictions	Total	11	36	43	52	54	59	65	68	75	79	83	86	98
Grass	0.8	0.3	1.4	1.3	0.2	1.0	0.6	0.5	1.3	0.0	-	0.4	3.4	1.4
Arable	1.0	0.0	5.5	0.0	0.0	2.7	0.0	3.5	0.9	-	-	0.0	1.5	0.4
Rough	44.2	51.3	99.9	7.1	35.1	50.7	43.3	5.9	64.8	0.0	-	63.9	99.9	36.8
Wood	59.0	84.2	49.9	40.3	51.8	97.7	70.6	17.2	60.9	0.1	-	75.7	62.8	62.9

Table 4.13 Hectares of the most common Glastir Options that restrict management of unimproved grassland

Glastir Option		Glastir Entry (ha)	Glastir Advanced (ha)	Total (ha)
41a	Grazed open country	74,892	30,779	105,671
19	Marshy grassland	10,963	3,829	14,792
19	Marshy grassland	10,963	2,172	13,135
18	Management of upland grassland	7,020	-	7,020
41b	Grazed open country – mix grazing	3,594	2,980	6,573
120	Unimproved acid grass	-	1,660	1,660
21	Saltmarsh	1,074	505	1,579
20	Heath	1,302	257	1,559
19b	Marshy grassland – mix grazing	943	248	1,191
25	Sand dunes	552	543	1,095
16	Management of upland heath	1,032	-	1,032
-	All Other Options	529	6,264	6,793

4.3. Overall representation of Glastir

Combining both the results of the Farm Practice Survey and an analysis of the scheme option data, the overall impact of Glastir was represented in the modelling through:

- Changes in fertiliser rates to grassland by farm type (Table 3.4)
- Changes in grazing livestock numbers, by livestock type (Table 3.5)
- Increases in the implementation rates of Farmscoper mitigation methods derived from the survey (Table 3.3) applied to all farms in Glastir and from the scheme option data by farm type and by WMC, separately for farms in Glastir Entry and Glastir Advanced (Table 4.4 and Table 4.5). Where the survey and scheme option data pertained to the same mitigation method, the scheme data was used.

These three impacts were incorporated within Farmscopper in such a way that their contribution to the total reduction in pollution could be determined.

5. Results

The following sections report the pollutant losses predicted by Farmscopper for Wales in the absence of Glastir, plus the current impacts of Glastir and the potential maximum impacts of the 'within-field' options which are comparable to the mitigation methods within Farmscopper.

The pollutant losses predicted by Farmscopper are the long term annual average values for loads delivered to watercourses. The impacts of mitigation methods and changes in management are the final overall effects, which may be realised immediately (e.g. following changes in nitrogen fertiliser), but could potentially take 10-20 years (e.g. for changes in soil status).

5.1. Baseline Pollutant Losses

Pollutant losses representative of farm practice in the absence of Glastir (and thus a baseline from which to which to assess Glastir), were calculated for the whole of Wales and summarised by farm type (Table 5.1) and by WMC (

Table 5.2). The differences in losses between farm types represents variation in farm management, particularly intensity of production, and the climatic risk factors associated with the typical locations of each farm type. Losses of nutrients are highest on pig and poultry farms due to the large amounts of manure that are generated, which for the purposes of modelling is assumed to be spread on land belonging to the farm, whereas in reality it would be spread around neighbouring farms and so the pollutant pressure would be more dispersed. Of the grazing farms, losses are greatest on the dairy farm, which is the most intensively stocked of the farms. Losses are greater on the LFA cattle and sheep farm than the lowland cattle and sheep because of greater rainfall in upland areas. Although the losses on LFA farms are not the highest, the fact that they occupy the greatest area (60% of all agricultural land) means they are the most significant source of pollution. The losses on horticulture farms are low as they often own large areas of low productivity land - from which losses are very small – alongside the horticultural crops. Emissions of methane are highest on dairy farms due to intensity of production, and nitrous oxide emissions are also highest here compared to farms except pig and poultry.

Table 5.1 Pollutant losses before the impacts of Glastir have been accounted for, disaggregated by farm type, expressed per hectare of agricultural land on that farm type.

Farm Type	Area (ha)	N (kg ha ⁻¹)	P (kg ha ⁻¹)	Z (kg ha ⁻¹)	CH ₄ (kg ha ⁻¹)	N ₂ O (kg ha ⁻¹)
Cereals	17,389	33.2	0.58	407.2	0.0	5.3
General	6,491	40.1	0.49	336.9	0.0	7.1
Horticulture	5,252	7.4	0.15	73.1	0.0	2.4
Pig	1,182	73.6	0.79	450.0	40.5	11.4
Poultry	30,991	74.6	0.74	325.7	6.8	13.5
Dairy	210,053	39.2	0.75	177.1	188.7	11.8
LFA	813,451	15.4	0.61	202.6	76.3	6.8
Lowland	160,117	14.7	0.38	111.2	66.1	7.4
Mixed	114,095	27.5	0.73	321.2	84.3	9.0
Total	1,359,021	21.7	0.61	203.6	89.9	8.0

Table 5.2 Pollutant losses before the impacts of Glastir have been accounted for, disaggregated by WMC, expressed per hectare of agricultural land within that WMC.

WMC	Area (ha)	N (kg ha ⁻¹)	P (kg ha ⁻¹)	Z (kg ha ⁻¹)	CH ₄ (kg ha ⁻¹)	N ₂ O (kg ha ⁻¹)
11	109,645	21.4	0.44	134.8	97.2	8.0
36	172,072	23.8	0.75	241.4	107.4	8.7
43	33,881	24.2	0.71	183.8	118.6	9.2
52	235,438	17.2	0.59	203.6	69.1	6.7
54	71,021	17.2	0.88	369.3	51.8	6.4
59	141,193	19.9	0.69	198.6	91.4	8.2
65	44,695	16.5	0.91	370.1	58.9	6.7
68	247,437	27.7	0.56	181.0	113.8	8.9
75	6,524	28.5	0.44	110.6	113.8	10.1
79	7,356	19.7	0.62	143.8	115.3	8.6
83	68,004	17.1	0.68	233.8	75.5	7.0
86	70,715	26.4	0.36	125.1	89.4	8.9
98	151,040	21.2	0.50	159.5	81.7	8.2
Total	1,359,021	21.7	0.61	203.6	89.9	8.0

Losses of nitrate are highest in WMC 75 (Teme) although this is only a small part of Wales. The next highest losses are found in WMC 68 (South West Wales) due to the large amount of dairying found in this catchment. Phosphorus and sediment losses are greatest in WMCs 54 (Ogmore to Tawe) and 65 (South East Valleys) due to the high proportion of drained silty soils in these catchments which are efficient at delivering these pollutants.

The average pollutant losses determined by Anthony et al. 2012 were 23.1 kg ha⁻¹ for nitrate, 0.57 kg ha⁻¹ for phosphorus and 269 kg ha⁻¹ for sediment (with spatial variation shown in Figure 1.2). The losses in Anthony et al. 2012 were validated against both water quality monitoring data and ecological monitoring data. These average figures are close to those in

Table 5.2 for nitrate and phosphorus, although the sediment figure is higher. The coarser spatial scale of the modelling in this project means that the range in losses by WMC (

Table 5.2) are not as wide as those by WFD waterbody in Figure 1.2.

5.2. Current Impacts of Glastir

The impacts of Glastir were represented as a change in fertiliser use, a change in livestock numbers and other impacts of Glastir (from both scheme options and changes in practice identified by the farm practice survey). Table 5.3 shows the overall impact of current Glastir agreements on the total Welsh agricultural pollutant loads and the contribution to the total from the three ways Glastir was represented. The overall impact is a 1% reduction in nitrate and phosphorus loads, with just over half of the reduction due to changes in fertiliser use. Reductions in sediment losses are smaller (0.1%) as changing fertiliser use has no impact and the Farmscoper model does not account for the impact of changes in stocking density on compaction or poaching. Impacts on methane and nitrous oxide are reductions of 0.6% and 0.8% respectively.

The impacts of Glastir shown on pollutant losses shown in Table 5.3 are diluted due to the amount of agricultural land in Wales not in scheme. Overall reductions on agricultural land on farms in scheme (Table 5.4) are over 2% for nitrate and phosphorus. The reductions on the individual fields where the options are actually implemented would be even greater. The impacts of Glastir options (particularly those eliminating nitrogen fertiliser, e.g. Options 15b and 15d) on pollutant losses from individual

fields can be very significant (over 50%), but such impacts are diluted by less effective options and land where no options (affecting diffuse pollution) are implemented or due to land not in Glastir.

Table 5.5 shows the impacts of Glastir on national pollutant losses by farm type. Impacts are greater on farms with grazing livestock, with highest reductions found on LFA farms due to the large reduction in sheep numbers associated with Glastir (Table 3.5) and the fact that Glastir agreements are more common in the central upland areas of Wales (Figure 1.1). There is an increase in methane emissions on the dairy farm, which is a result of the increase in dairy livestock due to Glastir that was found by the farm practice survey. The spatial variation in the proportion of land under Glastir shown in Figure 1.1 explains the range in impact of Glastir across the different WMCs (Table 5.6), with reductions in nitrate of 1.8% in WMC 83 (Upper Dee) but only 0.1% in WMC 79 (Tidal Dee).

Anthony et al., 2013 assessed the impacts of six land management representative of the range of options in Glastir, with three scenarios of different numbers of farms in scheme (3,500, 4500 and 5,500 farms), but assuming all appropriate land on each farm was under the different options. Under the medium number of farms scenario, reductions in nutrient losses for the different measures ranged from 0.2% (Retain Winter Stubble) to 6% (Grassland with no inputs). Accounting for the much lower implementation rates found in this project than the maximum assumed in Anthony et al (2013) and the smaller reductions in livestock and fertiliser found by the survey (Table 3.4 and Table 3.5) than assumed in Anthony et al (2013), then the reductions predicted in this report are comparable to those in Anthony et al (2013).

Table 5.3 Percentage reductions in national agricultural pollutant loads, due to current Glastir agreements (to 2015), including the primary cause of the reductions.

Reduction due to:	N (%)	P (%)	Z (%)	CH₄ (%)	N₂O (%)
Changes in fertiliser usage	0.52	0.50	0.00	0.00	0.40
Changes in livestock numbers	0.30	0.23	0.00	0.64	0.31
Other modelled impacts of Glastir	0.18	0.21	0.11	0.00	0.08
Total	1.00	0.94	0.11	0.64	0.79

Table 5.4 Percentage reductions in agricultural pollutant loads on agricultural land on farms in Glastir, due to current Glastir agreements (to 2015).

	N (%)	P (%)	Z (%)	CH₄ (%)	N₂O (%)
Total	2.24	2.17	0.37	1.41	1.75

Table 5.5 Percentage reductions in national agricultural pollutant loads by farm type, due to current Glastir agreements (to 2015).

Farm Type	N (%)	P (%)	Z (%)	CH₄ (%)	N₂O (%)
Cereals	0.12	0.08	0.05	-	0.13
General	0.21	0.22	0.13	-	0.12
Horticulture	0.34	0.17	0.01	-	0.20
Pig	0.03	0.05	0.06	0.00	0.02
Poultry	0.01	0.12	0.10	0.00	0.03
Dairy	0.44	0.56	0.22	-0.20	0.45
LFA	1.82	1.33	0.00	1.59	1.20
Lowland	0.64	1.48	0.80	0.39	0.38
Mixed	0.61	0.45	0.26	0.23	0.45

Table 5.6 Percentage reductions in agricultural pollutant loads by WMC, due to current Glastir agreements (to 2015).

WMC	N (%)	P (%)	Z (%)	CH₄ (%)	N₂O (%)
11	0.87	1.15	0.06	0.80	0.87
36	0.56	0.59	0.07	0.19	0.49
43	0.52	0.73	0.07	0.02	0.55
52	1.66	1.44	0.17	1.33	1.20
54	1.12	0.86	0.03	0.77	0.73
59	1.29	1.22	0.03	0.94	0.94
65	1.18	0.80	0.11	0.81	0.72
68	0.57	0.46	0.17	0.13	0.46
75	0.95	1.02	0.15	1.19	0.82
79	0.14	0.15	0.00	0.02	0.11
83	1.85	1.43	0.07	1.46	1.27
86	0.66	0.95	0.09	0.73	0.56
98	1.47	1.30	0.13	1.51	1.10

5.3. Potential Impacts of Glastir

Both ‘within-field’ options which could be mapped to Farmscoper mitigation methods, and mitigation methods that were found through the survey to be higher on scheme farms made only a small contribution to the overall reductions in nitrate and phosphorus due to Glastir (c. 20% of the 1% total reduction; Table 5.3). For each of these mitigation methods, Farmscoper was used to determine the impact of raising implementation to 100% of all appropriate land across Wales, irrespective of scheme entry. The results of this, shown in Table 5.7, are that many of the mitigation methods would have limited impact at national scale because they tackle losses from sources which contribute a very small proportion of the total national load (e.g. losses from manure heaps and tracks) or partial areas of arable fields (e.g. headlands) when arable is a small proportion of the total land area.

The most effective mitigation methods are establishing cover crops (1.4%, 2.7% and 6.5% reductions in nitrate, phosphorus and sediment respectively), in-field and riparian buffer strips (c. 2% reductions

in sediment) and fencing off streams from livestock (1.5% reduction in phosphorus). The reductions for these individual methods are high despite estimates of current implementation already being high (e.g. 50% for fencing off streams from livestock; Table 3.2).

The overall combined impact of all of these methods being raised to 100% implementation are reductions in national agricultural loads of 4.3% for nitrate, 8.4% for phosphorus and 11.1% for sediment. These reductions are much greater than those actually found as a result of Glastir (Table 5.3) and demonstrate that it is not that the options within Glastir are ineffective, but that marginal implementation across the whole of Wales is too low for a significant effect. Although the entirety of Wales being in Glastir is an unrealistic scenario, the high reductions in Table 5.7 show that the scheme could potentially have a significant local effect if options were more intensely focussed.

Table 5.7 Percentage reductions in national agricultural pollutant loads, assuming that each mitigation method in the Farmscoper library that was associated with a Glastir option, or which was found through the survey to be higher on scheme farms, was separately fully implemented on all relevant land across Wales, plus the percentage reduction due to implementing all the mitigation methods at once

Farmscoper Method		N (%)	P (%)	Z (%)	CH ₄ (%)	N ₂ O (%)
4	Establish cover crops in the autumn	1.39	2.65	6.48	-	0.15
13	Establish in-field grass buffer strips	0.02	0.62	1.92	-	0.00
14	Establish riparian buffer strips	0.15	0.73	2.16	-	0.06
21	Fertiliser spreader calibration	0.06	-	-	-	0.01
22	Use a fertiliser recommendation system	1.06	0.15	-	-	0.69
26	Avoid spreading manufactured fertiliser to fields at high-risk times	0.11	1.26	-	-	0.01
52	Increase the capacity of farm slurry stores to improve timing of slurry applications	0.18	0.54	-	-	0.02
62	Cover solid manure stores with sheeting	0.06	0.23	-	-	0.01
67	Manure Spreader Calibration	0.44	-	-	-	0.05
76	Fence off rivers and streams from livestock	0.25	1.48	-	-	0.03
79	Farm track management	0.00	0.01	-	-	0.00
102	Management of woodland edges	0.02	0.04	0.06	-	0.04
107	Beetle banks	0.02	0.24	0.77	-	0.00
108	Uncropped cultivated margins	0.09	0.17	0.37	-	0.09
113	Undersown spring cereals	0.29	0.54	1.27	-	0.03
114	Management of grassland field corners	0.47	1.00	1.42	-	1.05
115	Leave over winter stubbles	0.28	0.83	0.81	-	0.03
Combined Impact		4.26	8.43	11.14	0.00	2.22

6. Conclusions

The Glastir agri-environment scheme has been the single operational agri-environment scheme in Wales since 2013, and is designed to support farmers as payment for ecosystem goods and services they provide, including improving water quality. A computer-modelling based approach has been used within this project in order to assess the impacts of current uptake of Glastir upon losses of nitrate, phosphorus and sediment from agricultural land, and thus evaluate the effectiveness of Glastir against one of its objectives. The approach also determined if there were any associated impacts on the greenhouse gases nitrous oxide and methane, to provide a more complete assessment of Glastir on

pollutant losses. The approach uses an existing model of agricultural pollution (Farmscoper; Gooday et al. 2014), which is able to account for the impacts of changes in farm practice that typically occur as a consequence of agri-environment schemes. The changes due to Glastir were determined from both the Second Welsh Farm Practice Survey (Anthony et al. 2016b) and information from Glastir Scheme agreements. Analysis of the farm practice survey and scheme agreement data identified reductions in stock numbers of up to 5% and fertiliser usage of up to 10% (when averaged across all scheme land). Implementation rates for a number of mitigation methods which represented some of the different 'within-field' Glastir options (e.g. riparian buffer strips, uncropped margins) were also found to be up to 10% when averaged across all appropriate land in Glastir – these implementation rates are additional to any background implementation rates resulting from previous schemes or initiatives.

The net impacts of Glastir, on national nitrate and phosphorus losses from all agricultural land (i.e. including land not in Glastir) were calculated to be reductions of up to 1%. The major cause of reductions in pollutant losses were the reductions in livestock numbers and fertiliser use, the within field options had limited impact (~0.2%). The impact on methane losses was a 0.6% reduction, solely due to reductions in livestock numbers, whilst the reduction in nitrous oxide, primarily due to reductions in both fertiliser and livestock, was 0.8%. Reductions on the land actually managed by farms in Glastir were over 2% for nitrate and phosphorus. The greatest reductions were calculated to be on cattle and sheep farms, due to the large reduction in sheep numbers identified by the survey and the greater uptake of Glastir in upland areas. These trends results in significant spatial variation in scheme effectiveness at Water Management Catchment scale, with reductions in some catchments of under 0.5% and some catchments achieving almost 2% reductions (from all land, including that not in Glastir).

Although the 'within-field' options were not the dominant cause of pollutant reductions, an assessment of their potential – assuming they were applied to all appropriate land across Wales – showed that a few of the individual options reduced pollutant losses by 1%, with a total reduction in pollutant losses to water from all options of between 4% (for nitrate) and 11% (for sediment). This highlights the potential of Glastir to achieve significant impacts on nutrient and sediment losses (particularly when combined with reductions in fertiliser use and stock numbers), and shows that it is the low overall uptake of options when considered at large spatial scales (e.g. Water Management Catchments or nationally) that result in the low impacts of current Glastir agreements.

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