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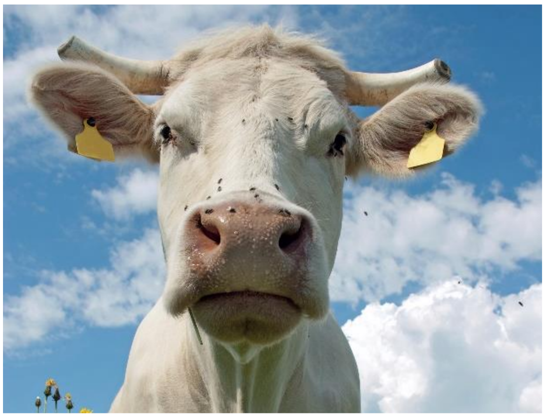


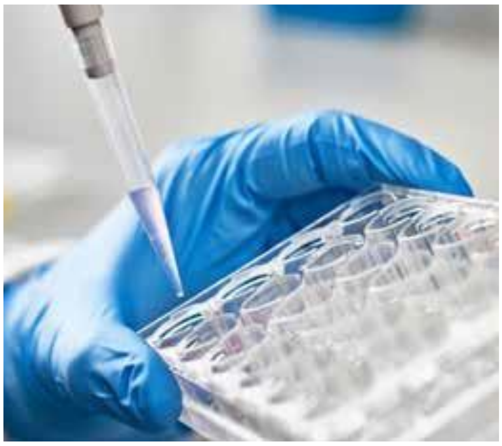

Impact Assessment of Measures to Address Agricultural Pollution (draft report)

Date 11 July 2019

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1 INTRODUCTION

This report is an impact assessment of a potential policy change to implement measures to address agricultural pollution across the whole of Wales.

The following key policy options are considered in this impact assessment:

- Option 1– Doing nothing (measures to address agricultural pollution implemented in current NVZ designated areas).
  There would be no change to the existing situation so the impact would be the ongoing annual costs to current NVZ farms and associated environmental benefits.
- Option 2 - Apply the measures to address agricultural pollution to the whole of Wales. These measures include:
    - Use a fertiliser recommendation system
    - Integrate fertiliser and manure nutrient supply
    - Do not apply manufactured fertiliser to high-risk areas
    - Avoid spreading manufactured fertiliser to fields at high-risk times
    - Increase the capacity of farm slurry stores to improve timing of slurry applications
    - Do not apply manure to high-risk areas
    - Do not spread slurry or poultry manure at high-risk times
    - Do not spread FYM to fields at high-risk times

2 METHODOLOGY AND ASSUMPTIONS

2.1 Methodology

A modelling approach was used to estimate the potential effects of different policy scenarios on pollutant loads as well as farm costs. The modelling work consisted of two main parts:

a) Using the Farmscoper tool to predict the effects of implementation of a range of mitigation measures relevant to the proposed measures across the whole of Wales or current NVZ areas on pollutant losses as well as impacts on farm costs.

b) Using the MANNER-*NPK* tool to model the effects of introducing a closed period for high available N manures (cattle slurry, pig slurry, broiler litter and layer litter) in accordance with the proposed measures on nitrate losses across the whole of Wales or the relevant NVZ areas.

The Farmscoper model is a decision support tool used to assess diffuse agricultural pollutant loads on a farm and quantify the impacts of farm pollution mitigation options on these. The tool allows for the creation of unique farming systems, based on combinations of livestock, cropping and manure management, and the assessment of the cost and effect of one or more mitigation methods from a library of over 100 methods contained within the tool, many based upon the Mitigation Method User Guide (Newell-Price et al., 2011). A detailed description of the model is presented in Appendix 1. Farmscoper modelling was used to estimate the effects on pollutant losses and the costs to farmers of implementation of a range of mitigation methods described in option 2 across the whole of Wales. The pollutants covered are nitrate, phosphorus, ammonia and nitrous oxide. Although Farmscoper can predict losses of sediment and methane (and other pollutants), the proposed measures are likely to have minimal impact on these pollutants.

The MANNER-*NPK* model (details presented in Appendix 2) is a decision support tool designed to show the impact of different application timings and methods on losses of nitrate, ammonia and nitrous oxide (Nicholson et al., 2013). MANNER-*NPK* was used to model the impacts on N loss of introducing the closed period for spreading high N available manure (cattle slurry, pig slurry, broiler litter and layer litter) across the whole of Wales or relevant NVZ areas.

The Farmscoper tool was parameterised using June Agricultural Survey (JAS) data from 2010 for Wales, with data entered for the 12 Water Management Catchments (WMC) which have at least 50% of their area in Wales.

Farmscoper contains a library of over 100 mitigation methods. A subset of these were selected that were considered to be likely to be taken up by famers, based upon expert assessment of the requirements of the proposed measures. The measures modelled are outlined in Table 2-1 and typically require improved fertiliser and manure practices. A full description of all the eight selected measures is presented in Appendix 3. However, it is envisaged that the biggest impacts (both costs and benefits) would come from increasing slurry storage to improve timing of slurry applications.

Farmscoper assumes a background rate of implementation of all mitigation measures representing current agricultural practice. These values, presented in Table 2-1 for both current NVZ and non-NVZ areas, are derived from national stratified farm practice surveys.

For the avoiding high risk times measures, current implementation is effectively represented in the initial modelling (which uses observed application timing information) and so the additional implementation of these measures is set to zero.

Table 2-1: Uptake of Farmscoper Measures (%)

No.	Measure	Non-NVZs (%)		NVZ areas (%)	
		Other farms	Extensive grazing farms	Other farms	Extensive grazing farms
1	Use a fertiliser recommendation system	80	50	100	80
2	Integrate fertiliser and manure nutrient supply	50	25	80	50
3	Do not apply manufactured fertiliser to high-risk areas	50	25	80	50
4	Avoid spreading manufactured fertiliser to fields at high-risk times	0	0	2	2
5	Increase the capacity of farm slurry stores to improve timing of slurry applications	0	0	2	2
6	Do not apply manure to high-risk areas	80	50	100	80
7	Do not spread slurry or poultry manure at high-risk times	0	0	2	2
8	Do not spread FYM to fields at high-risk times	0	0	2	2

For Option 2 (proposed measures applied to whole Wales), it was assumed in the modelling that the measures being implemented across the whole of Wales would increase uptake of these measures from the current practice value to 100% implementation. The benefits of extending the closed periods in terms of reduced nitrate-N leaching to water were modelled separately using the model MANNER-*NPK.* To avoid double counting, additional runs from Farmscoper were done with measure 5 (Increase the capacity of farm slurry stores to improve timing of slurry applications) and measure 7 (do not spread slurry or poultry manure at high-risk times) turned off, as these measures have similar impacts to the modelling done with MANNER-*NPK*. The results on environmental impacts from both models were then combined. It should be noted, however, the combined effect does not take into account interactions between the closed period measure and the other measures. Therefore, the combined modelled effect represents the maximum reduction in nitrate loss and the actual reduction may be lower.

The 2010 June Census farm holding level data was used for both models to ensure consistency and comparability of results for adding up impacts predicted by the models. Although more up-to-date Census data is available for Farmscoper estimation, it is not available for MANNER-*NPK* estimation beyond 2010. A comparison between 2010 and 2018 Census data suggests that land area and sheep numbers have gone up by about 10% while cattle numbers have not changed. Broadly speaking, the estimation on loads could potentially be underestimated by 10% (due to the contribution from dairying not changing), although relative percentage changes in impacts are minimal.

Table 2-2: Comparison of livestock numbers and land use between 2010 and 2018

Description	2010	2018	2018 figures as a % of 2010 figures*
Livestock numbers			
Total cattle & calves	1,138,127	1,134,135	99.6
Total sheep and lambs	8,244,162	9,530,790	115.6
Total pigs	26,974	23,199	86.0
Total poultry	7,570,679	8,180,544	108.1
Land Use			
Arable (ha)	85,229	93,818	110.1
Horticulture (ha)	1,301	1,678	129.0
Grass + sole rights rough grazing (ha)	1,353,367	1,514,535	111.9
Commons (ha)	180,305	180,305	100.0
Woodland (ha)	69,128	96,767	140.0
Total (ha)	**1,689,330**	**1,887,103**	**111.7**

Data Source: Welsh Government; * Calculated by authors.

2.2 Assumptions Used for Cost and Benefit Estimates

Variables of Interest

Some policy scenarios will increase capital costs to farmers as well as farmers' time input and operational costs. There are also potential benefits to farmers from reduced synthetic fertiliser costs. The environmental savings for fertiliser nitrogen were estimated as part of savings in operational costs within the environmental modelling. The environmental benefits from more efficient manure application include potential reductions in three types of pollution: (i) Greenhouse Gas (GHG) emissions to air; (ii) ammonia emissions to air; and (iii) nitrate-N and total phosphorus emissions to water.

Valuations of environmental benefits

Monetary benefits of changes in pollutant loads are estimated by multiplying the change in tonnes by the monetary value per tonne (see Table 2-3) for GHG emissions, ammonia nitrate-N and phosphorus emissions. These monetary savings have then been discounted following Green Book guidance.

It should be noted that there is a large range of estimates of the monetary value per tonne of pollutant/emission reduction.

For valuation of GHG emission savings, the central cost of carbon for non-traded GHG emissions in the UK is used (£68 per tonne of CO_2e in 2019), the full range of the monetary cost estimate is £34-£102 per tonne of CO_2e in 2019. The central estimate of forecast prices for carbon has been used for each year over the period from 2019/2020 to 2038/2039. Similarly, the damage cost estimate associated with ammonia emissions fall over a large range. The central estimate used in the analysis is £6,046 per tonne but the full range is £1,133 to £18,867 per tonne.

The central value of these estimates has been used to quantify the environmental benefits in terms of reduced ammonia, phosphorus, nitrate-N and GHG emission savings.

Table 2-3: Variables impacted on and their monetary value

Pollutant	Central Value	Range	Data source
GHG savings (£/t)	£68	£34-£102	Non-traded CO_2, central values in 2018 prices. Source: Department for Business, Energy and Industrial Strategy. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/793632/data-tables-1-19.xlsx (Table 3)
Ammonia savings (£/t)	£6,046*	£1,133-£18,867	2018 damage cost central value. National averages in 2017 prices. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/770576/air-quality-damage-cost-guidance.pdf
Nitrate-N savings (£/t)	£430	£240-£620	EA/Defra figures in 2014 prices as part of DTC Programme (Project LM0304)
Phosphorus (£/t)	£12,970	£2,770-£22,660	EA/Defra figures in 2014 prices as part of DTC Programme (Project LM0304)

*Ammonia value increased significantly because of a re-evaluation of the damage costs, especially relating to human health. There is also some movement to factor in wider ecosystem service costs.

The analysis assumes that there is full compliance with the measures in option 2. Should compliance be less than that, then costs and benefits will both be less but the net monetary effect will be in the same direction.

Time horizon and discounting rate

The costs and benefits of the policy scenarios are assessed over a 20-year period (which is assumed as the lifetime of slurry stores) from year 2019. The non-amortised value of capital costs was used in the NPV calculations, assuming zero residual value at the end of the 20-year policy period.

A discounting rate of 3.5% was used in this impact assessment as recommended by the Green Book[1] to estimate the Net Present Value (NPV) of costs and benefits.

[1] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/685903/The_Green_Book.pdf

3 DETAILED RESULTS: OPTION 2 (PROPOSED MEASURES APPLING TO ALL OF WALES)

3.1 Changes in Pollutants

Implementation of the chosen measures across the whole of Wales leads to a reduction in nitrate, phosphorus, ammonia and nitrous oxide emissions. The impact of increased slurry storage on nitrate losses was estimated using MANNER-*NPK* and the impacts of increased slurry storage capacity on P, NH_3 and N_2O losses was estimated using FARMSCOPER. Other measures were modelled with Farmscoper for all pollutants (Table 3-1).

Table 3-1: Percentage change in pollutant emissions when all measures associated with the proposed measures are applied to the whole of Wales

Pollutant	% change in losses	Absolute change in losses (kt)	Absolute emission levels for the current practice (kt)
Nitrate	-4.83	-1.90	39.24
Phosphorus	-5.90	-0.08	1.39
Ammonia	-0.90	-0.26	29.37
Nitrous Oxide	-3.15	-0.46	14.68

When the measures are implemented individually, the reductions for all pollutants are relatively small, generally less than 1%. The biggest impact on nitrate losses was increasing slurry storage capacity (2.4% reduction) and on ammonia emissions 'Integrate fertiliser and manure nutrient supply', (0.5% reduction) (see

Table 3-2); ‘not spreading slurry/poultry manure at high risk times’ has the biggest impact on phosphorus losses (1.8%) and nitrous oxide losses (1.1%).

Table 3-2: Percentage change in pollutant following 100% implementation of individual measures, expressed relative to current practice (%).

Measure	Nitrate	P	NH3	N2O
Use a fertiliser recommendation system	-0.56	-0.08	-0.31	-0.34
Integrate fertiliser and manure nutrient supply	-0.97	-0.80	-0.51	-0.61
Do not apply manufactured fertiliser to high-risk areas	-0.14	-0.04	-0.11	-0.11
Avoid spreading manufactured fertiliser to fields at high-risk times	-0.19	-1.48	-0.26	-0.02
Increase the capacity of farm slurry stores to improve timing of slurry applications	-2.4	-0.67	0.21	-0.03
Do not apply manure to high-risk areas	-0.02	-0.02	0.00	0.00
Do not spread slurry or poultry manure at high-risk times*		-1.84	0.00	-1.12
Do not spread FYM to fields at high-risk times	-0.68	-1.25	0.00	-1.00

* Nitrate reduction for method 7 included in method 5

3.2 Costs of Implementation

It is estimated that implementing all 8 measures together across all of Wales results in upfront capital costs to the farming industry of £78-98 million plus ongoing operational costs of £14m per year (see Table 3-3). This excludes measure 10 (not spreading manure at high risk times) which has a negligible implementation cost.

'Integrating fertiliser and manure nutrient management' and 'using a fertiliser recommendation system' result in reduced costs of £4.75m and £3.02m respectively (see Table 3-4Table 3-3), due to reduced use of manufactured fertiliser and more efficient use of fertiliser respectively (for those farms not already implementing the measures as per Table 2-1). All other measures are associated with increased costs – the most costly measures being 'avoiding spreading manufactured fertiliser at high risk times' and 'avoiding spreading manufactured fertiliser to high risk areas' (an increase of £13.28m and £8.69m respectively), due to the yield penalties associated with applying less fertiliser to crops. The 'increased slurry storage' measure also results in a large increase in capital costs from the baseline (between £78-£98m), due to investment costs associated with extending/building new slurry storage (detailed at Appendix 4).

Table 3-3: Implementation costs of mitigation measures associated with current practice and the additional costs when measures associated with the proposed measures are implemented across the whole of Wales.

Costs	Costs of current practice	Cost of Option 2	Difference
Capital costs	£272m	£360m	£88m*
Operation costs	£62m	£78m	£16m

* the average of £78m (if all extra slurry storage capacity was lagoons) and £98m (all extra slurry storage capacity was above ground tanks)

Table 3-4: Comparison between costs of current practice and 100% implementation of individual measures.

No.	Measure	Changes in capital costs	Changes in operational cost
1	Use a fertiliser recommendation system	0	-£3.02m
2	Integrate fertiliser and manure nutrient supply	0	-£4.75m
3	Do not apply manufactured fertiliser to high-risk areas	0	£8.69m
4	Avoid spreading manufactured fertiliser to fields at high-risk times	0	£13.28m
5	Increase the capacity of farm slurry stores to improve timing of slurry applications	£78-98 million	£1.56-1.98m*
6	Do not apply manure to high-risk areas	0	0.00
7	Do not spread slurry or poultry manure at high-risk times	0	0.00
8	Do not spread FYM to fields at high-risk times	0	0.00

*Assuming running costs at 2% of the capital cost of slurry storage

It is considered that measures 6, 7 and 8 have no specific implementation costs, beyond the need for adequate storage (measure 5), manure and nutrient planning (measures 1 and 2) and record keeping (see section 3.3).

3.3 Admin cost of record keeping and nutrient planning

The completion of records and plans required by the proposed measures is a formal process and bringing together accurate figures can be a challenge. Our estimates are based on a survey of farmers within NVZs in Wales, undertaken by ADAS for the Welsh Government[2].

[2] Survey of the Management Practices and NVZAP and CSF Funding Impacts. ADAS 2012

The following assumptions were made for calculating costs:

- The figures below are based on the farmer's time, costed at £20/hr[3].
- A previous ADAS survey of Welsh farmers showed that approximately 43% already have a soil nutrient plan and 62% already have a manure management plan.[4]
- The 2012 survey of farming practice (ADAS, 2012) identified 40 hrs as the average setup time across all farm types and sizes.
- Average annual time is an additional 20 hours from the survey (across all farm types and sizes).
- The estimates are average values since all farms will vary in soil type, topography, field size and number, and management approach, but are suitable for producing a total for the whole of Wales.

There are 11,434 farms outside current NVZ areas (see Table 3-5). The annual cost for record keeping and planning (20 hours per year) is estimated at £4.57m, with an additional £4.57m (20 hours per farm) upfront cost in the first year.

Table 3-5: No. of farms by farm type inside/outside NVZ areas.

Farm Type	Non-NVZ	NVZ
Cereals	1294	215
General	781	358
Horticulture	441	180
Indoor Pig	1038	42
Poultry	1235	117
Dairy	1449	188
LFA Grazing	2008	43
Lowland Grazing	1815	788
Mixed	1373	252
Total	**11,434**	**2,183**

In addition to the farmers' own time for record keeping and planning, they may incur costs for professional planning application fees to build/expand slurry storage when planning permission is needed. This cost is around £3,500 per application. We assume 50% of the non-cropping farms outside NVZs (8,918) would need to apply for planning permission, this cost is estimated to be £15.6 million in the first year.

3.4 Environmental benefits

The environmental benefits are monetised by multiplying the change in tonnes of emission levels by the monetary value per tonne (see Table 3-6) for GHG emissions, ammonia emissions and Nitrate-N leaching. The total environmental benefits is estimated at £319

[3] Source: Defra. Cost rate for farm managers.
[4] Assessment of the Contribution of the Wales Agri-Environment Schemes to the Improvement of Water Quality and the Mitigation of Climate Change. ADAS 2012.

million (not discounted) with the majority coming from reductions in GHG emissions. After discounting, this value for environmental benefits is £219 million.

Table 3-6: Valuation of environmental benefits

Pollutant	Annual Emission levels (kt)			Unit value (£/t)	Annual benefit (£)	Benefit of reductions in emissions over 20 years (£)
	Baseline	Whole wales scenario	Changes			
Nitrate-N	39.2	37.3	-1.9	£430	£0.8m	£16m
Ammonia	29.4	29.1	-0.3	£6,046	£1.6m	£32m
GHG*	8,247	8,110	-138	£68-£141**	£9.4-£19.4m	£250m
Phosphorus	1.39	1.31	-0.08	£12,970	£1.0m	£21 m

*This is calculated on CO_2e basis, where 1kg methane (CH4) = 25kg CO_2e and 1kg of nitrous oxide (N_2O)= 298kg CO_2e.

** This is the non-traded carbon price for 2019. There is a time series of predicted prices for non-traded carbon which goes up to £141/t in 20 years' time.

The annual environmental benefit values (not discounted) are presented in Table 3-7.

Table 3-7: Valuation of annual environmental benefits of GHG reductions (£m)

Year	Carbon prices (£/t)	GHG (£m)
2019/20	68	9.4
2020/21	69	9.5
2021/22	70	9.7
2022/23	72	9.9
2023/24	73	10.0
2024/25	74	10.2
2025/26	75	10.3
2026/27	76	10.5
2027/28	77	10.7
2028/29	79	10.8
2029/30	80	11.0
2030/31	81	11.1
2031/32	88	12.2
2032/33	96	13.2
2033/34	103	14.2
2034/35	111	15.3
2035/36	118	16.3
2036/37	126	17.3
2037/38	133	18.4
2038/39	141	19.4
Total		249.5

3.5 Net Present Value calculations

If applying the proposed measures to the whole of Wales, there will be an additional cost to farmers of £393m. This is largely comprised of the additional capital cost of slurry storage at £88m in the first year and associated planning permission cost of constructing/expanding slurry stores at £15.6m. The extra time input from farmers is estimated to cost £2 million per year and operational costs of £16m per year (associated with measures 1, 2 and 5).

The whole Wales option will generate about £219m in environmental benefits over 20 years, most of which comes from reductions in GHG emissions.

The costs and benefits as well as NPV for Option 2 are presented in

Table 3-8, which indicates a **net cost of implementation of £174 million over 20 years**.

Year	2019	19/20	20/21	21/22	22/23	23/24	24/25	25/26	26/27	27/28	28/29	29/30	30/31	31/32	32/33	33/34	34/35	35/36	36/37	37/38	38/39	Total NPV
Costs	88.0	34.2	20.5	20.5	22.3	22.3	22.3	22.3	22.3	22.3	22.3	22.3	22.3	22.3	22.3	22.3	22.3	22.3	22.3	22.3	22.3	513
NPV of costs	88.0	33.1	19.2	18.5	17.9	17.3	16.7	16.1	15.6	15.1	14.6	14.1	13.6	13.1	12.7	12.3	11.8	11.4	11.1	10.7	10.3	393
Benefits	-	12.9	13.0	13.2	13.3	13.5	13.7	13.8	14.0	14.1	14.3	14.4	14.6	15.6	16.7	17.7	18.7	19.8	20.8	21.8	22.9	319
NPV of benefits	-	12.4	12.1	11.9	11.6	11.4	11.1	10.9	10.6	10.4	10.1	9.9	9.7	10.0	10.3	10.6	10.8	11.0	11.2	11.4	11.5	219
NPV of net benefits	88.0	20.6	7.0	6.6	6.3	5.9	5.6	5.3	5.0	4.7	4.4	4.2	3.9	3.1	2.4	1.7	1.0	0.4	0.1	0.7	1.2	174

Table 3-8: NPV calculations (£m)

Year	2019 (capital)	19/20	20/21	21/22	22/23	23/24	24/25	25/26	26/27	27/28	28/29	29/30	30/31	31/32	32/33	33/34	34/35	35/36	36/37	37/38	38/39	Total NPV
Costs	88.0	34.2	20.5	20.5	22.3	22.3	22.3	22.3	22.3	22.3	22.3	22.3	22.3	22.3	22.3	22.3	22.3	22.3	22.3	22.3	22.3	513
NPV of costs	88.0	33.1	19.2	18.5	17.9	17.3	16.7	16.1	15.6	15.1	14.6	14.1	13.6	13.1	12.7	12.3	11.8	11.4	11.1	10.7	10.3	393
Benefits	-	12.9	13.0	13.2	13.3	13.5	13.7	13.8	14.0	14.1	14.3	14.4	14.6	15.6	16.7	17.7	18.7	19.8	20.8	21.8	22.9	319
NPV of benefits	-	12.4	12.1	11.9	11.6	11.4	11.1	10.9	10.6	10.4	10.1	9.9	9.7	10.0	10.3	10.6	10.8	11.0	11.2	11.4	11.5	219
NPV of net benefits	88.0	20.6	7.0	6.6	6.3	5.9	5.6	5.3	5.0	4.7	4.4	4.2	3.9	3.1	2.4	1.7	1.0	0.4	0.1	0.7	1.2	174

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APPENDIX 1. DETAILS ON FARMSCOPER

FARMSCOPER is a decision support tool used to assess diffuse agricultural pollutant loads on a farm and quantify the impacts of farm pollution mitigation options on these. The tool allows for the creation of unique farming systems, based on combinations of livestock, cropping and manure management, and the assessment of the cost and effect of one or more mitigation methods from a library of over 100 methods contained within the tool, many based upon the Mitigation Method User Guide (Newell-Price et al., 2011).

The initial version of Farmscoper was developed under Defra Project WQ0106 (Gooday and Anthony, 2010) as a policy support tool for cost-effectiveness assessments of pollution mitigation and is further described in Gooday et al. (2014a). The tool was further enhanced under Defra Project FF0204 (ADAS et al., 2012) and again under Defra Project SCF0104 (Gooday et al. 2014b), which added a clear calculation of the costs of measure implementation and allowed the tool to be applied at catchment to national scale.

The pollutant losses in Farmscoper are a synthesis of a number of validated models used for policy decisions. Full details are given in the referenced reports, but as an example the nitrate losses are derived from coefficients in the NEAP-N model (Lord and Anthony, 2000 and Silgram et al., 2001), which have been disaggregated into the source-apportionment system used by Farmscoper using outputs from other more process based nitrate-leaching models (N-CYCLE (Scholefield et al., 1991), NITCAT (Lord, 1992), MANNER (MANure Nutrient Evaluation Routine; Chambers et al., 1999) and EDEN (Gooday et al., 2008)).

APPENDIX 2. MANNER-NPK MODELLING

Objectives

MANNER-NPK is a decision support tool designed to show the loss of pollutants from agricultural land after organic manure applications (Nicholson et al., 2013). MANNER was used to model the impacts on N loss of introducing the closed period for spreading high N available manure (cattle slurry, pig slurry, broiler litter and layer litter) across the whole of Wales or relevant NVZ areas. MANNER has been used previously to model the impacts of introducing a closed period in England using a similar methodology as described below (DEFRA project WT0932).

Methodology

There are two key stages to the MANNER modelling: batch running of the MANNER model to represent all possible parameters (e.g. climate, soils, manure types, application method) at a 5km scale and a weighting of the results of these runs to represent management under current practice and modified practice due to a closed period.

The batch runs of MANNER were performed using local climate for each 5km grid square in Wales, for three land use types (spring sown, winter sown and grass), two soil types (sandy/shallow and other) and a range of application methods bandspread, broadcast, deep injection, shallow injection) and delays to incorporation (not incorporated, within one week, within 24 hours and within 2 Hours) as appropriate for each manure type. Simulations included applications of manure on the 1st and 15th of each month to give a predicted nitrate loss under each combination of climate, soil type, land use and application conditions.

Losses for each month were then weighted by the proportion of grassland, winter sown crop and spring sown crop in each 5km square (derived from 2010 census data), and the proportion of each soil type in each square (sandy/shallow or other). They were also weighted by farm practice, using data on the proportion of each manure type applied by crop type by each of the four methods (and the delay to incorporation derived from the British Survey of Fertiliser Practice (BSFP), (using 2008-2010 data). Data on timings of manure application by month and crop type were also derived from the same source (Table 4-1). For cattle slurry, data specifically for Wales was used. Due to there being very few records of application in Wales for pig slurry, layer manure and broiler litter, data for England was also used for these manure types.

Table 4-1. Current manure application timings (%). From BSFP data 2008-2010. Welsh data used for cattle slurry, English and Welsh data combined for other manure types. Note that each row totals to 100%

	January	February	March	April	May	June	July	August	September	October	November	December
Cattle Slurry	4	24	18	22	3	3	2	7	11	3	1	2
Spring sown	1	26	15	50	4	0	0	0	0	0	0	3
Winter sown	0	26	17	3	0	0	0	17	30	7	0	0
Grass	12	19	23	13	6	9	6	4	2	3	2	2
Pig Slurry	13	9	10	33	5	2	6	5	7	6	3	2
Spring sown	36	5	12	37	2	0	0	0	0	1	5	2
Winter sown	0	0	8	32	6	0	6	13	22	11	1	0
Grass	2	23	9	29	6	6	12	1	0	6	3	2
Layer Manure	2	3	24	19	0	6	3	17	18	3	3	1
Spring sown	0	1	2	0	0	0	2	45	40	9	0	0
Winter sown	7	8	36	38	1	0	0	1	0	0	9	0
Grass	0	0	35	20	0	19	7	5	13	0	0	1
Broiler Litter	3	19	30	11	3	4	0	14	11	5	0	0
Spring sown	10	16	34	23	9	0	0	4	2	0	1	1
Winter sown	0	10	10	0	0	0	0	38	29	12	0	0
Grass	0	29	46	9	1	11	0	0	2	2	0	0

APPENDIX 3. FARMSCOPER MEASURES

This annex briefly describes each of the mitigation measures in Farmscoper that have been applied in this assessment and then shows a table of the rules used to calculate the impact, which contains the apportionment coordinates tackled and the percentage reduction in the loss from those coordinates.

Use a fertiliser recommendation system

Use a recognised fertiliser recommendation system (e.g. RB209, PLANET and other supplementary guidance) to plan manufactured fertiliser applications to all crops; do not exceed recommended rates. Time fertiliser applications to minimise the risk of nutrient losses (e.g. avoid autumn N use and manage early spring applications to drained soils). Use a professional FACTS (Fertiliser Advisers Certification and Training Scheme) qualified adviser.

Fertiliser recommendation systems take account of the following factors: soil nutrient supply (based on soil analysis), winter rainfall, previous cropping and soil type, crop nutrient requirements for a given soil and climate, crop requirement for nutrients at various growth stages, the amount of nutrients supplied to the crop by added organic manures and by previous manure applications, soil pH and the need for lime. A good fertiliser recommendation system ensures that the necessary quantities of nutrients are available when required for uptake by the crop. Nutrients are only applied when the supply of nutrients from all other sources is insufficient to meet crop requirements. As a result, the amount of excess nutrients in the soil is reduced to a minimum. Use of a recommendation system should also ensure that the soil is in a sufficiently fertile state to maximise the efficient use of nutrients already in the soil, or supplied from other sources such as fertilisers/organic manures. Maintaining an appropriate balance between different nutrients (i.e. NPK) is also important to maximise the efficient uptake of all nutrients and reduce environmental losses to a minimum.

Source	Area	Pathway	Type	Timescale	Form	Impact
Chemical	Arable Grass	Runoff Preferential Leaching	Fertiliser	Short Medium	Dissolved	10

Integrate fertiliser and manure nutrient supply

Use a recognised fertiliser recommendation system (e.g. RB209, PLANET, MANNER-NPK and other supplementary guidance) to make full allowance of the nutrients applied in organic manures and reduce manufactured fertiliser inputs accordingly. Use laboratory analysis to gain a better understanding of manure nutrient contents and supply. Use a professional FACTS (Fertiliser Advisers Certification and Training Scheme) qualified adviser.

Recommendation systems should be used to provide a robust estimate of the amount of nutrients supplied by organic manure applications. This information can then be used to determine the amount and timing of additional manufactured fertilisers needed by the crop. Fertiliser use statistics suggest that, in many cases, this will result in a reduction in fertiliser inputs (particularly on arable and maize crops) compared with current practice and a concomitant reduction in diffuse nutrient pollution.

Source	Area	Pathway	Type	Timescale	Form	Impact
Chemical	Arable Grass	Runoff Preferential Leaching	Fertiliser	Short Medium	Dissolved	0 - 25†

† The impact value is farm specific and depends upon the total amount of manure N relative to the total amount of fertiliser N for that farm.

Do not apply manufactured fertiliser to high-risk areas

Do not apply manufactured fertiliser at any time to field areas where there are direct flow paths to watercourses. For example, areas with a dense network of open drains, wet depressions (flushes) draining to a nearby watercourse, or areas close to road culverts/ditches. The risk of pollution is reduced by not applying fertiliser at any time to hydrologically well-connected areas where it could easily be transferred to a watercourse.

Source	Area	Pathway	Type	Timescale	Form	Impact
Chemical	Arable Grass	Runoff	Fertiliser	Short	Dissolved	25‡
Chemical	Arable Grass	Runoff Preferential Leaching	Fertiliser	Medium	Dissolved	10‡

‡ Farmscoper assumes that 5% of a farm is a high risk area, irrespective of soil type, climate or management. This reduction is thus only applied to 5% of the arable / grass area.

Avoid spreading manufactured fertiliser to fields at high-risk times

Do not spread manufactured fertiliser at times when there is a high-risk of surface runoff or rapid movement to field drains i.e. when soils are 'wet'. Do not spread N fertiliser between September and February when there is little or no crop uptake and there is a high-risk of nitrate leaching loss (unless there is a specific crop requirement during this period)

Fertiliser timing affects the potential for mobilisation of nutrients from land to water. Avoiding spreading fertiliser to fields at high-risk times reduces the availability of N and P for loss in surface runoff or drainflow. Surface runoff is most likely to occur when rain falls on sloping ground, when soils are 'wet', frozen or snow covered. The rapid preferential flow, through the soil, of N and P from applied fertilisers is most likely to occur from (drained) soils when they are 'wet' and rainfall follows soon after application. Avoiding N fertiliser application in the autumn/winter reduces the amount of nitrogen available for leaching by over-winter rainfall.

Source	Area	Pathway	Type	Timescale	Form	Impact
Chemical	Arable Grass	Runoff Preferential	Fertiliser	Short	Dissolved	2

Increase the capacity of farm slurry stores to improve timing of slurry applications

Expand slurry storage facilities for the collection and storage of slurry, to allow spreading at times when there is a low-risk of runoff and when there is an actively growing crop to utilise nutrients applied in the slurry. The storage provides increased flexibility in land application timing, so there will be fewer occasions when a lack of storage forces slurry applications to occur when here is a high-risk of surface runoff or drainflow to water i.e. when soils are 'wet'.

This measure was modelled using MANNER (see previous Appendix) and so the Farmscoper rules are not included here.

Do not apply manure to high-risk areas

Do not apply manure to field areas where there is a high-risk of direct loss to watercourses, e.g. directly adjacent to a watercourse, borehole or road culvert, to shallow soils over fissured rock or widely cracked soils over field drains, to areas with a dense network of open (surface) drains, spring lines or wet depressions (flushes). These areas have a high-risk of rapid transport of manure-borne pollutants to watercourses, so manure applications (particularly of slurry) should be avoided wherever possible.

Source	Area	Pathway	Type	Timescale	Form	Impact
Animal	Arable Grass	Runoff	FYM Slurry Litter	Short	Dissolved	25‡

‡ Farmscoper assumes that 5% of a farm is a high risk area, irrespective of soil type, climate or management. This reduction is thus only applied to 5% of the arable / grass area.

Do not spread slurry or poultry manure at high-risk times

Do not apply slurry or poultry manure to fields at times when there is a high-risk of surface runoff e.g. in winter when soils are 'wet' or frozen hard, or when heavy rain is expected in the next few days. Do not apply slurry or poultry manure to fields at times when there is a high-risk of rapid percolation to field drains e.g. in winter and spring when soils are 'wet'. Do not apply slurry or poultry manure to fields late in the growing season (i.e. autumn/early winter) when there is no crop to utilise the added N. Slurries and poultry manures have 'high' readily available N contents (>30% of total N). Avoiding the application of these materials at times when surface runoff or rapid preferential flow to field drains is likely to occur reduces water pollution risks. Also, avoiding application in autumn/early winter will help to reduce over-winter nitrate leaching losses. Slurry / poultry manure applications in autumn/early winter add readily available N to the soil at a time when there is little N uptake by crops and will increase over-winter nitrate leaching losses, particularly from nitrate 'leaky' sandy and shallow soils. Applications later in winter/spring present less of a risk, as there is less opportunity for nitrate to be leached before crop growth commences.

Source	Area	Pathway	Type	Timescale	Form	Impact
Animal	Arable Grass	Runoff Preferential	Slurry Litter	Short	Dissolved	25

Do not spread FYM to fields at high-risk times

Avoid spreading (straw-based) FYM to fields at times when there is a high-risk of surface runoff or drainflow, for example, where rain falls shortly after applying FYM to 'wet' soils. There is a risk of pollution if solid manures are spread under conditions where heavy rain following application could transport nutrients to surface water systems. As FYM is stackable and has a lower moisture content than slurry, it will not add sufficient water to the soil to initiate surface runoff or preferential flow to field drains; pollutants will only be transported to watercourses when there is heavy rainfall following application. 'Fresh' FYM has a higher content of readily available N, and generally presents a greater risk of pollution than 'old' FYM that has been stored for several months.

Source	Area	Pathway	Type	Timescale	Form	Impact
Animal	Arable Grass	Runoff Preferential	FYM	Short	Dissolved	25

APPENDIX 4. SLURRY STORAGE COST ESTIMATION

Estimating baseline slurry storage capacity

Surveys of slurry storage capacity in England and Wales (Smith *et al*., 2000; 2001; 2001) reported average capacities of 3.5 months for pig slurry; 3.3 months for beef slurry; and 3.8 months for dairy slurry (Table 4-2). These values include the effect of some farms reporting no slurry storage. Natural Resources Wales (NRW) have recently (2019) surveyed slurry storage capacity on 230 dairy farms in Wales (Andrew Chambers, *pers. comm*.). The milking herd size weighted average storage capacity was a comparable 4.1 months. For the purpose of this report we have assumed a baseline storage capacity of 3.5 months or 105 days for all livestock types.

Table 4-2. **Surveyed volume weighted percentage (%) distribution of farmer estimates of slurry storage capacity (months) on farms in England and Wales, by animal type (Smith *et al*., 2000; 2001; 2001).**

Animal Type	Months					
	0 to <1	1 to 2	3 to 4	5 to 6	7 to 8	9+
Pig	27	18	13	32	4	6
Beef	25	12	32	25	6	0
Dairy	16	11	35	22	16	0

Calculating slurry volumes

Slurry storage volumes were calculated by integrating total livestock counts for Wales from the 2018 June Agricultural Survey, with livestock properties and management practice data in order to calculate annual average slurry storage requirements by month.

Initial excreta volumes by livestock type were taken from NVZ guidance documents. This excreta was apportioned by month between fields, yards and housing. Excreta in housing was apportioned between solid manure and slurry systems according to results of the 2nd Welsh Farm Practice Survey (Anthony et al., 2016), which found over 70% of manure on dairy farms was managed as slurry, but only 10-20% on cattle and sheep farms. There was no solid manure generated on yard areas - excreta deposited was either managed as slurry, dirty water or simply not collected (based on data in 1st Welsh Farm Practice Survey (Anthony et al., 2011), which found approximately 62% was collected in slurry stores on dairy farms and 20% on cattle and sheep farms). An area of yard was specified per animal, by livestock type (0.9 m^2 per sheep, 4.3 m^2 for beef cattle and 6.4 m^2 for dairy cattle; Webb et al., 2001), with a proportion of this area roofed and guttered. Any rain falling on the un-covered area was assumed to be sent to slurry store, dirty water or uncollected as per fractions mentioned above. Monthly average rainfall data for 1981-2010 for Wales was used, with a total annual rainfall of 1460 mm. For dairy animals, an additional allowance of 25 litres per day per cow was made for water used in washing the dairy parlour, which was all assumed to be sent to the slurry store. This allowed for a total volume of slurry generated per month to be calculated, and thus storage capacity required to store manure for a specified period. From this, a surface area of the slurry storage could be determined, and this allows for the calculation of additional volume of material to be managed resulting from rain falling into the storage facility (which was assumed to be uncovered). With all calculations undertaken on a monthly basis, the impacts of storing an additional month or two of material can be determined.

Table 4-3. Slurry storage volumes and costs of additional slurry storage capacity based on whole Wales NVZ

Livestock type	Slurry storage capacity		Additional storage capacity required (m^3)	Cost of additional storage (£)	
	Baseline*	NVZ Compliant**		Above ground store ***	Lagoon***
Dairy	4,623,378	6,319,053	1,695,675	84,783,750	67,827,000
Beef	705,671	960,441	254,770	12,738,500	10,190,800
Pigs	11,210	18,088	6,878	343,900	275,120
Total	5,340,259	7,297,582	1,957,323	97,866,150	78,292,920

*baseline slurry storage capacity estimated at 3.5 months
** 5 months capacity for cattle slurry and 6 months for pig slurry
*** Costs of slurry storage assumed to be £50/m^3 for above ground stores and £40/m^3 for lagoons

Baseline (3.5 month) slurry storage capacity was estimated at 5.3 million m^3 with dairy systems accounting for over 85% of slurry production (Table 2). The NVZ compliant storage capacity (i.e. 5 months for cattle and 6 months for pigs) was estimated at 7.3 million m^3 an increase of c. 1.9 million m^3 compared with baseline estimates.

The cost of the additional storage was calculated using a figure of £50/m^3 for above ground (steel or concrete tanks) and £40m^3 for lagoon stores. These unit cost figures were adjusted from Nix 2019 (where steel tanks cost £50-60/m^3 and lagoons stores cost £45/m^3) based on expert opinion/industry knowledge and the fact that some farms are likely to extend existing stores rather than building new slurry storage. The total costs of additional storage based on above ground storage were estimated at *c.*£98 million with dairy slurry accounting for *c.*£85 million, beef slurry c.£13 million and pig slurry c.£340,000. The total costs of additional lagoon storage capacity were estimated at c.£78 million, with dairy accounting for *c.*£68 million, beef slurry c.£10million and pig slurry *c.*£275,000.

APPENDIX 5. MANNER-*NPK* MODELLING RESULTS

In order to model the closed period scenario, the closed period rules (Table 4-4) were implemented across the whole of Wales.

Table 4-4. Closed periods for spreading high readily available N manures

Sandy/Shallow Soils	**Closed Period**
Grassland	1st Sept - 31st Dec
Tillage	1st Aug - 31st Dec
Other Soils	**Closed Period**
Grassland	15th Oct - 31st Jan
Tillage	1st Oct - 31st Jan

Any slurry or poultry manure currently spread during the closed period was redistributed amongst the other months in the year according to the original proportion spread in each month. This resulted in a new set of weightings for each manure type, soil type and land use combination (Table 4-5 and Table 4-6).

These proportions were used to weight the N loss in each 5km square by the appropriate proportions of manure spread under each combination of scenarios, calculating a weighted proportion N loss value for each square under the current practice assumptions and the closed period assumptions. These proportions were then applied to the total amount of manure N spread at a 10km^2 scale (Derived from Manures-*GIS*; Defra project WQ0103). Losses were then summed across all of the 10km squares in Wales to provide an estimate of national N loss under the baseline and closed period scenarios.

Table 4-5. Predicted manure application timings (%) under the current closed periods for sandy/shallow soils. Note that each row totals to 100%

	January	February	March	April	May	June	July	August	September	October	November	December
Cattle Slurry	5	20	30	25	14	3	3	1	0	0	0	0
Spring sown	1	27	16	51	4	0	0	0	0	0	0	0
Winter sown	0	57	36	6	0	0	0	0	0	0	0	0
Grass	13	21	25	14	6	10	6	4	0	0	0	0
Pig Slurry	14	10	13	44	7	3	8	0	0	0	0	0
Spring sown	40	5	13	40	3	0	0	0	0	0	0	0
Winter sown	1	0	16	61	11	1	11	0	0	0	0	0
Grass	2	26	11	33	7	7	14	1	0	0	0	0
Layer Manure	3	10	36	24	0	9	16	2	0	0	0	0
Spring sown	1	21	28	6	0	5	40	0	0	0	0	0
Winter sown	8	9	41	42	1	0	0	0	0	0	0	0
Grass	0	0	41	23	0	22	9	6	0	0	0	0
Broiler Litter	4	32	45	12	4	4	0	0	0	0	0	0
Spring sown	11	18	37	25	10	0	0	0	0	0	0	0
Winter sown	0	49	51	0	0	0	0	0	0	0	0	0
Grass	0	30	48	9	1	11	0	0	0	0	0	0

Table 4-6. Predicted manure application timings (%) under the current closed periods for all other soil types. Note that each row totals to 100%

	January	February	March	April	May	June	July	August	September	October	November	December
Cattle Slurry	0	27	21	24	4	4	2	8	11	0	0	0
Spring sown	0	28	16	52	4	0	0	0	0	0	0	0
Winter sown	0	28	18	3	0	0	0	18	32	0	0	0
Grass	0	24	29	16	7	11	7	5	2	0	0	0
Pig Slurry	0	12	14	45	6	3	7	5	8	0	0	0
Spring sown	0	9	21	66	4	0	0	0	0	0	0	0
Winter sown	0	0	9	36	7	0	7	15	25	0	0	0
Grass	0	26	11	33	7	7	14	1	0	0	0	0
Layer Manure	0	4	27	22	0	6	3	18	19	0	0	0
Spring sown	0	1	2	0	0	0	3	49	44	0	0	0
Winter sown	0	9	44	45	1	0	0	1	0	0	0	0
Grass	0	0	35	20	0	19	7	5	13	0	0	0
Broiler Litter	0	20	32	12	4	4	0	16	12	0	0	0
Spring sown	0	18	38	26	10	0	0	4	2	0	0	0
Winter sown	0	11	12	0	0	0	0	43	33	0	0	0
Grass	0	30	47	9	1	11	0	0	2	0	0	0

Table 4-7 summarises the changes in the percentage of total Nitrogen applied which is lost as nitrate under current practice and under full implementation of the current closed period rules across Wales as well as the overall change for Wales when combining all of the high available N manure types. Implementing the closed period reduces N losses for all manure types between 23 and 63%, resulting in an overall 34% decrease for all high N manure (Table 4). This is consistent with results seen in previous work (DEFRA project WT0932) where a 30% reduction was reported in nitrate losses from pig and cattle slurry after the implementation of a closed period comparable to the current closed period. The biggest reductions are seen in pig slurry N losses (63%), but as pig slurry only contributes 0.18% of the total applied N from all four manure types it makes a negligible contribution to the overall change.

The results are sensitive to the assumption that manure currently spread in the closed period will be spread in the other months in proportion to the original distribution. This approach has been used in previous studies into the environmental impacts of introducing closed periods (DEFRA project WT0932; Lord *et al*. 2009). If the farm practice under the closed period is to use a different distribution of manure applications (for example moving all manure from the closed period till after the closed period) then the results will differ.

Table 4-7. N Losses and % changes for Wales under current practice and with the closed period for high available N manure implemented across all of Wales.

Cattle slurry	**N (t)**	**% N Loss**	**% Change from current practice**
Applied	13,717	-	-
Baseline Loss	722	5.3	-
Scenario Loss	473	3.4	-34
Pig slurry			
Applied	57	-	-
Baseline Loss	4	6.4	-
Scenario Loss	1	2.4	-63
Broiler litter			
Applied	13,416	-	-
Baseline Loss	127	0.9	-
Scenario Loss	98	0.7	-23
Layer litter			
Applied	3834	-	-
Baseline Loss	93	2.4	-
Scenario Loss	53	1.4	-43
Total			
Applied	31,024	-	-
Baseline Loss	946	3.0	-
Scenario Loss	626	2.0	-34