Explanatory Memorandum to the Water Resources (Control of Agricultural Pollution) (Wales) Regulations 2021.

This Explanatory Memorandum has been prepared by the Department for Economy, Skills and Natural Resources and is laid before Senedd Cymru in conjunction with the above subordinate legislation and in accordance with Standing Order 27.1.

Minister/Deputy Minister's Declaration

In my view, this Explanatory Memorandum gives a fair and reasonable view of the expected impact of the Water Resources (Control of Agricultural Pollution) (Wales) Regulations 2021. I am satisfied that the benefits justify the likely costs.

Lesley Griffiths MS
Minister for Environment, Energy and Rural Affairs

27 January 2021

1. Description

The Regulations establish measures to protect the environment from pollution caused by agricultural activities.

The Regulations impose limits on the amount of nitrogen from fertilisers which may be applied to land; a requirement to undertake nutrient management planning; controls on where, when and how nutrients are applied and ensures the storage of manure is appropriate for it to be utilised efficiently. The Regulations also includes provisions to include a review of proposals (if any are submitted within 18 months of the Regulations coming into force) on an alternative suite of measures to those in these Regulations to prevent or reduce pollution caused by agriculture.

2. Matters of special interest to the Legislation, Justice and Constitution Committee.

None

3. Legislative background

The Regulations are made using the powers conferred by sections 92 and 219(2)(d) to (f) of the Water Resources Act 1991.

The Regulations make provision in accordance with Council Directive 91/676/EEC concerning the protection of waters against pollution by nitrates from agricultural sources (OJ No. L 375, 31.12.91, p. 1) and aspects of Directive 2000/60/EC establishing a framework for Community action in the field of water policy (OJ No. L 327, 22.12.2000, p. 1).

Sections 92 of the Water Resources Act 1991 gives the Welsh Ministers the power to make regulations for preventing and controlling any poisonous, noxious or polluting matter for the purpose of preventing or controlling the entry of the matter into any controlled waters.

Functions of the Secretary of State under section 92 and section 219 were transferred to the National Assembly for Wales under article 2 of, and Schedule 1 to, the National Assembly for Wales (Transfer of Functions) Order 1999 (S.I. 1999/672). As regards section 92, functions were transferred in relation to those parts of Wales which are outside the catchment areas of the rivers Dee, Wye and Severn. In relation to those parts of Wales which are within those catchment areas, functions under section 92 are exercisable by the National Assembly for Wales concurrently with the Secretary of State. By virtue of section 162 of, and paragraph 30 of Schedule 11 to, the Government of Wales Act 2006 functions under sections 92 and 219 now vest in the Welsh Ministers.

These Regulations are being made under the negative resolution procedure in accordance with section 219(1) of the Water Resources Act 1991.

4. Purpose and intended effect of the legislation

Agricultural activities are one of the main causes of water pollution and ammonia emissions which are detrimental to public health, the environment, biodiversity and the economy. While many farms in Wales operate to high standards, comply with the regulatory baseline and follow good practice guidance, many do not. The Regulations target agricultural activities which present a risk of pollution to reduce the level of environmental pollution caused by poor practice.

The Regulations will protect water (and air quality) from poor agricultural practice by reducing losses of pollutants from nutrients across the whole of Wales. Currently, regulations for the protection of the environment from agricultural pollution are limited. In the absence of an improved regulatory baseline, detrimental impacts on the environment and the resilience of ecosystems necessary to enhance and protect biodiversity and public health will continue to occur. Wales' agricultural industry may also be harmed if the regulations are not introduced, particularly where compliance or regulatory equivalence is necessary for trade purposes. The regulations will fulfil existing requirements under the Nitrates Directive and Water Framework Directive to minimise this risk.

The Regulations will enable more efficient use of nutrients and enable the agricultural industry to demonstrate improved production standards. The Regulations will also protect farms performing to good or high standards from the reputational damage to the industry caused by poor practice elsewhere.

The measures in the Regulations are expected to reduce losses of pollutants to the environment each year by approximately 2,000 tonnes, an environmental benefit equating to £300m. This including nitrates, phosphorus, ammonia and nitrous oxide. The biggest impact on nitrate losses is attributed to increased slurry storage, phosphorus and nitrous oxide losses from not spreading at high risk times and ammonia from integrating fertiliser and manure applications. Due to the large range of potential environment costs associated with these pollutants and the variability of farm types and practices, there can be no certainty of the cost benefit ratio. While the impact of the measures will be minimal for farms already compliant with existing regulations and which follow good practice guidance, the greatest costs are attributed to those businesses not compliant with existing regulatory measures and which do not follow good practice recommendations. In this respect, the Regulations are proportional and aligned to the polluter pays principle.

Regulatory Impact Assessment

Introduction

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

Wales' natural resources are among our most valuable assets. They provide essential services including food, water and land. These are as fundamental to the long-term success of our economy as they are to the quality of our natural environment and the well-being of our communities. These resources are under pressure from challenges, including agricultural pollution.

A significant proportion of Wales' nutrient input to the environment originates from diffuse pollution, individual small sources of pollution which collectively cause a significant impact. Agricultural activities are one of the main causes of water pollution and ammonia emissions which are detrimental to public health, the environment, biodiversity and the economy.

Acute point-source pollution incidents also effect water quality and can cause significant losses in biodiversity in large stretches of the aquatic ecosystem. It can take many years for full recovery to be achieved following large scale incidents, if at all.

While the primary intention of the proposal is to reduce water pollution from agriculture the approach will be advantageous to other policy aims such as reduced atmospheric emissions. The proposed measures are designed to avoid pollution swapping and prevent or minimise increased losses of nutrients to the environment (including greenhouse gases, phosphorus and ammonia) as a result of measures primarily focussed on reducing losses of nitrogen.

The following key policy options are considered in this impact assessment, with the measures under each option listed in Table 1-1:

- **Option 1** – Doing nothing: 2.4% of Wales remains designated as Nitrate Vulnerable Zones (NVZs).

  There would be no change to the existing situation. This option provides the baseline against which the costs and benefits of the following options will be assessed.

  Option 2 - Apply measures to the whole of Wales with a review clause to consider the introduction of earned autonomy.

- **Option 3** – Designate additional areas as NVZs (8% of Wales).

- **Option 4** – Introduce regulations across the whole of Wales; with 8% designated as NVZ and different measures elsewhere; with a review clause for earned autonomy.

Table 1-1 Measures and spatial applicability under the different policy options

	Option 2	Option 3	Option 4	
	All Wales	Proposed NVZ Area	Proposed NVZ Area	Rest of Wales
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 *(5-month storage requirement)*	✓	✓	✓	
Increase the capacity of farm slurry stores to improve timing of slurry applications *(4-month storage requirement)*				✓
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	✓	✓	✓	✓

For each of these options, it was assumed that compliance with the measures would increase from the current practice (which may be compliance with existing regulation and is described within this report) to full compliance with the new measures.

The impacts of adding the following measures to option 4 were also considered:

- Do not apply manufactured fertiliser to high-risk areas
- Avoid spreading manufactured fertiliser to fields at high-risk times (no person may spread nitrogen fertiliser if the soil is waterlogged, flooded, snow covered, frozen or has been frozen for more than 12 hours in the previous 24 hours and weather conditions must be taken into account – no closed period applies).

However, the definition of ‘high risk times’ for fertiliser applications in this report (see Section 2.2.4) negated the need to model these measures, as option 4 with the measures included is effectively the same as option 2.

The costs and environmental impacts of implementing the measure ‘high risk times’ for applications of manufactured fertiliser are very uncertain as they will mainly depend on soil and weather conditions in early spring (i.e. February and March). If fertiliser applications are delayed until after the end of March there is an increased risk that crop yields will be affected as a result of sub-optimal crop nutrient supply. In order to assess the uncertainty associated with implementing the ‘high risk times’ measure, two options were considered, for each scenario where option ‘a’ avoided fertiliser applications between October and March and option ‘b’ avoided fertiliser applications between October and February.

The options considered reflect the requirements of European Directives, including the Nitrates Directive and Water Framework Directive, as well as retained EU Law and the responses to relevant published consultations. The responses to the consultation on the Review of the Designated Areas and Action Programme to Tackle Nitrate Pollution in Wales were the key element of the policy development. Responses to other related consultations, including on the storage of silage and slurry and the sustainable management of natural resources were also considered.

The consultations referred to can be accessed using the following links:

https://gov.wales/nitrate-vulnerable-zones-wales

https://gov.wales/review-water-resources-control-pollution-silage-slurry-and-agricultural-fuel-oil-wales-regulations

https://gov.wales/taking-forward-wales-sustainable-management-natural-resources

Consultation with stakeholders has taken place through the Wales Land Management Forum sub-group on agricultural pollution, as well as with individual stakeholders. This includes affected individuals and internal consultation with Welsh Government officials to ensure policy alignment.

Minutes of meetings of the Wales Land Management Forum sub-group and a progress report on the work of the sub-group can be found using the following link:

https://naturalresources.wales/guidance-and-advice/business-sectors/farming/wales-land-management-forum-sub-group-on-agricultural-pollution/?lang=en

The resulting regulations will be reviewed every four years but this will be dependent on our future relationship with the European Union over the coming months and years. The Welsh Government will continue to work with stakeholders, including the Wales Land Management Forum sub-group, as part of the review process.

1 Methodology and Assumptions

1.1 *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 (Gooday et al., 2014) to predict the effects of the proposed measures on pollutant losses as well as on farm costs as relevant to each policy option.

b) Using the MANNER-*NPK* tool (Nicholson et al., 2013) to model the effects of avoiding high risk times for high available N manures (cattle slurry, pig slurry, broiler litter and layer litter) in accordance with the proposed measures.

Three additional components of work were undertaken to fully account for the costs of measures and monetise the estimated pollutant reductions:

a) Estimate the costs associated with increased slurry storage capacity

b) Estimate the costs associated with record keeping and manure and nutrient planning

c) Review the damage costs associated with the different pollutants

The range of potential implementation and damage costs was accounted for with a sensitivity analysis. For some of the key measures (either those with significant costs or greater uncertainty in the costs), high, medium and low cost estimates were produced. The review of damage costs also produced a central estimate and upper and lower bounds for each pollutant. The sensitivity analysis thus considered the consequences of using the high, medium or low implementation costs, and the high, medium and low environmental damage costs.

The pollutants considered are nitrate, phosphorus, ammonia and nitrous oxide. The assessment considers the management of livestock manures only and not other organic materials (e.g. biosolids, digestate and compost)[1]. The assessment does not specifically consider the impacts of the measures on organic farming as this makes up a very small proportion of the agricultural land in Wales.

1.1.1 Farmscoper

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 losses. It was developed by ADAS with Defra and EA funding and has been used both internally within those organisations and in a number of external projects looking at the impacts of regulation and agri-environment schemes (e.g. Gooday et al., 2015; Collins and Zhang, 2016; Gooday and Whitworth 2017; Collins et al., 2018; Elliott et al., 2019).
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

[1]. The N loading from other organic materials (e.g. biosolids, digestate and compost) is estimated at less than 3% of total N inputs (BSFP, 2018).

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 tool can be used to simulate losses from multiple farming systems, to allow predictions at catchment scale or larger. A more detailed description of the model is presented in Appendix 1.

The Farmscoper tool was parameterised using June Agricultural Survey (JAS) data from 2018 for Wales. The JAS was used to determine average cropping and livestock for different farm types and sizes. The farm types considered were the 9 robust farm types (RFT), with the Cattle and Sheep LFA RFT further subdivided into Specialist Sheep, Specialist Beef and Mixed; the farm sizes considered were based on standard labour requirement. Separate farms were made for land inside and outside of the proposed NVZ area. The total number of farms in Wales, by type and size, is shown in Table 1-1. Additional management information for these farms was taken from national stratified surveys including the 1st and 2nd Welsh Farm Practice Surveys (Anthony et al., 2011; Anthony et al., 2016), the Defra Farm Practice Surveys and the British Survey of Fertiliser Practice.

Table 1-1: Number of farms in Wales by farm type and farm size (based on standard labour requirement)

	Hobby	Small	Medium	Large	Total
Cereal	304	62	25	29	**420**
General Cropping	76	19	9	23	**127**
Horticulture	769	27	9	25	**830**
Specialist Pig	220	2	2	1	**225**
Specialist Poultry	981	32	28	52	**1,093**
Dairy	188	205	307	914	**1,614**
LFA – Specialist Sheep	2,162	863	535	1,126	**4,686**
LFA – Specialist Beef	816	138	24	31	**1,009**
LFA – Mixed Livestock	3,803	1,066	627	860	**6,356**
Lowland Cattle and Sheep	1,750	403	156	191	**2,500**
Mixed Livestock	892	110	48	119	**1,169**
Other	4,285	336	94	63	**4,778**
Total	**16,246**	**3,263**	**1,864**	**3,434**	**24,807**

Pollutant losses were calculated for each of these different farms under each of the soil and climate zones recognised by Farmscoper, with the results expressed as losses per hectare. These losses were then mapped back on to the LPIS field parcels (where every field parcel had been assigned to a farm type, size, climate and soil type and either inside or outside the proposed NVZ area).

The LPIS dataset contained information for 610,000 field parcels, covering a total area of 1.69m hectares. For 545,000 of these parcels, a farm ID was provided, for 23,470 different farms. Of these farms, 14,663 could be directly linked to JAS farms (which accounted for 1.20m hectares). A further 5,898 farms (62,759 fields; 0.18m hectares) were joined to JAS farms by matching as close as possible the LPIS area of a farm with the JAS area for all unmatched farms, with matches constrained by the Small Area (a spatial designation) allocated to each JAS farm and the Easting and Northing provided. A total of 4,246 of the JAS farms (out of 24,807) were unaccounted for, and these were classed as either 'other' or hobby farms (which accounted for over 85% of the unmatched Jas farms) which have low nutrient use and very few livestock. In the creation of the 'average' farms used in the Farmscoper modelling, the livestock numbers were scaled to ensure the total livestock numbers across Wales (and within the proposed NVZ area) remainder close to the JAS totals when distributed across the LPIS parcels. Although there is some uncertainty about the accuracy of the mapping of the farm data, the methodology was designed to preserve JAS livestock numbers and LPIS land areas. As the results in this report are being summarised at national (or proposed NVZ) scale, the spatial uncertainty has limited impact on the overall modelled outputs.

Changes in pollutant losses predicted by Farmscoper due to measure implementation depend on (i) the effectiveness of the measures at reducing pollution and (ii) the current (and future) uptake of the measures. Parameterisation of these values are based upon the scoring system shown in Table 1-2, with a central value selected that represents the range within which the impact or implementation is expected to be[2], - the values selected to parameterise the different mitigation measures are described in the following sub-sections. Farmscoper uses a source apportionment coordinate system, so the impact of a mitigation measure may be targeted at one (or more) of the coordinates – for example buffer strips may reduce losses by 50% in surface runoff, but have no impact on losses in drain flow or to groundwater.

[2] This could reflect, for example the uncertainty in survey data or its applicability, or the variation in evidence for effect. The use of a scoring system allows for easy comparison between the different pollutants and multiple mitigation methods within Farmscoper.

Table 1-2 Confidence ranges and central values used by Farmscoper for estimating current implementation of measures and impact potential

Category	Implementation or Impact (%)	Uncertainty Range	Description
A	-	-	None
B	2	0 to 10	Very Low
C	10	2 to 25	Low
D	25	10 to 50	Moderate
E	50	25 to 80	High
F	80	50 to 95	Very High
G	100	100	Total

1.1.2 MANNER-*NPK*

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 MANNER-*NPK* decision support tool is recognised as the industry standard tool for estimating crop available nutrient supply, nitrate leaching and ammonia volatilisation losses following manure applications. It was used to derive the 'look up' tables in AHDB's Nutrient Management Guide (AHDB, 2020) which detail crop available N supply from contrasting manure application timings and methods

1.2 *Description of measures*

1.2.1 Use a fertiliser recommendation system

Description

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.

(i) Nitrogen

Most agricultural soils require applications of nitrogen from fertiliser and/or organic materials on an annual basis to ensure optimum crop growth. Most of the mineral nitrogen in the soil is present as nitrate, which is mobile in the soil. Any nitrate that is present in the soil at the start of the winter is unlikely to be taken up by crops as growth slows due to cold temperatures and reduced light intensity. When excess winter rainfall occurs, and water drains through the soil the nitrate is at risk of being lost from the soil by leaching.

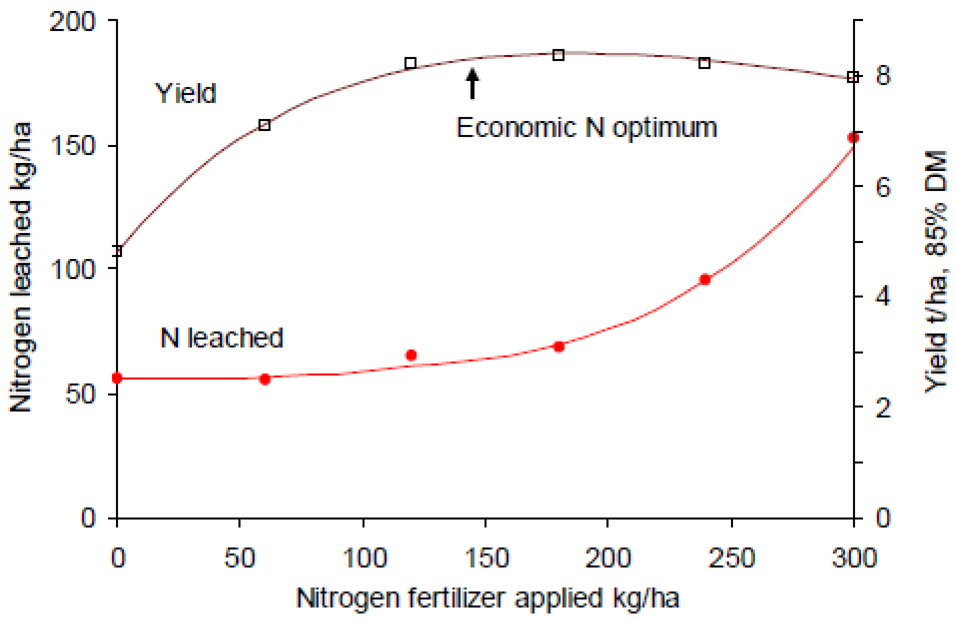

Figure 1-1: Impact of manufactured fertiliser nitrogen applications on winter wheat yields and nitrate leaching losses (Lord and Mitchell, 1998)

Nitrogen applications to arable crops that supply less than economic optimum will result in sub-optimal crop yields and quality whilst applications that exceed crop requirement will increase the risk of nitrate leaching (Figure 1-2; Lord and Mitchell, 1998; Figure 2-2 Johnson et al., 2011).

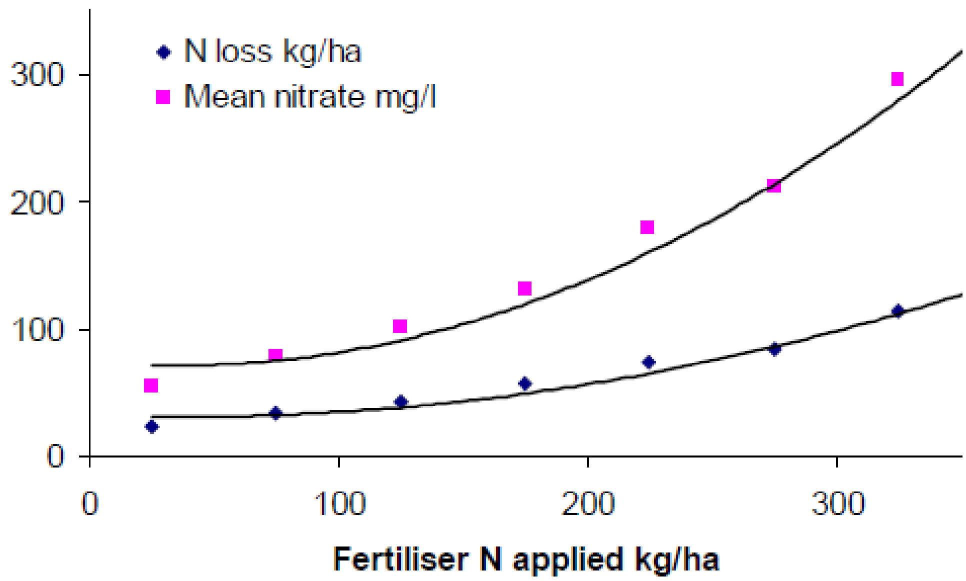

Figure 1-2: The effect of nitrogen fertiliser applications on drainage water nitrate concentrations and nitrate leaching losses (Johnson *et al.*, 2011)

Nitrous oxide emissions occur from soils as a result of the microbially mediated processes of nitrification and denitrification. Factors that affect nitrous oxide emissions include soil moisture content, temperature and mineral nitrogen content. Generally nitrous oxide emissions are related to nitrogen inputs from manures and fertilisers with elevated emissions where nitrogen supply exceeds crop requirement (Figure 1-3; Cardenas *et al.*, 2010).

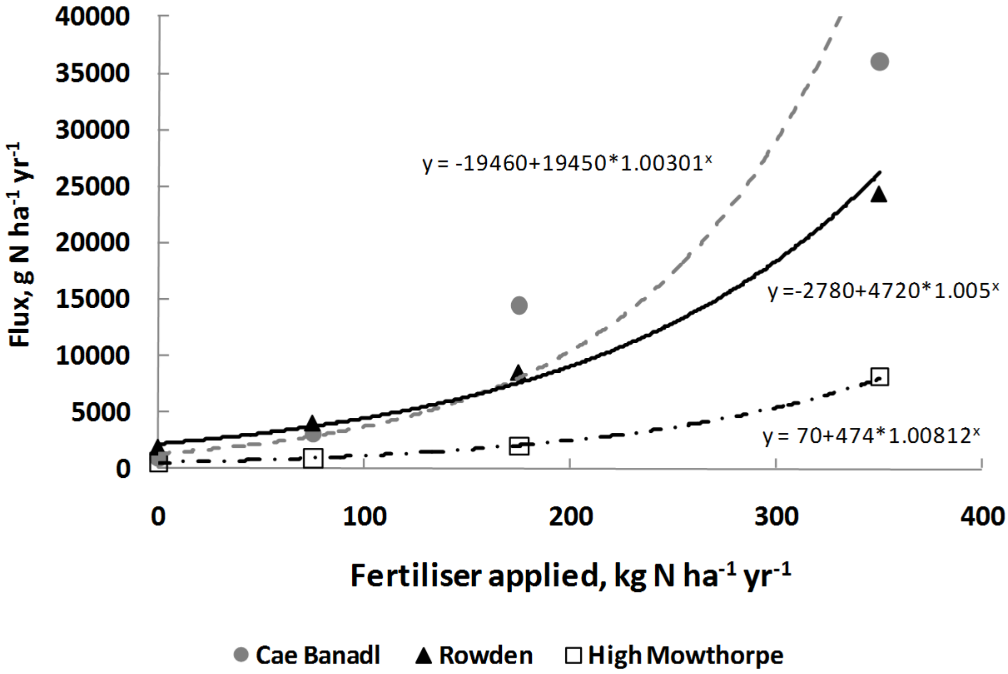

Figure 1-3: The effect of manufactured fertiliser nitrogen application rate on nitrous oxide emissions at 3 contrasting grassland sites (Cardenas *et al.*, 2010).

(ii) Phosphorus

A large proportion of phosphorus (P) in soils is bound in forms that are not readily available to the plant or at risk of leaching to water (i.e. fixed or residual P), because of the strong affinity that some soil substances (clays, iron-Fe/aluminium-Al/calcium-Ca) have for P (Holford, 1997). Consequently, managing crop available P supply is based on maintaining sufficient amounts in the soil for the needs of a crop rotation rather than an individual crop.

AHDB's Nutrient Management Guide (RB209) uses a soil P index system (based on the Olsen extractable P levels in topsoil) to provide guidance on P supply from manufactured fertilisers and organic materials. For grassland and most arable crops the target soil P index is 2 (16-25 mg/l Olsen P). For soils below the target index it is recommended to apply P at rates that exceed crop offtake to ensure optimum crop yields and to build up soil reserves. Where soils are at target index, fertiliser rates should match crop offtake to maintain soil fertility at optimum levels and where soil P levels are above target index, P fertiliser applications are not recommended as they represent an unnecessary cost and increase the risk of P losses to water (Figure 1-4; Poulton *et al.,* 2013, Heckrath *et al.,* 1995 Withers *et al.,* 2017).

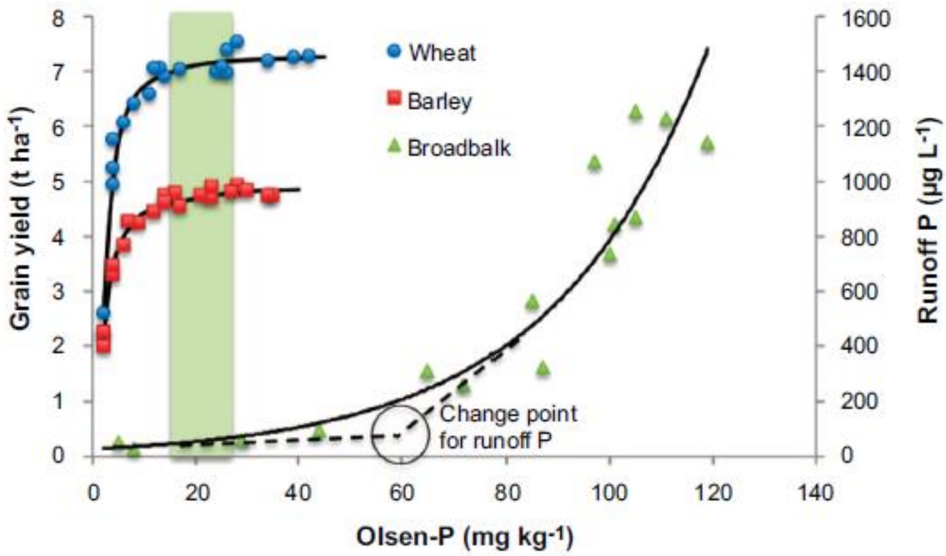

Figure 1-4: The impact of Olsen extractable P levels on crop yields and soluble P losses to water (Poulton *et al*., 2013, Heckrath *et al.,* 1995). Graph taken from Withers *et al.,* (2017).

The extent to which soil is saturated with P will influence the risk of P losses to water. The soil saturation capacity depends on the quantities and forms of Fe, Al and Ca present in the soil and P is more strongly bound in the order Fe>Al>Ca (Withers, 2011). Risks of P loss to water have been reported to greatly increase once P saturation exceeds a threshold of 20-30% (Heckrath *et al*., 1999, Kleinman *et al*., 2000; Nair *et al*., 2004). P saturation threshold broadly equates to Olsen soil P indices of 3, 4 and 5 for sand, loam and clay soils, respectively. Consequently, soils with P indices above these levels represent an increased risk of P losses to water.

At the farm level, the impact of fertiliser recommendation schemes on increasing nutrient use efficiency and reducing diffuse pollution will vary depending on the current level of nutrient use. Data from the British Survey of Fertiliser Practice (2018) indicate 88% of tillage land and 52% of grassland in England and Wales received applications of manufactured fertiliser nitrogen in 2017. Fertiliser phosphate was applied to only 44% of tillage land and 30% of grassland in England and Wales.

The survey data suggest that this method is likely to have a small overall impact on fertiliser use. The average field rates for nitrogen reported in BSFP are similar to those typically recommended in AHDB's Nutrient Management Guide (RB209) for arable crops and application rates on grass are typically lower than those recommended in RB209 (Figure 1-5; Figure 1-6). Also, data suggest that applications of phosphate and potash fertiliser have declined over recent years (Figure 1-7) with little scope for further reductions.

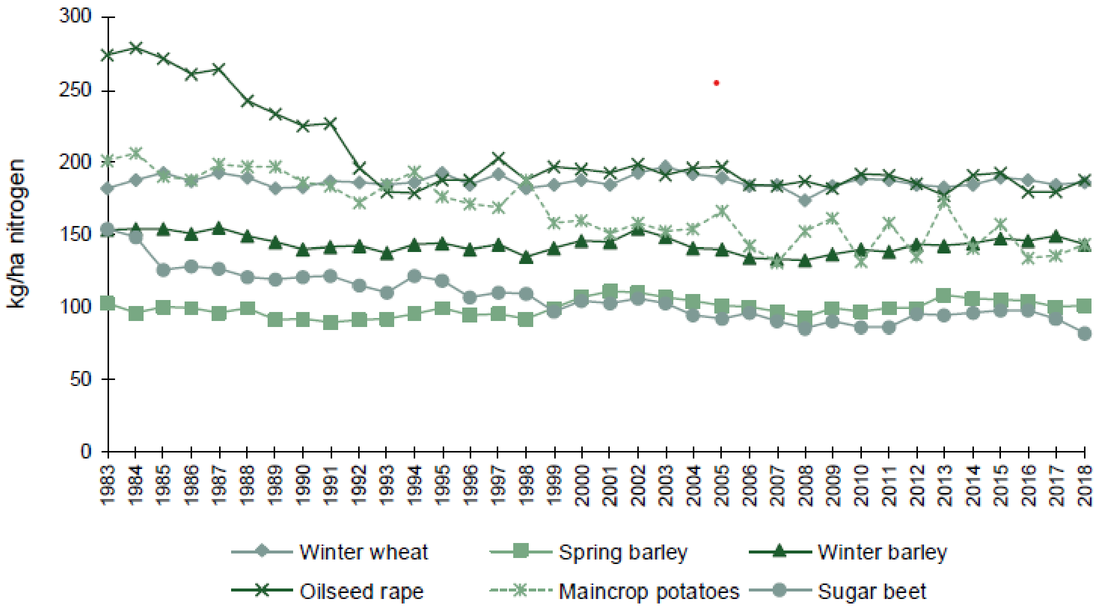

Figure 1-5: Average nitrogen fertiliser rates applied to tillage crops across England and Wales (Taken from BSFP, 2018)

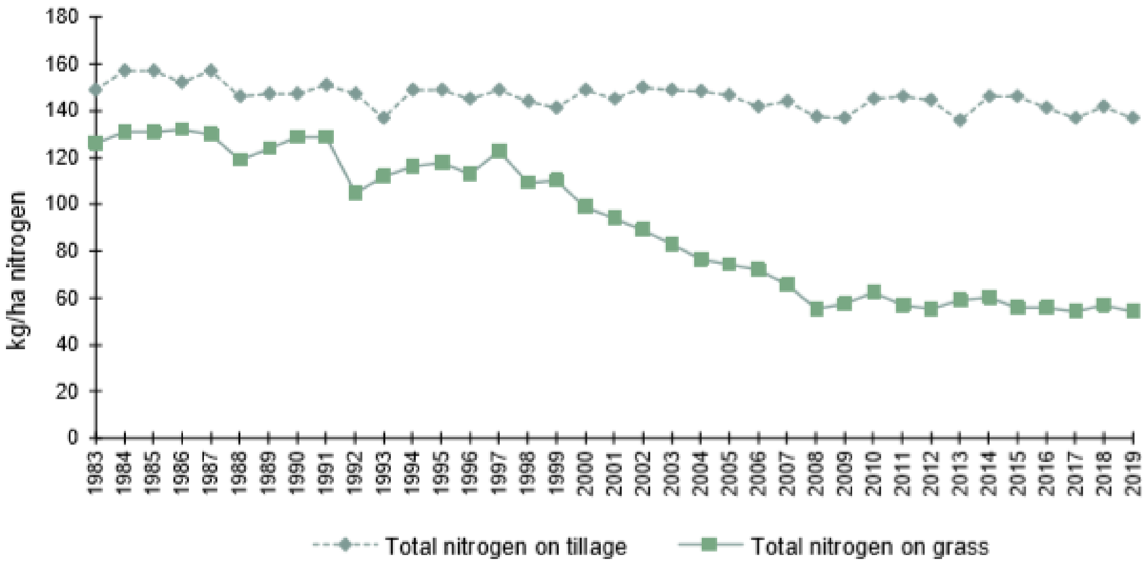

Figure 1-6: Total nitrogen fertiliser use across tillage and grassland in Great Britain (BSFP, 2019)

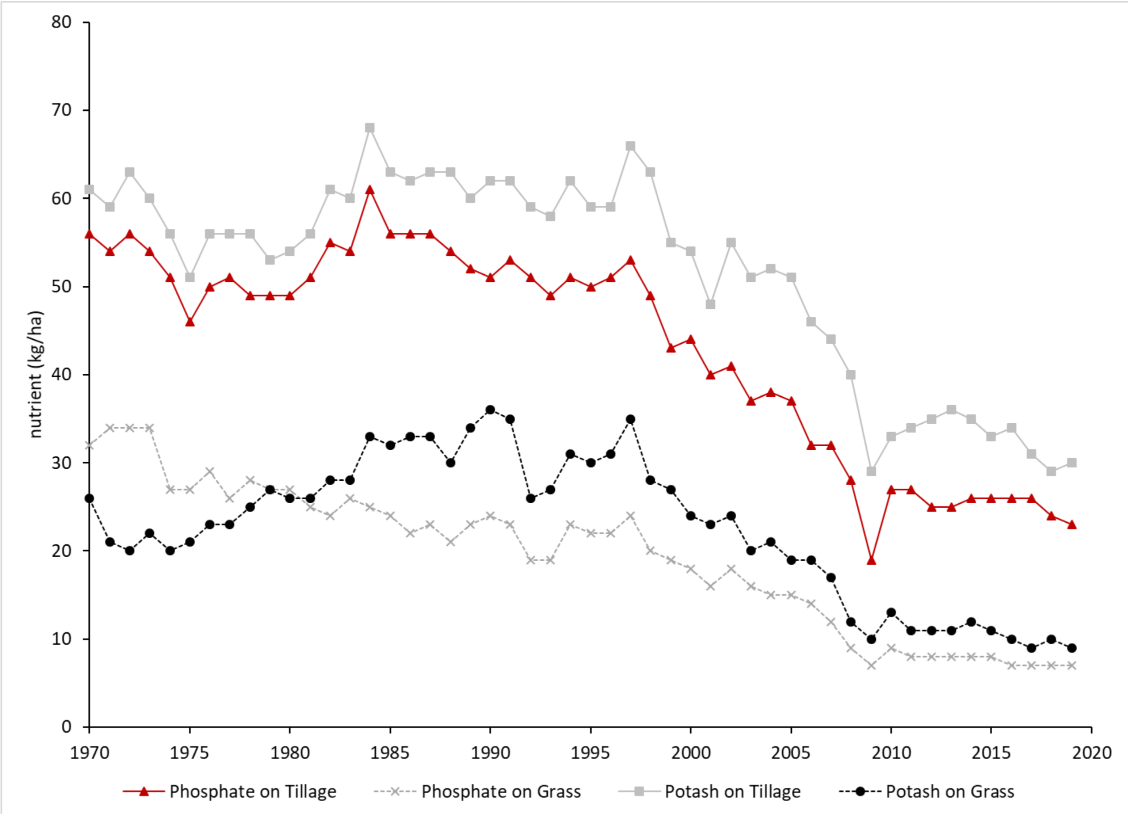

Figure 1-7: Average field phosphate and potash rate across England and Wales (BSFP, 2019)

Anthony et al (2012) reported that the majority of farmers in Wales either used their own knowledge (64%) or took professional advice (35%) when estimating fertiliser requirements and that only 4% claimed to use RB209 or any software directly themselves revealing scope for improvement. Anthony et al (2016) reported that 39-57% of surveyed farmers in Wales used a fertiliser recommendation system.

Based on expert knowledge, responses to the survey and modelling results it was determined that the use of a fertiliser recommendation systems would result in no reduction in phosphorus losses and between a 5 – 10% reductions in nitrate losses from arable and grassland systems. These calculations were based on the following assumptions:

- For manufactured phosphorus the use of a fertiliser recommendation system was interpreted as ensuring a balance of annual fertiliser input and crop off-take to maintain an appropriate soil phosphorus index.

- For nitrogen it was assumed that the use of a recommendation system would enable an improvement in the precision of applications rather than a reduction in the quantity applied. The NITCAT and N-CYCLE models (Lord, 1992; Scholefield et al., 1991) were then used to calculate the effect of a 25% reduction in the average error in estimating optimum nitrogen for the crops on each of representative farm types.

After discounting livestock manure phosphorus input-offtake balances were all negative and indicated that fertiliser applications could not be reduced in the absence of manures. There was, therefore, no direct impact of this mitigation method on the use of manufactured phosphorus fertiliser.

Anthony et al., (2012) conclude that more precise use and application of manufactured nitrogen fertiliser is likely to reduce nitrate losses from the combined fertiliser and soil nitrogen supply by between 5 and 10% for both arable and grassland.

Newell Price *et al.,* (2011) suggested that the use of fertiliser recommendation systems had the potential to reduce nitrogen and phosphorus losses to water and ammonia and nitrous oxide emissions to air by c.5%.

Williams et al., (2017) suggest that where excess nutrients are applied implementing a nutrient management plan can reduce fertiliser costs and risks of water and air pollution. However, where insufficient nutrients are applied a nutrient management plan may lead to increased fertiliser use which may increase absolute losses to the environment but reduce losses per unit of production. Information from Welsh Farm Practice Survey (Anthony 2012) reported 43% of farmers have a soil nutrient plan suggesting there was scope to improve the precision of fertiliser application rates for each year.

Representation in Modelling

Based on the information described above, Farmscoper assumes that losses associated with nitrogen fertiliser will be reduced by 10%, whilst those with phosphate fertiliser by 2%, reflecting the lower potential for changes in P fertiliser usage.

Farmscoper assumes that improvements in nutrient use efficiency that come from matching crop available nutrient supply to crop demand and soil nutrient status, ensuring optimal fertiliser timings and the maintenance of soil pH at target levels will reduce average fertiliser inputs by 5% on arable farms and increase average productivity of grassland by 10% compared with baseline, which equates to savings of approximately £5 ha^{-1} and £11 ha^{-1} respectively.

Current implementation of this measure in Farmscoper is assumed to be 50% as a baseline, with rates higher inside NVZ areas and lower on extensive grazing systems. This is based on Defra Farm Practice Survey (2012), which found 16% and 48% of farmers use the Tried and Tested paper based planning system or PLANET software, respectively, and the 2nd Welsh farm Practice Survey (Anthony et al., 2016) which found 57% of Dairy farmers used a fertiliser recommendation system, but only 40% of cattle and sheep farmers did.

1.2.2 Integrate fertiliser and manure nutrient supply

Description

Organic materials are valuable sources of plant nutrients and if used effectively they can reduce the need for applications of manufactured fertilisers to meet optimum crop needs (Table 1-3). Fertiliser recommendation systems (e.g. RB209, PLANET, MANNER-*NPK* and other supplementary guidance) provide guidance on how to make full allowance of the nutrients applied in organic manures and reduce manufactured fertiliser inputs accordingly. Laboratory analysis of manures can provide better understanding of manure nutrient contents and supply. MANNER-*NPK* information on application rates, timings and methods can be used to quantify crop available nutrient supply and provide estimates of nitrogen losses to water and air following application.

The nitrogen fertiliser replacement value of organic manures can be increased by applying manures in spring to reduce nitrate leaching losses. For slurries, the use of precision application techniques can reduce ammonia emissions and ensure that applications are spread evenly across known bout widths. In order to maximise the nitrogen value of slurry and poultry manures it is usually necessary to apply them in spring to minimise nitrate leaching losses. The use of low emission spreading techniques such as trailing hose on arable land and trailing shoe and shallow injection of grassland will reduce ammonia losses and further increase the nitrogen value of slurry.

For solid manures it is likely that applications will supply more phosphate and potash than is used by a crop in a single year. Consequently, annual applications of manure to the same field can increase soil P contents to levels where there is an increased risk of P losses to water. Targeting manure applications to fields where soil P and K status are below target indices will maximise manure fertiliser replacement values.

Table 1-3: Nutrients supplied by spring application timings of different organic materials (based on typical manure analysis figures in AHDB's Nutrient Management Guide (RB209))

Manure type	Application Rate (t/ha)	Crop Available N (kg/ha)	Total P_2O_5 (kg/ha)	Total K_2O (kg/ha)	Crop Available SO_3 (kg/ha)
Pig Slurry	35	63	63	84	12
Pig FYM	35	25	210	280	30
Cattle Slurry	40	36	48	128	10
Cattle FYM	40	24	128	320	14
Poultry Manure	8	72	200	144	38
Biosolids Cake	20	33	360	12	24

The impact of this measure on reducing diffuse pollution will depend to what extent farmers are already accounting for nutrients supplied by organic materials when planning their manufactured fertiliser use. The BSFP (2019) suggests that where farmers have used organic materials manufactured fertiliser nitrogen and phosphate applications were reduced by c. 20 kg/ha N and c.15 kg/ha P_2O_5, respectively.

The savings in nitrogen fertiliser use as a result of integrating manures into nutrient management plans will represent an annual saving once the method has been adopted. However, the P and K value of the manure applications will depend on the P and K status of the soil. Where soils are deficient in P and K i.e. at soil index 0 and 1, then the available crop P and K fraction of the manure should be accounted for. When soils are P and K index 3, there is no requirement for fertiliser P and K for grass and arable crops, consequently the P and K applied by the manures will have no value. Information from the PAAG suggest that c. 30% of soils in Wales exceed target levels and will not require annual P and K inputs from either manufactured fertilisers or organic materials to support optimum crop growth.

In order to identify the maximum and minimum cost benefit for this measure two scenarios (i) accounting for manure N only and (ii) accounting for all manure nutrients have been assessed for each option.

Representation in Modelling

Farmscoper assumes that fertiliser losses could be reduced by up to 25%, depending upon the amount of manure applied relative to the amount of fertiliser currently used. Farmscoper assumes a saving is made due to reduced fertiliser usage, which is estimated at £6 per tonnes of FYM and £3 per m^3 of slurry and £28 per tonne of poultry manure. These figures are based on current fertiliser prices for nitrogen, phosphorus and potash, assumed nitrogen efficiency and nutrient availability. However, there is uncertainty surrounding the fertiliser replacement value of the manure. It is possible to account for the nitrogen fertiliser replacement value of the manures as in the vast majority of agronomic situations annual applications of nitrogen are required for optimal crop growth. In contrast the phosphate and potash value of the manure applications will depend on the supply of these nutrients from the soil with no requirement for manufactured fertiliser P and K inputs to arable and grass crops when soils are at or above soil index 3 and for horticulture, potatoes and maize crops when soils are at or above index 4. Accounting for only the nitrogen in manures reduces the savings in slurry to £0.6 per m^3 and poultry manure to £4 per tonne. There is not assumed to be a reduction in the number of fertiliser applications, which could result in an additional cost saving.

The 2nd Welsh Farm Practice Survey (Anthony et al., 2016) found that the percentage of farmers using professional advice or manure testing, and standard values such as RB209 to assess the nutrient value of spread manures was 19 and 11% respectively. However, the majority of farmers (73%) assessed the nutrient value of spreads manures using own knowledge and experience, whereas 20% of farms did not assess at all. Of these, 50% solely rely on own knowledge or experience when assessing the nutrient value of spread manures. The Defra Farm Practice Survey (2012) found 57% of farms assess or calculate the value of their manures, and only 24% tested the nutrient content by taking samples. Based on this current implementation of this measure in Farmscoper is assumed to be 50% as a baseline, with rates higher inside NVZ areas and lower on extensive grazing systems. Information provided by Menter a Busnes (Cate Barrow, Pers |comm) suggest that since 2016 c. 3,000 nutrient management plans have been completed via Farming Connect. This may suggest that the 50% baseline in Farmscoper is an underestimation of the implementation of this measure. However, details of farm type, size and nutrient use for the farms and information on whether farmers are following the plans is not available.

1.2.3 Do not apply manufactured fertiliser to high-risk areas

Description

Do not apply manufactured fertiliser to field areas where there is a significant risk of fertiliser getting into surface water. This could include sloping land or 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. Not applying fertiliser to crops will significantly reduce yields as there will be insufficient crop available nutrient supply to support optimum crop growth.

The following evidence suggests that ‘high risk areas’ occupy approximately 5% of the agricultural area:

- Compaction due to machinery: Anthony et al (2012a) found this was reported on 25% of dairy farms and 10% of cattle and sheep farms. The compacted area within such fields is estimated at 1-2% of the total area.
- Poaching from livestock: Gooday et al (2015) reviewed a range of evidence which suggested that 3% of field areas had visible poaching damage from livestock. Observations suggest that an area of poaching around a livestock feeder or trough can cover 20m around the feeder, which equates to c2% of a 5-ha field.
- Anthony et al (2012b) surveyed areas of soils with tile drainage and the area of land affected by evidence of drain failure. The proportion of land affected by sustained waterlogging ranged from 2% on arable farms to 13% on upland cattle

and sheep farms. As a proportion of all soils (not just those with tile drainage), the affected area would be a smaller percentage.

There are no surveys which provide information on the amount of fertiliser applied to steeply sloping land. In this study it is assumed that nationally very small amounts of fertiliser are applied to steeply sloping land due to the practicalities involved, and so any additional impacts from avoiding these areas have not been accounted for.

Representation in Modelling

Farmscoper assumes losses associated with fertiliser on the 'high risk areas' are entirely negated.

The 2nd Welsh Farm Practice Survey (Anthony et al., 2016) found a baseline of 56% of dairy farmers had a soil nutrient management plan, but only 25% of cattle and sheep farms in SDAs. Farms in Glastir, Tir Gofal or Tir Cynnal were more likely to have soil nutrient management plans. Farmscoper assumes a baseline of 50% of 'high risk areas' are avoided, with values greater inside NVZs and lower on cattle and sheep farms.

Farmscoper assumes a 50% yield reduction for arable crops and 30% reduction in grass yields over 5% of the agricultural area as a result of implementing this measure, which equates to £210 ha^{-1} and £600 ha^{-1} for high risk areas on grassland and arable land respectively. There would also be the need to identify high risk areas, typically through the creation of a nutrient management plan. Costs of this are dealt with separately (see Section 1.4.1).

1.2.4 Avoid spreading manufactured fertiliser to fields at high-risk times

Description

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 drain flow. 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.

The risks of water pollution following application of manufactured fertilisers will vary according to soil type which controls the pathway for water and nutrient loss and on the soil moisture content. Nitrate is mobile in soils and is at risk of being leached from the soil when drainage occurs. Phosphorus is more immobile in soils and the risks of phosphorus leaching is highest when soils are saturated with P or where rapid transfer of P from the soil to water occurs following applications of fertiliser P or organic manures.

On sandy soils (which occupy less than 5% of Wales; Figure 1-8), drainage occurs slowly over winter by piston displacement in the unsaturated phase, with wetting fronts moving to depth at rates of a few metres a year depending on drainage volumes and the pore volume of the soil and base rock. Consequently, the highest risk of water pollution on sandy soils is following nitrogen fertiliser applications in the autumn/winter period when the nitrate supplied is unlikely to be taken up by crop growth.

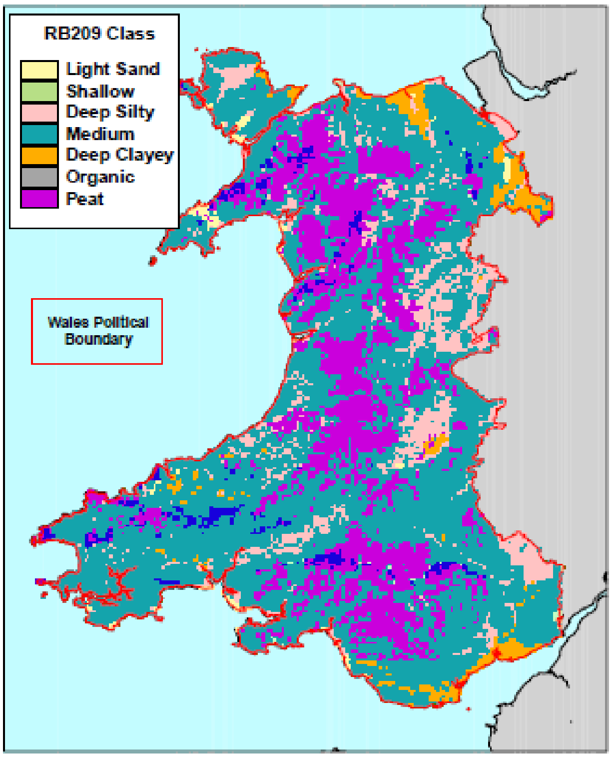

Figure 1-8: RB209 soil classification for Wales

On undrained clay and medium loam soils, surface runoff is likely to occur in rapid response to rainfall events, because of the impermeable nature of the soil matrix (Goss *et al.,* 1978). Where an effective drainage system is present, much of the water that would otherwise be lost as surface runoff, will move rapidly from the soil surface through macropores that have developed naturally or have been created through the installation of pipe drains, mole drains or subsoiling fissures, with transit times influenced by rainfall volume and intensity (Goss *et al.,* 1983). On these soil types which occupy the majority of the productive land in Wales (Figure 1-8) the highest risk of water pollution following fertiliser application is likely to be when soils have a soil moisture deficit of less than 10mm – i.e. drainage will occur when hydrologically effective rainfall (I.e. rainfall-evapotranspiration) exceeds 10mm.

As part of this study the IRRIGUIDE water balance model (Bailey and Spackman, 1996) was used to quantify high risk times by estimating daily soil moisture deficits for two soil types (sandy loam and clay loam), two crop types (grass and winter wheat) for 9 locations chosen to be representative of contrasting agroclimatic zones across Wales (i.e. Aberystwyth, Llangefni, Bangor, Wrexham, Fishguard, Haverfordwest, Welshpool, Newport Pembrokeshire and Newport Gwent). The model was run using 30 year (1987-2018) average climate data for each site. The model uses information on volumetric moisture content, crop cover, rooting depth and weather data to estimate evapotranspiration and soil drainage.

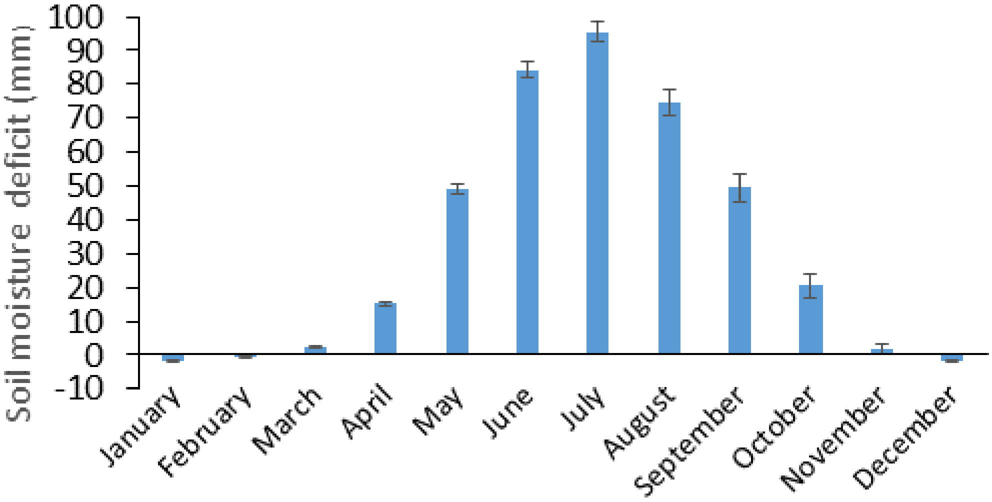

Figure 1-9: Average estimated monthly soil moisture deficit in Wales (based on 30 year average climate data from 9 sites across Wales)

The model runs indicate that, on average, soils across Wales were close to field capacity at the end of February (i.e. soil moisture deficit close to 0) with soil moisture deficits of less than 10 mm predicted at the end of March (Figure 1-9). There was some annual variation in soil moisture deficit at the end of March. In 6 years out of 30 (1990, 1997, 2002, 2003, 2012 and 2019) soil moisture deficits greater than 10 mm were predicted at the end of March. These drier years contrasted with 6 years (1992, 1994, 2006, 2009, 2010 and 2015) when soils were at field capacity or drainage was occurring at the end of March. There was little difference in estimated soil moisture deficits between soil and crop types reflecting the low growth rates during the winter months for grass and arable crops. This suggests that applying fertiliser during February and March could be considered 'high risk'.

There are few studies that have investigated the impact of fertiliser application timings by date on crop yields. Generally, the guidance provides information to ensure that sufficient nitrogen is applied to support crop growth at critical points in the growing season. E.g. In cereals, when the crop is growing rapidly between growth stages 30 and 39 (Stem extension and Flag leaf emergence; Figure 1-10) which usually occurs between the end of March to the middle of May depending on soil and weather conditions.

Figure 1-10: Growth stages for Winter wheat (taken from AHDB's Wheat Growth Guide (www. ahdb.org.uk/wheatgg)

For winter wheat, AHDB's Nutrient Management Guide recommends that '*where more than 120kg/ha N is required 40 kg/ha N should be applied between mid-February and early March. The balance of the application should be applied in one or two dressings during early stem extension. Where more than 120 kg N/ha remains to be applied, half should be applied at the start of stem extension (not before April) and half at least two weeks later (not after early May)*'.

Information provided by ADHB's Wheat Growth Guide suggests that delaying fertiliser applications until early April is unlikely to have a significant impact on wheat yields in most years. Similarly, on grassland soil and weather conditions are likely to have more significant impact on grass growth than delaying fertiliser applications until early April. However, where weather conditions prevent uptake of nitrogen in April and May (e.g. continued period of dry weather following application) there is a risk that cereal and grass yields will be reduced.

Delaying fertiliser applications until the end of March is likely to significantly affect crops established in late winter/early spring which have a requirement for fertiliser to be applied in the seed bed. For example, early potatoes, which are typically planted in south-west Wales at the end of January or beginning of February would be particularly disadvantaged if the measure prevented fertiliser applications in February. The crop is usually grown on c. 500-1000 ha.

Representation in Modelling

In order to assess the uncertainty of this measure on operational costs and environmental benefits yields two versions of this measure were modelled for each option. For Option 'a' fertiliser applications were not allowed from October to March, and Option 'b' fertiliser applications were not allowed between October to February.

Surveys suggest that a small amount of N and P fertiliser is applied before March (c. 6% of total applications; BSFP, 2018), so the impacts of this restriction window (to end of February) on losses to water were small – a 2% reduction in N and P losses in runoff or drain flow shortly after application (as opposed to residual losses post-harvest for nitrogen, which will be unchanged). With the restrictions lengthened into March, reductions a 10% reduction in nutrient losses from fertiliser applications during this period was assumed.

As the modelling that underpins Farmscoper is based upon fertiliser timing information derived from the British Survey of Fertiliser Practice, current implementation is captured in the modelling and so the implementation of the mitigation measure is set to 0.

With restrictions on fertiliser applications to the end of February, it was assumed that crop yields were unaffected, so there was no cost associated with option b. With restrictions to the end of March (option a), Farmscoper assumes a 10% reduction on crop yields one year in 10 to reflect yield reductions that may occur from sub-optimal crop available nutrient supply early in the growing season.

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

Description

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 nitrate leaching, surface runoff or drainflow to water i.e. when soils are ‘wet’.

The current statutory requirement for farmers outside Nitrate Vulnerable Zones is to comply with the Water Resources (Control of Pollution) (Silage, Slurry and Agriculture Fuel Oil) (Wales) Regulations 2010 (SSAFO) which require storage of 4 months excreta production and an allowance for the highest rainfall expected in 5 years (M5). This method assumes that increasing slurry storage capacity to 5 months excreta production plus M5 rainfall will reduce the likelihood that slurry will be applied to land under conditions which are likely to increase the risk of water pollution.

Representation in Modelling

Farmscoper assumes that losses of ammonia from manure storage will be increased by 25% due to the increased amount of manure being stored being increased by 25% (there is potentially a marginal further increase due to the increased surface area of the store), but losses of ammonia from manure spreading will consequently be decreased.

The impacts of improved timing of manure applications, facilitated by the increased storage, are described in Section 1.2.7.

The costs of implementing this measure were calculated separately (see Section 1.4.2).

1.2.6 Do not apply manure to high-risk areas

Description

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.

‘Avoiding high risk areas’ for manure applications is assumed to affect the same area as for fertiliser applications i.e. 5% of the agricultural area. However, it is assumed that there is no impact on crop yields as a result of introducing this measure as the likelihood that manures were the sole source of nutrient inputs to support crop growth in these areas is small.

Representation in Modelling

Farmscoper assumes short term incidental losses associated with manure on the ‘high risk areas’ are reduced by 80%. Losses are not entirely negated (unlike not applying fertiliser to high risk areas) as the manure will still be applied somewhere.

To avoid double counting costs from reduced yields associated with sub-optimal nutrient supply from both this measure and ‘Do not apply manufactured fertiliser to high-risk areas’, and the difficulty in determining what proportions of crop nutrient demands are met by fertiliser or manure (within these high risk areas), the potential yield penalty has been attributed solely to ‘Do not apply manufactured fertiliser to high-risk areas. In this study, the only costs implementing this measure are associated with the need to identify high risk areas, typically through the creation of a manure management plan. Costs of this are dealt with separately (see Section 1.4.1).

Implementation of this mitigation measure is 80%, with higher rates inside NVZ areas and lower rates on cattle and sheep farms. The Defra Farm Practice Survey (2012) found 65% of grazing livestock farms and 90% of dairy farms had a manure management plan. The 2nd Welsh Farm Practice Survey (Anthony et al., 2016) found a baseline of 83% of dairy farmers had a manure management plan, but only 50-60% of cattle and sheep farms. Farms in Glastir, Tir Gofal or Tir Cynnal were more likely to have soil nutrient management plans.

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

Description

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).

As is the case for manufactured fertiliser applications the risks of nitrate and phosphorus losses to water following slurry applications will vary according to soil and crop type, soil moisture content and rainfall in the days/weeks after application. Data reported by Chambers et al. (2000) suggest that up to 20% of total nitrogen supplied by slurry and poultry manure applied to free- draining soils before the establishment of winter cereals can be lost by nitrate leaching (Figure 1-11). Similarly nitrate leaching following autumn applications to grassland were 15% of total N applied compared with less than 5% from late winter/early spring timings (Figure 1-12). Nitrate leaching occurs following slurry / poultry manure applications in autumn/early winter as a result of readily available N being added to the soil at a time when there is little N uptake by crops. The amount of N lost by leaching is controlled by the amount of readily available N supplied and the volume of drainage after application. Nitrate leaching losses from farmyard manure are lower than from slurry and poultry manure applications reflecting their lower readily available N content.

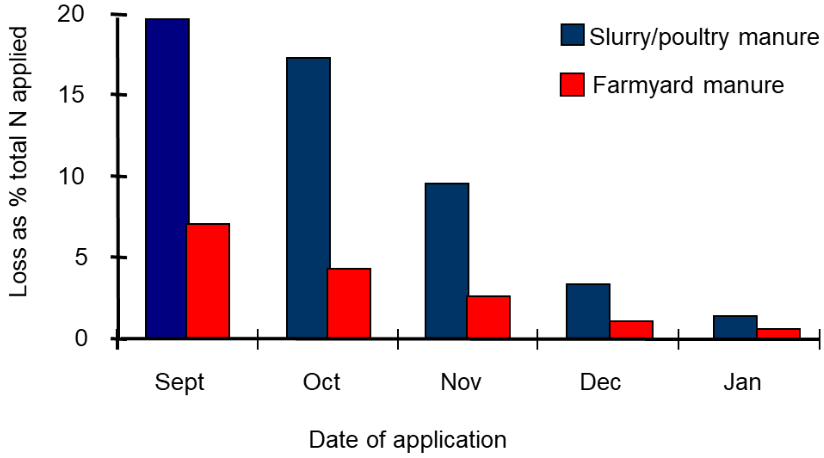

Figure 1-11: Nitrate leaching losses following contrasting application timings of slurry/poultry manure and farmyard manure to free-draining arable soils

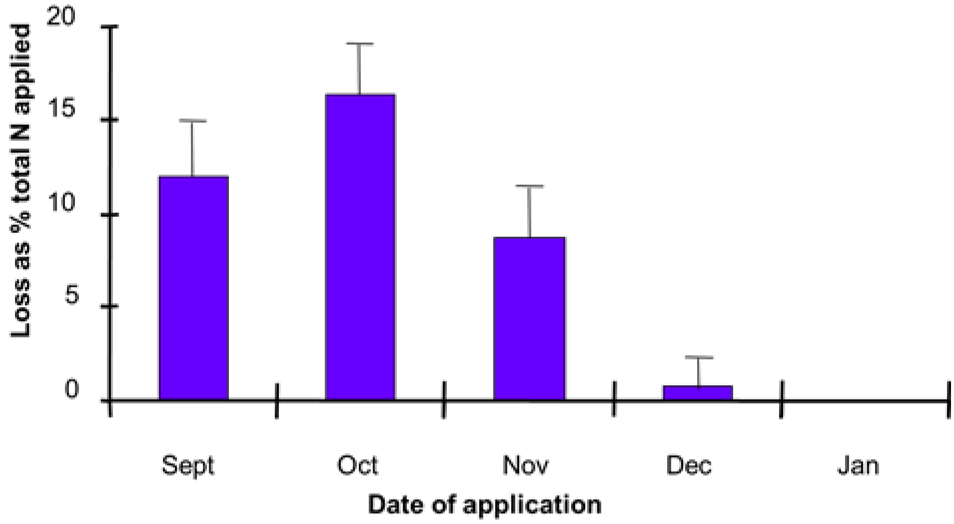

Figure 1-12: Nitrate leaching losses following contrasting cattle slurry applications to free draining grassland soils (Chambers et al., 2000)

On clay and medium soils the risks of water pollution are greatest when slurry applications are made to soils that are ‘wet’. Defra project WQ0118 investigated the effect of contrasting slurry application timings on drainage water quality at three sites in England over 4 drainage seasons. The project showed that when slurries were applied to soils with moisture deficits of less than 10 mm, and rainfall occurred within 2 weeks of application, drainflow ammonium-N and phosphorous concentrations increased (Figure 1-13 and Figure 1-14) and contaminated drainage water was observed (Figure 1-15).

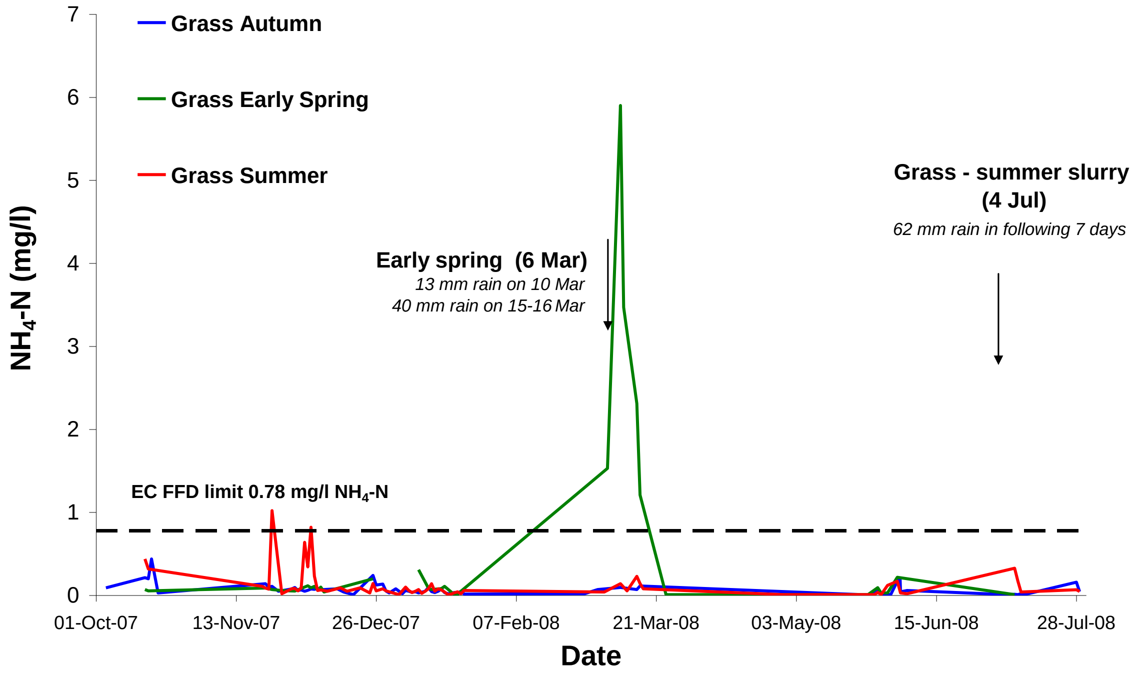

Figure 1-13: Ammonium-N concentrations in drainage water following contrasting slurry application timings to drained clay soils (Defra project WQ0118)

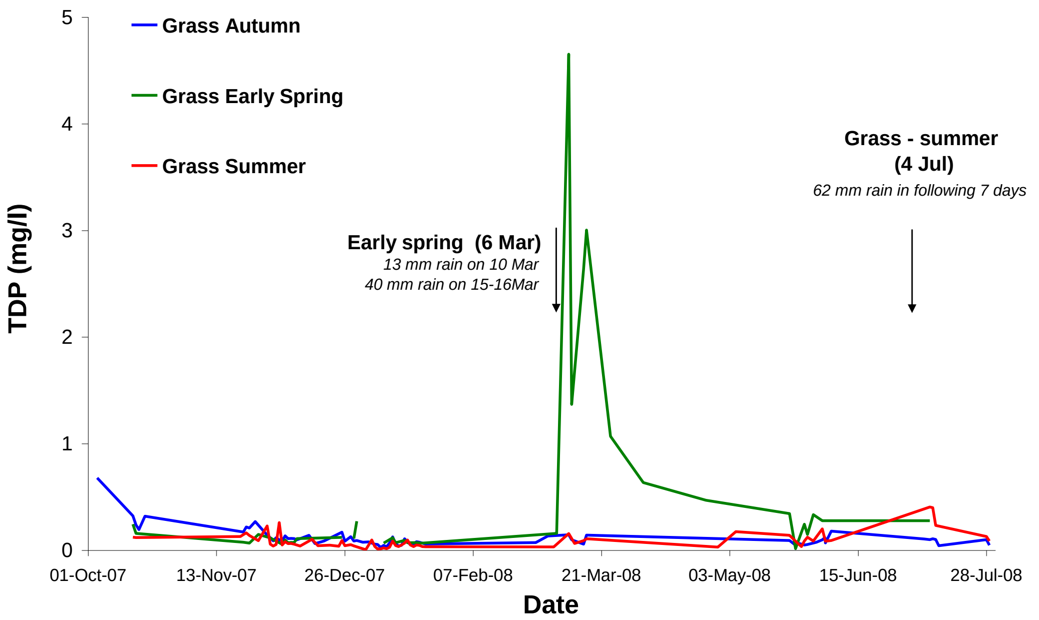

Figure 1-14: Total dissolved phosphorus concentrations in drainage water following contrasting slurry application timings to drained clay soils (Defra project WQ0118)

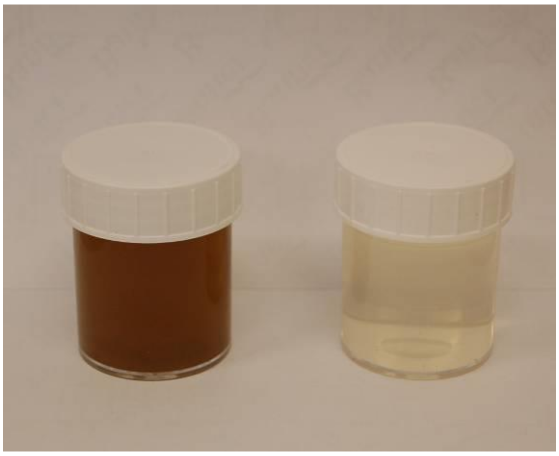

Figure 1-15: Drainage water samples 10 days after March slurry application to drained clay soils withc.10mm soil moisture deficit.

The project suggested that in order to minimise the risks of diffuse water pollution, over-winter slurry storage capacity should be sufficient to prevent applications to soils when soil moisture deficits were below 20 mm (Table 1-4).

Table 1-4: Risk management guidelines for slurry application timing (from Defra project WQ0118)

Soil moisture deficit (mm)	Risk
>20	Low
10-20	Moderate
<10	High

The IRRIGUIDE (Bailey and Spackmann, 1996) modelling carried out as part of this study suggests that soil moisture deficits across Wales at the end of March were c.10mm which suggests that slurry applications in March would pose a high risk of ammonium-N and phosphorous contamination of surface waters. As the risks of nitrate leaching losses are greatest following autumn application timings it can be suggested that high risks times for water pollution for slurry and poultry manure applications run from the beginning of October until the end of March. This indicates that in order to minimise the risks of applying slurry at high risk times 6 months storage capacity is required.

Information from Natural Resources Wales (Andrew Chambers, Pers Comm) suggest that there were 180 and 160 surface water pollution incidents from agriculture in 2018 and 2019, respectively. Some of these incidents are likely to be caused by failures of slurry management including leaking slurry stores and the application of slurry to soils when there is a high risk of runoff or drainage water contamination which may be a result of insufficient storage capacity. Increasing slurry storage capacity to 6 months is likely to reduce the risk of point source as well as diffuse water pollution.

Representation in Modelling

The impacts of this measure for nitrate, ammonia and nitrous oxide were calculated using the MANNER model, which explicitly accounted for the impacts of changing timing from a baseline distribution of timing derived from the British Survey of Fertiliser Practice. The MANNER modelling is described in more detail in the Appendix.

For phosphorus, Farmscoper assumed a reduction in short term losses from manure of 50%.

The costs of this measure are solely associated with additional storage to facilitate improved manure timing, which are calculated separately (see Section 1.4.2).

1.2.8 Do not spread farmyard manure to fields at high-risk times

Description

Avoid spreading (straw-based) FYM to fields at times when there is a high-risk of surface runoff or drain flow, for example, where rain falls shortly after applying FYM to ‘wet’ soils i.e. those with a soil moisture deficit of less than 10mm. 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. The high dry matter content and low readily available nutrient content of farmyard manure result in a lower risk of pollution than following applications of slurry. It will not add sufficient water to the soil to initiate surface runoff or preferential flow to field drains; ‘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.

Representation in Modelling

Farmscoper assumes a reduction in short term losses from manure of 25%.
As the modelling that underpins Farmscoper is based upon manure application timing information derived from the British Survey of Fertiliser Practice, current implementation is captured in the modelling and so the implementation of the mitigation measure is set to 0.

There are no significant costs associated with this measure.

1.3 *Assumptions Used for Cost and Benefit Estimates*

1.3.1 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 manufactured 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 increased manure nutrient use efficiency 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 losses to water.

1.3.2 Societal Benefits – Water

An estimated 3.8 billion m^3 of water is used in Wales each year with the majority used for electricity generation and public water supply (Morris, J. & Camino, M., 2011). The value of the water used in Wales each year has been estimated at £57million based on Natural Resources Wales standard unit charges of c. £15/1000m^3. In addition, Wales has 11 lowland and 10 upland wetland sites (inland marshes and peat bogs) covering

3,458 ha which provide flood control, recreation and bio-diversity benefits which have been estimated to be worth c. £643/ha per year giving a value of c.£2.2 million/year. Wales is also an important provider of freshwater fishing activities with market value for fishing rights of £90 million. The freshwater fishing industry also supports an estimated 700 jobs (Maule, G. 2018).

Water pollution from agriculture affects different stakeholders (Defra, 2014) including:

- Water companies must use costly processes to remove agricultural pollutants to produce safe drinking water
- Members of the public obtain reduced recreational value from use of watercourses, e.g. angling
- Members of the public suffer increased risk of illness when bathing
- Members of the public obtain reduced non-use benefits from watercourses due to ecosystem damage from agricultural water pollution and eutrophication of freshwater and marine water
- Commercial shellfisheries and fish farms suffer an increased risk of contaminated produce from unclean water and therefore a loss of sales
- The tourism sector could suffer losses from beaches that are closed due to failing bathing water standards
- Other farmers suffer loss of revenue due to potential health risks if polluted water is abstracted unknowingly and applied to sensitive crops, such as salad. Poor water quality may also prohibit the planting of certain crops

The value of economic benefit from reducing agricultural pollution has been reported in a number of studies. Metcalf et al (2012) surveyed households from across England and Wales in order to assign a value to the implementation of measures to meet Water Framework Directive targets for water quality. The study suggested the value placed on improving water quality ranged between £2,263 to £39,168 per km^2 depending on the population density (areas with higher population densities put greater value on the measures) the location of the improvement and the ecological scope of that improvement.

Estimates derived from information reported by O'Gorman and Bann (2008) suggested that in Wales, costs associated with agriculture's contribution to bathing water failures and the impacts of less than good quality river water were c.£1.5 million/year.

Defra (2016) suggest that it is inappropriate to assign single average figures to describe the environmental benefit of reductions in agricultural water pollution due to the geographic and temporal variation in pollutant concentrations. The damage caused by the pollutant will also vary according to the size of the water catchment, the degree to which it is used by humans or supports wildlife and the baseline water quality. It is suggested that a range of values is used to quantify the economic impacts of reductions in nutrient losses to water.

There are a range of environmental damage costs reported for nitrate and phosphorus loss to water in different environmental impact assessments. Defra 2016 quote a central value of 33p/kg (range 0-48p/kg) for nitrate and £19.89/kg (range £4.20-£35.06/kg) for phosphorous. In contrast, figures reported in Defra project LM0304) suggest central values of 43p/kg (range 24-62p/kg) for nitrate and £12.79 for phosphorus (range £2.77-£22.66/kg).

In this project we have chosen to use the figures recently published in Defra's Enabling Natural Capital Approach (ENCA) Databook which gives central values of 97p per kg (range 69p-£1.26/kg) for nitrate and £30.00 (range 26.66 to 33.34 /kg) for phosphorus. The ENCA methodology sets the standard for studies quantifying the impacts of agricultural practices on Natural Capital.

1.3.3 Societal Benefits – Air

Carbon

GHG emissions is measured as the equivalent amount of carbon dioxide (CO_2e). Methane (CH_4) and Nitrous Oxide (N_2O) are converted to CO_2e using their respective conversion factors of 25 and 298. The standard unit used is equivalent tonnes (tCO_2e).

The carbon valuation methodology evolved over time. In December 2007, the approach to carbon valuation adopted the use of the shadow price of carbon (SPC) as the basis for incorporating carbon emissions in cost-benefit analysis and impact assessments. It is based on estimates of the lifetime damage costs associated with greenhouse gas emissions, known as the social cost of carbon (SCC), and it takes more account of uncertainty compared to the SCC approach adopted previously.

GHG values are based on the economic cost of mitigating a unit of carbon. The carbon value will vary depending on the sector from which the emissions occur. There are two types of sectors: the traded sector (which is defined as those activities covered by the EU Emissions Trading System (EU ETS) with a market price for carbon) and non-traded sector (which included all other sectors not covered by the EU ETS). Agriculture is included in the non-traded sector.

The changes in GHG emissions from the agricultural sector are valued at the non-traded carbon prices published by The Department for Business, Energy & Industrial Strategy (BEIS; Table 1-5).

Table 1-5: Non-traded carbon prices for year 2021-2040 (£/CO2et) in 2018 prices.

Year	Low	Central	High
2021	35	70	106
2022	36	72	107
2023	36	73	109
2024	37	74	111
2025	38	75	113
2026	38	76	114
2027	39	77	116
2028	39	79	118

2029	40	80	120
2030	40	81	121
2031	44	88	132
2032	48	96	144
2033	52	103	155
2034	55	111	166
2035	59	118	178
2036	63	126	189
2037	67	133	200
2038	70	141	211
2039	74	148	223
2040	78	156	234

Source: BEIS modelling.

Ammonia

Various valuation methodologies have been used for air quality appraisals, which include: impact pathways approach (IPA), damage cost approach (a set of monetary impact values per tonne of emission), activity costs approach (monetary value per KWh energy used) and abatement costs approach.

Abatement costs approach should be used when the policy/project is expected to push emission concentrations above legal limits. This approach is used to assess the cost of offsetting measures (the "abatement cost") only for the amount of air quality that breaches the relevant obligation.

Activity costs approach is often used in policies associated with fuel consumption, particularly when change in fuel is known but changes in pollutant emissions are unknown.

IPA is the best practice approach but resource intensive. This approach is best suited for project that are more than £50million with the main objective of the policy or project being changes in air quality.

Damage cost method is an approach developed by Defra to enable proportionate analysis when assessing relatively small impacts on air quality (NPV <£50m). This approach is deemed to be most appropriate to be used in this appraisal assessing the impact of policy changes in NVZ regulations.

Damage costs are a set of impact values, measured as per tonne of emission by pollutant, which are derived using the more detailed IPA in order to estimate the societal costs associated with small changes in pollutant emissions. The damage cost methodology has evolved over the years and currently includes values for impacts on human health, productivity, amenity, environmental health and ecosystem services.

Defra updates and publishes ammonia damage cost prices each year, the most recent published (2020) range of ammonia price (central value) is £7,923 with a range from £1,521 to £24, 476 in 2017 prices. The damage cost value for ammonia in the previous year (2019) was £6,064 (central value) with a range between £1,133 and £18,867. The increase in ammonia value reflects the most recent re-evaluation of damage costs relating to human health and the inclusion of wider ecosystem service impact.

The most recent ammonia damage cost data (2020) was used in this appraisal.

1.3.4 Summary of prices used for valuation of environmental benefits

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 (Table 1-6). The central estimate of forecast prices for carbon has been used for each year over the period from 2021-2040. Similarly, the damage cost estimate associated with ammonia emissions fall over a large range. The central estimate used in the analysis is £7,923 per tonne but the full range is £1,521 to £24,476 per tonne in 2017 prices. 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 as well as the low and high end values to illustrate the value range of environmental benefits.

Table 1-6: Variables impacted on and their monetary value

Pollutant	Central Value (£/t)	Value Range (£/t)	Data source
GHG	£68	£34-£102	Non-traded CO_2values 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	£7,923*	£1,521-£24,476	Defra Air Quality Damage Cost Guidance (2020). National averages in 2017 prices. https://www.gov.uk/government/publications/assess-the-impact-of-air-quality/air-quality-appraisal-damage-cost-guidance
Nitrate-N	£970	£690-£1,260	ENCA services databook
Phosphorus	£30,000	£26,660-£33,340	ENCA services databook

*Ammonia value increased significantly from year 2018 because of a re-evaluation of the damage costs, especially relating to human health and the inclusion of wider ecosystem service costs.

As the prices for different pollutants were based on different reference year, the prices were then adjusted to the 2018 price base year (which is the latest base year that was used across all pollutant prices from various valuation sources in the table above) using Gross Domestic Product (GDP) deflator for this appraisal.

The analysis assumes that there is full compliance with the measures. 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.

1.4 *Costs of implementing measures*

For most of the mitigation measures, costs of implementation were taken from the Farmscoper modelling. However, costs of record keeping and for slurry storage were calculated separately as described in the following sub-sections.

1.4.1 Administrative cost of record keeping and nutrient planning

The completion of records and plans required by the proposed measures is likely to add additional administrative costs to farm business. For some farms the measures will have little or no impact as they may already be keeping records as part of existing land management or farm assurance schemes.

The estimates for the administrative costs associated with nutrient management planning are based on a number of assumptions as outline below:

- Farmer’s time is costed at £20 per hr[3].
- 74% of dairy farms, 55% of cattle and sheep farms (outside of SDAs) and 46% of cattle and sheep farms (inside of SDAs) already have a soil nutrient plan (Anthony et al., 2016).
- 40 hrs is the typical time to create a nutrient management plan (Johnson et al., 2012). Because of the large proportion of farms in Wales that are small, this value was scaled by farm size. This value was assumed to represent a farm of 24 to 40 ESU (Economic Size Units; Table 3-5), with the time scaled by average area for the other farms sizes (resulting in 6 hours for the smaller farms and 70 hours for the largest farms). This suggests that the average cost of a farmer produced nutrient management plan was £800/farm (range £130-£1400) which is lower than typical charge of between £1,000 and £2000 for plan produced by a FACTS qualified adviser (Mel Holloway, Pers Comm).
- Average annual time is an additional 20 hours from the survey (Johnson et al., 2012). This value was also scaled by farm size which was equivalent to £400/farm which is lower than the £700-£900/farm typically charged by a FACTS qualified adviser (Mel Holloway, pers comm.).

[3] £20/hr is judged to be representing the average cost rate. The hourly rate is ranging from £12.11 (farm managers’ time) to £40/hr using a consultant. £12.11 is the average hourly rate for managers and proprietors in agriculture and horticulture in Wales [source: Office for National Statistics (ONS), 2019. Earnings and hours worked, region by occupation by four-digit SOC: ASHE Table 15.5a -Hourly pay - Gross (£) - For all employee jobs]. According to Nix 2020 pocket guide (p.168), farm management cost at Grade 6 is £15.96/hr.

- 71% of manure on dairy farms, 19% on cattle and sheep farms (outside of SDAs) and 11% on cattle and sheep farms (inside of SDAs) is managed as slurry (Anthony et al., 2012a).
- Half of the farms with slurry storage would need professional planning to build or expand their facilities. The cost of this would be £3,500 per application (Kenny Dhillon, pers comm).
- Current impacts of NVZs have been ignored due to the small proportion of farmers within the existing areas (and as these may have been included in the survey figures used)

Costs were calculated by farm type and farm size (Table 1-7) using European Size Units (ESU), and accounting for those farms inside the existing NVZ area.

The overall costs for slurry storage and associated costs for applying for planning permissions, as well as planning time for nutrient management plan are the same for Option 2 and Option 4 (Table 1-8). The extra time put into nutrient management planning comes from the requirement of implementing the measure 'using a fertiliser recommendation system' by farm both inside and outside NVZs. The estimated costs for planning include: £4.3m (before discounting) for on-going additional planning on all farms and £4m (before discounting) upfront costs for those farms currently without a plan. There is a further cost of £3.5m (before discounting) in planning fees for the additional slurry storage facilities.

For option 3 (Table 1-9), the costs are lower and include: £0.13m (before discounting) for on-going additional planning on all farms and £0.09m (before discounting) upfront costs for those farms currently without a plan. There is a further cost of £0.16m (before discounting) in planning fees for the additional slurry storage facilities.
The cost assessments assume that farms that are under 8 ESUs have low levels of nutrient inputs from fertilisers or manures and do not need detailed nutrient management plans. These farms are defined in the NVZ guidance as:

- In the calendar year have 80% of the agricultural area of the holding is in grass
- The total amount of nitrogen in organic manure applied to the holding, whether directly by animal or as a result of spreading is no more than 100 kg/ha N
- The total amount of nitrogen in manufactured fertiliser nitrogen applied to the holding is less than 90 kg/ha N
- No organic manures are brought on to the holding

Table 1-7: Number of active farms in Wales by farm type and farm size (defined by Economic Size Units) from 2019 June Agricultural Survey Data

Farm Type	< 8	8 - 24	24 - 40	40 - 100	> 100	Total Number of Active Farms
Cereal	128	59	60	71	102	420
General cropping	47	30	12	22	16	127
Horticulture	644	28	40	31	87	830
Dairy	104	1,086	34	341	49	1,614
Cattle and Sheep LFA	5,322	316	1,531	1,707	3,175	12,051
Cattle and Sheep Lowland	1,279	56	276	231	658	2,500
Mixed	769	79	80	127	114	1,169
Pigs	213	2	3	1	6	225
Poultry	955	79	12	39	8	1,093
Other	4582	5	22	8	161	4,778
Total	14,043	1,740	2,070	2,578	4,376	24,807

Table 1-8: Additional Planning requirements, by farm type, using data from June Agricultural Survey and other assumptions listed above (Option 2 & Option 4), Excluding Farms <8 ESU

Farm Type	Total Number of Active Farms outside existing NVZ area	Fraction of Farms with Existing Plan	Total Time for Ongoing Planning (hrs)	Total Number of Farms Requiring New Plan	Total Upfront Time for New Plan (hrs)	Proportion of Farms with Slurry	Total Number of Farms with Slurry	Total Number of Farms Requiring Planning
Cereal	254	0.55	5,693	114	5,124	0	0	0
General cropping	76	0.55	2,025	34	1,823	0	0	0
Horticulture	168	0.55	3,306	76	2,975	0	0	0
Dairy	1,377	0.74	44,425	358	23,101	0.71	978	489
Cattle and Sheep LFA	6,561	0.46	126,869	3,543	137,018	0.11	722	361
Cattle and Sheep Lowland	1,051	0.55	19,044	473	17,140	0.19	200	100
Mixed	367	0.55	8,836	165	7,953	0.15	55	28
Pigs	8	0.55	183	4	164	0.15	1	1
Poultry	130	0.55	3,940	59	3,546	0.15	20	10
Other	187	0.55	2,635	84	2,371	0	0	0
Total	**10,179**		**216,955**	**4,909**	**201,214**		**1,975**	**987**

Table 1-9: Additional Planning requirements, by farm type, using data from June Agricultural Survey and other assumptions listed above (Option 3), Excluding Farms <8 ESU

Farm Type	Total Number of Active Farms outside new NVZ area	Fraction of Farms with Existing Plan	Total Time for Ongoing Planning (hrs)	Total Number of Farms Requiring New Plan	Total Upfront Time for New Plan (hrs)	Proportion of Farms with Slurry	Total Number of Farms with Slurry	Total Number of Farms Requiring Planning
Cereal	18	0.55	412	8	371	0	0	0
General cropping	19	0.55	495	9	447	0	0	0
Horticulture	3	0.55	100	2	90	0	0	0
Dairy	104	0.74	3,447	27	1,792	0.71	74	37
Cattle and Sheep LFA	24	0.46	385	15	416	0.11	3	1
Cattle and Sheep Lowland	69	0.55	1,047	31	942	0.19	13	7
Mixed	21	0.55	540	9	486	0.15	3	2
Pigs	1	0.55	30	0	27	0.15	0	0
Poultry	3	0.55	36	1	32	0.15	0	0
Other	3	0.55	36	1	32	0	0	0
Total	**260**		**6,528**	**104**	**4,635**		**94**	**47**

1.4.2 Slurry storage costs

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., 2012a), which found approximately 62% was collected in slurry stores on dairy farms and 20% on cattle and sheep farms).

The contribution of rainfall to slurry storage requirement was based on the highest rainfall expected in 5 years (M5) assuming annual rainfall for Wales of 1460mm. 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. T1460 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.

Understanding the current level of slurry storage capacity in Wales is difficult because of the lack of detailed survey data. 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. 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. As the Water Resources (Control of Pollution) (Silage, Slurry and Agriculture Fuel Oil) (Wales) Regulations 2010 (SSAFO) require 4 months excreta production and an allowance for the highest rainfall expected in 5 years (M5) the baseline assumed that farms were complying with SSAFO regulations.

Previous studies calculating slurry storage requirements have followed Defra and Welsh guidance at the time which recommended using average annual rainfall to calculate the contribution that rainfall made to slurry storage volumes. Following consultation with Welsh Government the contribution of rainfall to slurry storage requirement in this study was calculated using M5 rainfall which is typically c. 10-20% higher than average rainfall.

The calculated baseline and additional storage capacity and additional costs required to increase slurry storage capacity to comply with the measures: (i) 'Increase the capacity of farm slurry stores to improve timing of slurry applications' – i.e. 5 months storage and (ii) 'Do not spread slurry or poultry manure at high-risk times' – i.e. 6 months storage are given in Table 1-10. The costs for above ground stores (i.e. constructed with a concrete base with either steel or concreate walls) has been assumed at £50/m^3 and the cost of earth-banked lagoon stores has been assumed at £40/m^3 (Nix, 2019). It is likely that costs will vary between farms according to the configuration of the farm steading, and availability of labour and materials etc.

Table 1-10: Capital costs of increasing slurry storage requirements (50% of yard area roofed).

Area	Slurry storage volume			Additional storage requirement		Additional Costs Above ground tank		Additional costs Lagoon	
	Million m^3					£ million			
	Baseline +	5 months	6 months	5 months	6 months	5months	6 months	5months	6 months
NVZ	0.91	1.08	1.27	0.17	0.35	8.53	17.92	6.82	14.32
92% of Wales	5.53	6.51	7.61	0.98	2.07	49.02	103.7	39.21	82.96
All Wales	6.45	7.60	8.88	1.15	2.43	57.54	121.7	46.03	97.30

+ Baseline assume compliance with SSAFO

For the whole of Wales baseline slurry storage capacity estimates were c. 6.5 million m^3 compared with c.7.6 million for 5 months storage and c.8.9 million for 6 months storage with dairy slurry accounting for c.85%, beef slurry 15% and pig slurry less than 1% of total volumes. The cost of the additional storage was estimated at between 46 million and 57 million for 5 months and £97 million and £122 million for 6 months storage, respectively (Table 1-10).

Costs of the additional storage requirement in the NVZ area were estimated at between £6 million and £8million for 5 months and £14 million and £18 million for 6 months storage respectively. For the area outside the proposed NVZ area the costs of additional were estimated at between £39 million and £49 million for 5 months and £83 million and £104 million for 6 months storage respectively. The lower costs associated with additional requirements in these areas compared to the whole of Wales reflect the smaller number of animals and consequently lower slurry volumes.

Yard runoff and water running from roofs can make a significant contribution to slurry storage capacity requirements, especially in areas of high rainfall. Baseline estimates assume that 50% of dirty yard areas are covered and no allowance is made for water collected from roofed areas. The assumptions are based on evidence from Defra farm practice survey (2006) which states that 40% of concrete yards are uncovered and Aitken et al. (2001) reported that rainfall falling on 65% of yards produced contaminated runoff.

The estimates that yard runoff water contributes around 20% of total annual slurry volumes collected. Further estimates of slurry storage capacity and capital costs were carried out with the area of dirty yard roofed increased to 75%. The additional capital costs associated with roofing the yards was estimated based on a cost of £80/m^2 (Nix, 2019; confirmed by Charles Bentley, Pers Comm.) and the slurry storage costs were adjusted to account for the lower storage requirement. The reduction in slurry spreading costs as a result of the reduced yard runoff component was also quantified.

The capital costs of increasing the area of roofed yard from 50% to 75% was estimated at £115 million for the whole of Wales, £15 million for the proposed NVZ area and £100 million for the area outside the proposed NVZ (Table 1-11). The additional roofing reduced the capital cost of an additional 5 months slurry storage by c.£15 million for all Wales, c£14 million for the area outside the proposed NVZ and c.£0.5 million for the NVZ area. Additional roofing reduced the capital cost of an additional 6 months storage by c. £17 million for all Wales, c£15 million for the area outside the proposed NVZ area and c.£2million for the NVZ area. Overall costs of roofing increased capital costs for 6 months storage by c. £97 million for the whole of Wales, £83 million for the area outside the proposed NVZ and c.£14million for the proposed NVZ area. Roofing increased overall capital costs for 5 months storage by c.£100 million for the whole of Wales, £86 million for the area outside the proposed NVZ and £15million in the proposed NVZ area. The additional capital costs were partly offset by savings in annual slurry spreading costs of £135k/ year in the proposed NVZ area, £900k/year in the area outside the proposed NVZ area and £1million/ year across the whole of Wales.

Table 1-11: Capital costs for slurry storage capacities and increasing covered yard area to 75% (costs based on average of tin tank and earth banked lagoon)

Area	5 months capacity			6 months capacity		
	Roof	Storage	Total	Roof	Storage	Total
NVZ	15	7	22	15	16	31
92% of Wales	100	31	131	100	77	177
All Wales	115	37	152	115	103	218

1.4.3 Sensitivity analysis of cost and benefit assessments

The range of potential implementation and damage costs was accounted for with a sensitivity analysis. For the following measures with the most significant costs and greatest uncertainty high, medium and low cost estimates were produced:

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

The review of damage costs also produced a central estimate and upper and lower bounds for each pollutant. The sensitivity analysis thus considered the consequences of using the high, medium or low implementation costs, and the high, medium and low damage costs.

For the uncertainty analysis, the high, medium and low costs for do not spread slurry and poultry manure at high risk times were represented by:

- High: Increasing the covered dirty yard area from 50% to 75% and rebuild 50% of slurry stores to hold 6 months slurry production
- Medium: Increasing the covered dirty yard area from 50% to 75% and extend slurry storage capacity from 4 to 6 months
- Low: Extend slurry storage capacity from 4 to 6 months.

The high medium and low costs for increase slurry storage were represented by:

- High: Increasing the covered dirty yard area from 50% to 75% and rebuild 50% of slurry stores to hold 5 months slurry production
- Medium: Increasing the covered dirty yard area from 50% to 75% and extend slurry storage capacity from 4 to 5 months
- Low: Extend slurry storage capacity from 4 to 5 months.

For Integrate fertiliser and manure nutrient supply:

- High: Only the crop available N in manure is accounted for
- Medium: The crop available N in manure is accounted for, and 30% of the available P and K
- Low: All of the available N, P and K is accounted for

For Do not apply manufactured fertiliser to high-risk areas:

- High: areas occupy 10% of fields
- Medium: areas occupy 5% of fields
- Low: areas occupy 2% of fields

For Avoid spreading manufactured fertiliser to fields at high-risk times:

- High: 10% yield loss occurs 1 year in 5
- Medium: 10% yield loss occurs 1 year in 10
- Low: 10% yield loss occurs 1 year in 15

1.5 *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 2021 to year 2040. 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 in line with the HMT's Green Book[4] guidance to estimate the Net Present Value (NPV) of costs and benefits of different policy scenarios. The initial year is 2021.

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

2 Results of Option Modelling

2.1 *Pollutant source apportionment*

Figure 2-1 to Figure 2-4 show the apportionment of national annual average agricultural pollutant losses predicted by Farmscoper, which reveal the major sources of pollution and help explain why certain types of measures may or may not have the potential to achieve sizeable impacts. For example, fertiliser is a greater source of losses of nitrate losses than it is phosphorus (18% compared to 10%; Figure 2-1), so measures targeting fertiliser have a greater potential to reduce nitrate losses. Measures controlling surface runoff losses could have greater impacts on phosphorus (where runoff is the source of 38% of the losses; Figure 2-3) than nitrate, where they contribute only 11%. Slurry is the source of 14% of nitrate losses, but only 6% of phosphorus (Figure 2-4).

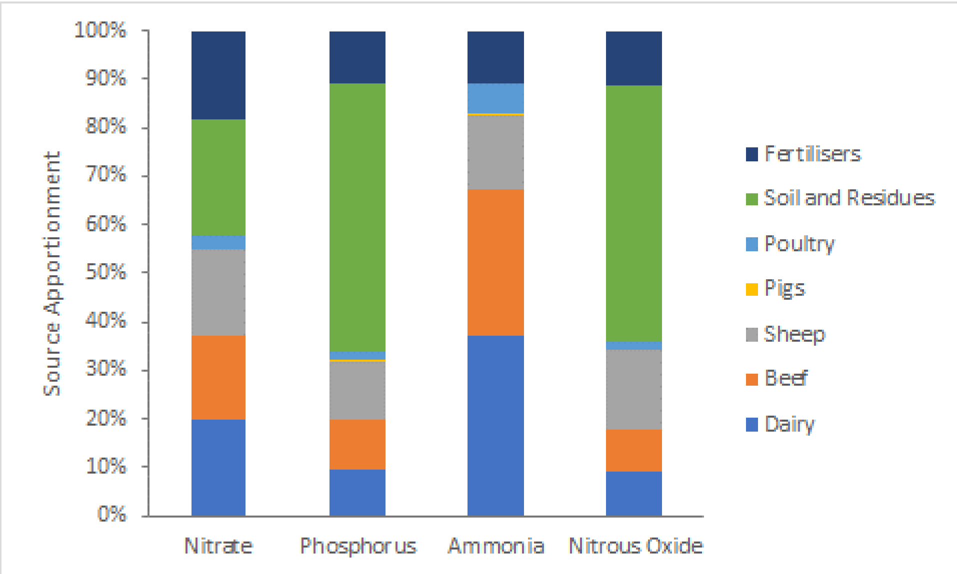

Figure 2-1 Apportionment of national annual average pollutant losses by source

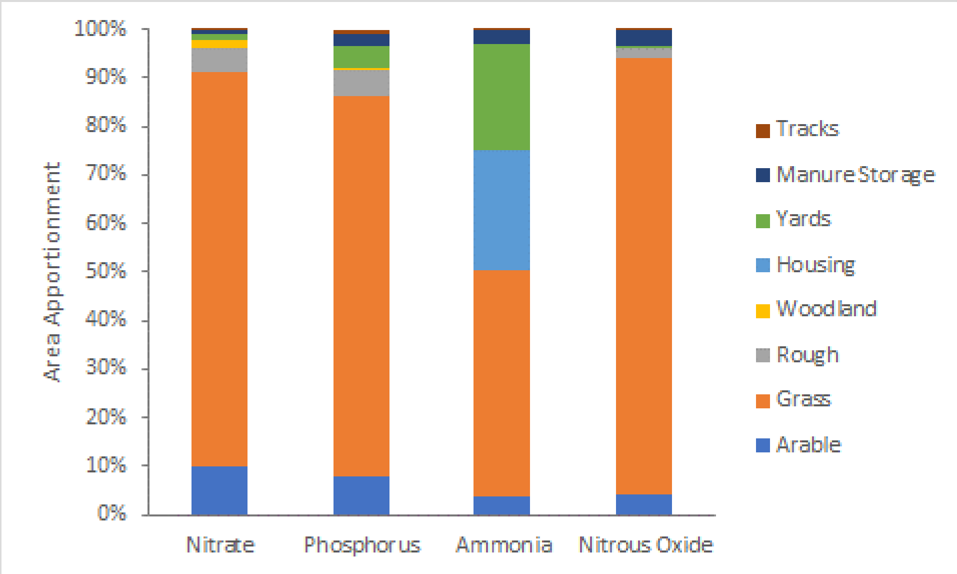

Figure 2-2 Apportionment of national annual average pollutant losses by area

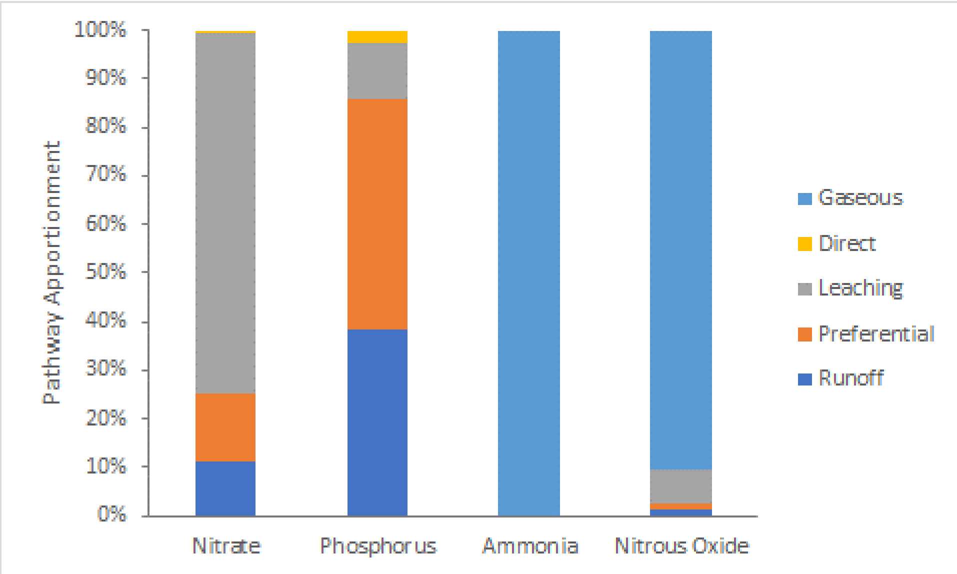

Figure 2-3 Apportionment of national annual average pollutant losses by pathway

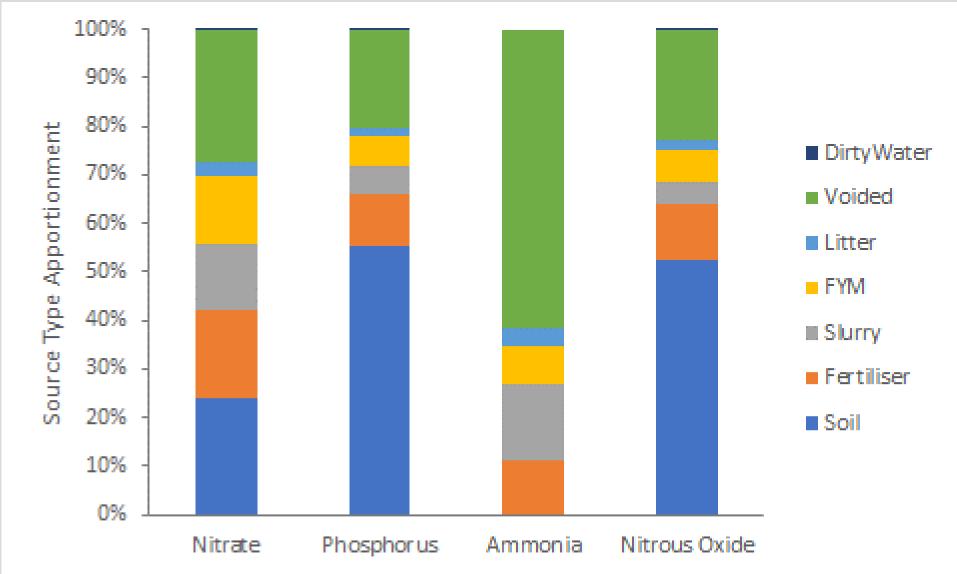

Figure 2-4 Apportionment of national annual average pollutant losses by source type

2.2 *Impacts of Individual Measures*

2.2.1 Pollutant Reductions

When the Option 2 measures are implemented individually across the whole of Wales, the percentage reductions in the national agricultural pollutant loads are relatively small, generally less around 1% (Table 2-1). Not spreading slurry/poultry manure at high risk times has the biggest impact, with a reduction of 3.6% on phosphorus losses. Integrate fertiliser and manure nutrient supply and using a fertiliser recommendation have the biggest impacts on ammonia and nitrous oxide emissions (0.6-0.8% reductions) due to reduced fertiliser usage. Not applying FYM to high risk areas has limited impact at national scale due to the relatively small contribution of incidental manure losses to the total load (Figure 2-4) and the fact that the manure is still applied somewhere on the farm. Increasing the capacity of slurry stores and avoiding spreading manure at high risk times results in an increase in ammonia emissions, although these are not as great as the savings achieved in other measures.

For the Option 3 measures, the reductions (Table 2-2; expressed relative to the pollutant load in the proposed NVZ area) are lower than those achieved nationally. This reflects the higher current implementation of these measures within the current NVZ area. However, avoiding spreading slurry and poultry manure at high risk times has a slightly greater impact, reflecting the greater contribution of these as a pollutant source in the NVZ area.

The reductions achieved by the Option 4 measures are the same as the of Option 2, except for Do not apply manufactured fertiliser to high-risk areas and Avoid spreading manufactured fertiliser to fields at high-risk times. In Option 4 these two measures only apply within the proposed NVZ area, and so the impact on national pollutant loads is very small.

Table 2-4 shows the impacts of Option 2, but as a percentage reduction in the contribution to the national load from the source being targeted (e.g. the impact of Use a fertiliser recommendation system is expressed as a percentage of the pollutant load attributable to fertilisers). Use a fertiliser recommendation system and Integrate fertiliser and manure nutrient supply reduce losses from fertiliser by about 5%, less for phosphorus as phosphorus fertiliser use is already low with little room for further reductions. Avoid spreading manufactured fertiliser to fields at high-risk times has a 10% reduction in phosphorus, but a much smaller reduction in nitrate – this is because most of the fertiliser loss for nitrate occurs post-harvest and so is less sensitive to the timing of application. Not spreading slurry or FYM at high risk times achieves greater reductions in losses attributable to manure for phosphorus than nitrate – this is because applications of manure result in nitrate losses in the following years (due to organic nitrogen in the manures) and these losses are not sensitive to application timing.

Table 2-1: Percentage change in pollutant losses following full implementation of individual measures required by Option 2, expressed relative to losses for the whole of Wales under current practice (%).

Measure	Nitrate	P	NH_3-N	N_2O
Use a fertiliser recommendation system	1.3	0.1	0.7	0.8
Integrate fertiliser and manure nutrient supply	1.1	0.5	0.6	0.7
Do not apply manufactured fertiliser to high-risk areas	0.3	<0.1	0.3	0.3
Avoid spreading manufactured fertiliser to fields at high-risk times (to End of March)	0.1	1.1	0.2	<0.1
Avoid spreading manufactured fertiliser to fields at high-risk times (to End of February)	<0.1	0.5	0.1	<0.1
Increase the capacity of farm slurry stores to improve timing of slurry applications	*	*	-0.2	*
Do not apply manure to high-risk areas	<0.1	<0.1	0.0	<0.1
Do not spread slurry or poultry manure at high-risk times	1.3	3.6	-0.1	0.1
Do not spread FYM to fields at high-risk times	0.4	1.0	0.0	0.8

* Increased slurry storage facilitates changing manure application timing, so the N, P and N_2O impacts of this measure are included under 'Do not spread slurry or poultry manure at high-risk times'.

Table 2-2: Percentage change in pollutant losses following full implementation of individual measures required by Option 3, expressed relative to losses within the proposed NVZ area under current practice (%).

Measure	Nitrate	P	NH_3-N	N_2O
Use a fertiliser recommendation system	0.7	0.1	0.4	0.5
Integrate fertiliser and manure nutrient supply	0.7	0.3	0.3	0.5
Do not apply manufactured fertiliser to high-risk areas	0.2	<0.1	0.2	0.2
Avoid spreading manufactured fertiliser to fields at high-risk times (to End of March)	0.1	0.9	0.2	<0.1
Avoid spreading manufactured fertiliser to fields at high-risk times (to End of February)	<0.1	0.5	0.1	<0.1
Increase the capacity of farm slurry stores to improve timing of slurry applications	*	*	-0.3	*
Do not apply manure to high-risk areas	<0.1	<0.1	0.0	<0.1
Do not spread slurry or poultry manure at high-risk times	1.7	3.1	-0.1	0.2
Do not spread FYM to fields at high-risk times	0.3	1.2	0.0	1.0

* Increased slurry storage facilitates changing manure application timing, so the N, P and N_2O impacts of this measure are included under ‘Do not spread slurry or poultry manure at high-risk times’.

Table 2-3: Percentage change in pollutant losses following full implementation of individual measures required by Option 4 expressed relative to losses for the whole of Wales under current practice (%).

Measure	Nitrate	P	NH_3-N	N_2O
Use a fertiliser recommendation system	1.3	0.1	0.7	0.8
Integrate fertiliser and manure nutrient supply	1.1	0.5	0.6	0.7
Do not apply manufactured fertiliser to high-risk areas (within proposed NVZ area only)	<0.1	<0.1	<0.1	<0.1
Avoid spreading manufactured fertiliser to fields at high-risk times (to End of March) (within proposed NVZ area only)	<0.1	<0.1	<0.1	<0.1
Avoid spreading manufactured fertiliser to fields at high-risk times (to End of February) (within proposed NVZ area only)	<0.1	<0.1	<0.1	<0.1
Increase the capacity of farm slurry stores to improve timing of slurry applications	*	*	-0.2	*
Do not apply manure to high-risk areas	<0.1	<0.1	0.0	<0.1
Do not spread slurry or poultry manure at high-risk times	1.3	3.6	-0.1	0.1
Do not spread FYM to fields at high-risk times	0.4	1.0	0.0	0.8

* Increased slurry storage facilitates changing manure application timing, so the N, P and N_2O impacts of this measure are included under 'Do not spread slurry or poultry manure at high-risk times'.

Table 2-4: Percentage change in the component of the pollutant losses targeted by each measure, following full implementation of individual measures required by Option 2, expressed relative to losses for the whole of Wales under current practice (%).

Measure	Component	Nitrate	P	NH_3-N	N_2O
Use a fertiliser recommendation system	Fertiliser	6.9	1.3	6.7	6.8
Integrate fertiliser and manure nutrient supply	Fertiliser	5.9	4.9	5.6	6.0
Do not apply manufactured fertiliser to high-risk areas	Fertiliser	1.9	0.4	2.6	2.4
Avoid spreading manufactured fertiliser to fields at high-risk times (to End of March)	Fertiliser	0.6	10.0	2.0	0.1
Avoid spreading manufactured fertiliser to fields at high-risk times (to End of February)	Fertiliser	0.3	2.0	1.0	<0.1
Increase the capacity of farm slurry stores to improve timing of slurry applications	Slurry	*	*	-1.5	*
Do not apply manure to high-risk areas	Manure	<0.1	0.2	0.0	<0.1
Do not spread slurry or poultry manure at high-risk times	Slurry / Poultry	8.2	50.0	-0.3	2.0
Do not spread FYM to fields at high-risk times	FYM	2.9	15.9	0.0	12.4

* Increased slurry storage facilitates changing manure application timing, so the N, P and N_2O impacts of this measure are included under ‘Do not spread slurry or poultry manure at high-risk times’.

2.2.2 Costs of Implementation

For Option 2, the ‘increased slurry storage’ measure (to 5 months) is responsible for increases in one-off capital costs from the baseline of £52m to £311m (Table 2-5) due to investment costs associated with extending/building new slurry storage (Section 3.4.2), with the range in costs resulting from assumptions about roofing yard areas and what proportion of storage can be extended rather than rebuilt. Do not spread slurry or poultry manure at high-risk times is assumed to require 6 months storage, so costs are even higher (up to £360m).

‘Integrating fertiliser and manure nutrient management’ resulted in reduced annual costs of between £25million and £5 million depending on whether the NPK value of the manures is accounted for or just the N value (see Section 2.2.2). Use of a fertiliser recommendation system resulted in reduced costs reflecting assumed improvements in the efficiency of fertiliser use. All other measures are associated with increased annual 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 £12.2 and £9.8m respectively for the Medium cost scenario), due to the yield penalties associated with applying sub-optimal fertiliser inputs. There are up front planning costs of £7.5m, with a £4.3m annual cost for those farms currently not keeping records or nutrient planning.

The costs for Option 3 (Table 2-6) are much lower, reflecting both the smaller area to which the measures are applied and the fact that implementation of most measures is higher within the existing NVZ area (and so is assumed to be part of the baseline). However, increased slurry storage could still cost over £50m due to the large number of cattle within the proposed NVZ area.

Costs for Option 4 (Table 2-7) are the same as for Option 2 (Table 2-5) except for Do not apply manufactured fertiliser to high-risk areas and Avoid spreading manufactured fertiliser to fields at high-risk times, which only apply within the proposed NVZ area and so costs are as per Table 2-6.

Table 2-5: Cost of implementation for full implementation of individual measures required by Option 2 across the whole of Wales, expressed relative to current practice. For some measures, high, medium and low cost estimates have been produced, as described in the relevant sections.

Measure	Range	Upfront capital costs	Annual operational costs	One-off planning costs
Use a fertiliser recommendation system[1]	-	-	-£8.8m	-
Integrate fertiliser and manure nutrient supply[1]	H	-	-£5.0m	-
	M	-	-£11.0m	-
	L	-	-£25.0m	-
Do not apply manufactured fertiliser to high-risk areas[1]	H	-	£19.6m	-
	M	-	£9.8m	-
	L	-	£3.9	-
Avoid spreading manufactured fertiliser to fields at high-risk times (to End of March)	H	-	£18.3m	-
	M	-	£12.2m	-
	L	-	£6.1m	-
Avoid spreading manufactured fertiliser to fields at high-risk times (to End of February)	H	-	£6.1m	-
	M	-	-	-
	L	-	-	-
Increase the capacity of farm slurry stores to improve timing of slurry applications	H	£311m [3]	£5.1m [2, 3]	-
	M	£152m [3]	£1.9m [2, 3]	
	L	£52m [3]	£1.0m [2, 3]	
Do not apply manure to high-risk areas[1]	-	-	-	-
Do not spread slurry or poultry manure at high-risk times[1]	H	£360m [3]	£6.1m [2, 3]	-
	M	£206m [3]	£3.0m [2, 3]	
	L	£109m [3]	£2.2m [2, 3]	
Do not spread FYM to fields at high-risk times	-	-	-	-
Nutrient planning and record keeping	-	-	£4.3m	£4.0m
Planning permission for new slurry storage	-	-	-	£3.5m

[1] All of these measures would require some form of nutrient planning and/or record keeping, which has been costed separately
[2] Operational costs are assumed to be 2% of the capital costs
[3] These costs for these two measures would not be additive. The costs assume a mix of lagoons and steel tanks

Table 2-6: Cost of implementation for full implementation of individual measures required by Option 3 across proposed NVZ area, expressed relative to current practice. For some measures, high, medium and low cost estimates have been produced, as described in the relevant sections.

Measure	Range	Upfront capital costs	Annual operational costs	One-off planning costs
Use a fertiliser recommendation system[1]	-	-	-£0.5m	-
Integrate fertiliser and manure nutrient supply[1]	H	-	-£0.5m	-
	M	-	-£1.1m	-
	L	-	-£2.5m	-
Do not apply manufactured fertiliser to high-risk areas[1]	H	-	£1.4m	-
	M	-	£0.7m	-
	L	-	£0.3m	-
Avoid spreading manufactured fertiliser to fields at high-risk times (to End of March)	H	-	£1.4m	-
	M	-	£0.9m	-
	L	-	£0.5m	-
Avoid spreading manufactured fertiliser to fields at high-risk times (to End of February)	H	-	£0.5m	-
	M	-	-	-
	L	-	-	-
Increase the capacity of farm slurry stores to improve timing of slurry applications	H	£43m [3]	£0.7m [2, 3]	-
	M	£22m [3]	£0.3m [2, 3]	-
	L	£8m [3]	£0.2 [2, 3]	-
Do not apply manure to high-risk areas[1]	-	-	-	-
Do not spread slurry or poultry manure at high-risk times[1]	H	£52m [3]	0.9[2, 3]	
	M	£30m [3]	0.4[2, 3]	
	L	£16m [3]	0.3[2, 3]	
Do not spread FYM to fields at high-risk times	-	-	-	-
Nutrient planning and record keeping	-	-	£0.13m	£0.09m
Planning permission for new slurry storage	-	-	-	£0.16m

[1] All of these measures would require some form of nutrient planning and/or record keeping, which has been costed separately
[2] Operational costs are assumed to be 2% of the capital costs
[3] These costs for these two measures would not be additive. The costs assume a mix of lagoons and steel tanks

Table 2-7: Cost of implementation for full implementation of individual measures required by Option 4 across the whole of Wales or the proposed NVZ area, expressed relative to current practice. For some measures, high, medium and low cost estimates have been produced, as described in the relevant sections.

Measure	Range	Upfront capital costs	Annual operational costs	One-off planning costs
Use a fertiliser recommendation system[1]	-	-	-£8.8m	-
Integrate fertiliser and manure nutrient supply[1]	H	-	-£5.0m	-
	M	-	-£11.0m	-
	L	-	-£25.0m	-
Do not apply manufactured fertiliser to high-risk areas (within proposed NVZ area only)[1]	H	-	£1.4m	-
	M	-	£0.7m	-
	L	-	£0.3m	-
Avoid spreading manufactured fertiliser to fields at high-risk times (to End of March) (within proposed NVZ area only)	H	-	£1.4m	-
	M	-	£0.9m	-
	L	-	£0.5m	-
Avoid spreading manufactured fertiliser to fields at high-risk times (to End of February) (within proposed NVZ area only)	H	-	£0.5m	-
	M	-	-	-
	L	-	-	-
Increase the capacity of farm slurry stores to improve timing of slurry applications	H	£311m [,3]	£5.1m [2,3]	
	M	£152m[3]	£1.9m [2,3]	
	L	£52m[3]	£1.0m [2,3]	
Do not apply manure to high-risk areas[1]	-	-	-	-
Do not spread slurry or poultry manure at high-risk times[1]	H	£360m[3]	£6.1m [2, 3]	-
	M	£206m [3]	£3.0m [2, 3]	-
	L	£109m [3]	£2.2m [2, 3]	-
Do not spread FYM to fields at high-risk times	-	-	-	-
Nutrient planning and record keeping	-	-	£4.3m	£4.0m
Planning permission for new slurry storage	-	-	-	£3.5m

[1] All of these measures would require some form of nutrient planning and/or record keeping, which has been costed separately
[2] Operational costs are assumed to be 2% of the capital costs
[3] These costs for these two measures would not be additive. The costs assume a mix of lagoons and steel tanks

2.3 *Impacts of Options*

The overall reductions in annual average pollutant loads due to the different options are shown in Table 2-8. Option 2 results in a 1,326 tonne reduction in annual nitrate losses. Option 3 results in a reduction approximately 10% of that achieved by Option 2, despite the measures only being applied in 8% of Wales – reflecting the greater pollutant pressures found inside the proposed NVZ areas. Reductions for Option 4 are 85-90% of those for Option 2 for nitrate, phosphorus and nitrous oxide, but only 70% for ammonia. This is because the two measures only applied within the NVZ area under Option 4 (Do not apply manufactured fertiliser to high-risk areas and Avoid spreading manufactured fertiliser to fields at high-risk times) have a bigger affect on ammonia losses than the other pollutants (see Table 2-1) reflecting the impact that urea applications have on ammonia emissions..

The Implementation costs (before discounting) for the High, Medium and Low cost scenarios are shown in Table 2-9 to Table 2-11. Option 4 results in a saving in annual operational costs for all three scenarios, but Options 2 and 3 only result in operational cost savings under the low cost scenario (where there is an optimistic assumption about the use of P and K in manures and thus the potential to reduce annual fertiliser costs). Implementing option b leads to savings in operational costs for both the medium and low cost scenarios where there are no yield penalties from delaying fertiliser applications. Upfront capital costs are as per the costs for Do not spread slurry or poultry manure at high-risk times in Table 2-5 to Table 2-7, as the construction of 6 months storage are the only capital costs. The planning costs do not vary with the cost scenarios.

Table 2-8: Reduction annual average pollutant loads (in tonnes) for the three options

Pollutant	Opt. 2a	Opt. 2b	Opt. 3a	Opt. 3b	Opt. 4a	Opt. 4b
Nitrate	1,326	1,311	136	135	1,207	1,206
Phosphorus (TP)	50	46	5	4	42	42
Ammonia (NH_3-N)	343	318	32	30	246	243
Nitrous Oxide (N_2O)	319	318	31	31	287	287

Table 2-9: Cost of implementation for the three options (High cost scenario), before discounting

Costs	Opt. 2a	Opt. 2b	Opt. 3a	Opt. 3b	Opt. 4a	Opt. 4b
Upfront capital costs[1]	£360m	£360m	£52m	£52m	£360m	£360m
Annual operational costs	£34.5m	£22.3 m	£2.8m	£1.9m	-£0.6m	-£1.5m
One-off planning costs	£7.5m	£7.5m	£0.3m	£0.3m	£7.5m	£7.5m

[1] the average of assuming all extra slurry storage capacity was lagoons and all extra slurry storage capacity was above ground tanks.

Table 2-10: Cost of implementation for the three options (Medium cost scenario), before discounting

Costs	Opt. 2a	Opt. 2b	Opt. 3a	Opt. 3b	Opt. 4a	Opt. 4b
Upfront capital costs[1]	£206m	£206m	£30m	£30m	£206m	£206m
Annual operational costs	£9.5m	-£2.7m	£0.5m	-£0.4m	-£11m	-11.8m
One-off planning costs	£7.5m	£7.5m	£0.3m	£0.3m	£7.5m	£7.5m

[1] the average of assuming all extra slurry storage capacity was lagoons and all extra slurry storage capacity was above ground tanks.

Table 2-11: Cost of implementation for the three options (Low cost scenario,) before discounting

Costs	Opt. 2a	Opt. 2b	Opt. 3a	Opt. 3b	Opt. 4a	Opt. 4b
Upfront capital costs[1]	£109m	£109m	£16m	£16m	£109m	£109m
Annual operational costs	-£17.2m	-£23.3m	-£1.8m	-£2.3m	-£26m	-27.0m
One-off planning costs	£7.5m	£7.5m	£0.3m	£0.3m	£7.5m	£7.5m

[1] the average of assuming all extra slurry storage capacity was lagoons and all extra slurry storage capacity was above ground tanks.

2.4 *Overall Cost-Benefit Assessments*

2.4.1 Environmental benefits

The environmental benefits are monetised by multiplying the change in tonnes of emission levels (Table 2-8) by the monetary value per tonne for GHG emissions, ammonia emissions and nitrate-N and Phosphorus leaching (Table 1-6).

The values were calculated using high, low and central prices for environmental pollutants from Table 1-6. Over a 20-year period, the total environmental benefits (central value, not discounted) are estimated at £304m for Option 2a, £30m for Option 3a and £262m for Option 4a, with the majority of the benefits coming from reductions in GHG emissions (Table 2-12). The environmental benefits of implementing option b (i.e. high-risk times for fertiliser application October-February) results in reduced environmental benefit mainly as a result of higher predicted ammonia emissions to air and phosphorus losses to water. Nitrate losses to water were predicted to be unchanged. (see Table 3 13).

Table 2-12: Changes in environmental benefits (relative to baseline) for NPK scenario, £m before discounting

Pollutant	Reductions in Emissions relative to baseline (£m), before discounting		
	Option 2a	Option 3a	Option 4a
Nitrate-N	28 (20-36)	3 (2-4)	25 (18-33)
Ammonia	56 (11-172)	5 (1-16)	40 (8-123)
GHG	188 (94-282)	18 (9-28)	169 (85-254)
Phosphorus	33 (29-36)	3 (2.7-3.3)	27 (24-30)
Total	**304 (153-526)**	**30 (15-51)**	**262 (135-440)**

Note: Central values are presented, with the range of values in brackets.

Table 3 13: Changes in environmental benefits (relative to baseline) for NPK scenario, £m before discounting for 'b' options

Pollutant	Reductions in Emissions relative to baseline (£m), before discounting		
	Option 2b	Option 3b	Option 4b
Nitrate-N	28 (20-36)	3 (2-4)	25 (18-33)
Ammonia	51 (10-159)	5 (1-15)	39 (8-121)
GHG	187 (94-281)	18 (9-27)	169 (85-254)
Phosphorus	30 (27-33)	2.6 (2.3-2.9)	27 (24-30)
Total	**297 (150-509)**	**29 (14-49)**	**261 (135-439)**

Note: Central values are presented, with the range of values in brackets.

2.4.2 Net Present Value calculations

The additional costs of the proposed measures to the whole of Wales (Option 2) is largely comprised of the additional capital cost for farm infrastructure associated with constructing/expanding slurry storage and roofing dirty yards of £110-£360m in the first year and associated planning permission cost for this storage at £3.5m. The extra time input from farmers is estimated to cost £4.0 million in the first year (for those farms currently without nutrient plans) and £4.3m per year to implement and maintain the plans for all farms. The costs of improving slurry management infrastructure are the same for Option 4.

The NPVs were calculated for all three policy options using high, medium and low estimates for both environmental benefit values (prices for environmental pollutants)[5]and costs (including capital costs and annual operational costs). This is to illustrate the impact of uncertainty on NPVs and how they will change when estimates for costs and benefits move from central values to upper and lower bounds.

For each option, a total of nine possible combinations of high, medium and low estimates of costs and benefits were compared. Table 2-134 to Table 2-156 show the ranges of NPV estimates for options 2ab, 3ab and 4ab at high, medium and low cost levels and environmental benefit prices.

Detailed NPV calculations for all policy options using central estimates of costs and benefits are shown in Table 2-167. (for all ‘a’ options) and Table 3.18 (for all ‘b’ options). The detailed NPV calculations for all the remaining scenarios are presented in Appendix 4.

The central estimates (both costs and environmental benefit prices are at medium levels) suggest that Option 4a and Option 4b give highest NPVs (benefits-costs). Option 4a has a total NPV of £121 million compared with £133m for Option 4b. Option 2a has the highest cost (NPV of -£140million) however, the NPV for option 2b is £28 million, reflecting predicted reductions in annual operational costs (net cost of £9.5m for Option 2a to a net saving of £2.7m for option 2b) from the lower predicted impact on crop yields associated with Option 2b.

When testing for NPV changes using upper and lower bounds of cost and benefit values, Option 4 provides the highest NPVs (benefits-costs) for majority of the cases. The exceptions are when NPVs are estimated using low or medium environmental benefit prices and high estimates for capital and operation costs, in which case Option 3b provides the highest NPV (least net cost).

When capital and operational costs are at low levels, the total NPV for Option 2a and Option 2b is similar to that of Options 4a and 4b, with Options 3a and 3b giving the lowest NPV.

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[5] Environmental emissions used central estimates. Sensitivity of estimates on environment emissions was discussed qualitatively in Section 2.

Table 2-134: NPVs (relative to baseline) by option (£m), medium capital and operational costs.

NPV (Benefits-Costs), £m	Option 2a	Option 2b	Option 3a	Option 3b	Option 4a	Option 4b
NPV (LOW environmental benefit prices)	-243.6	-72.6	-27.8	-15.4	33.4	46.1
NPV (MEDIUM environmental benefit prices)	-140.0	28.2	-17.7	-5.6	120.7	133.1
NPV (HIGH environmental benefit prices)	21.6	183.3	-2.6	8.8	251.6	263.4

Table 2-145: NPVs (relative to baseline) by option (£m), high capital and operational costs

NPV (Benefits-Costs), £m	Option 2a	Option 2b	Option 3a	Option 3b	Option 4a	Option 4b
NPV (LOW environmental benefit prices)	-752.5	-581.5	-81.7	-69.3	-266.6	-253.9
NPV (MEDIUM environmental benefit prices)	-648.9	-480.7	-71.6	-59.5	-179.3	-166.9
NPV (HIGH environmental benefit prices)	-487.4	-325.7	- 56.5	- 45.1	-48.3	-36.3

Table 2-156: NPVs (relative to baseline) by option (£m), low capital and operational costs

NPV (Benefits-Costs), £m	Option 2a	Option 2b	Option 3a	Option 3b	Option 4a	Option 4b
NPV (LOW environmental benefit prices)	234.3	318.5	19.1	25.8	352.1	359.1
NPV (MEDIUM environmental benefit prices)	337.8	419.3	29.1	35.5	439.4	446.1
NPV (HIGH environmental benefit prices)	499.4	574.4	44.2	50.0	570.3	576.3

Table 2-167: NPV calculations (£m) using central estimates, for ‘a’ options

	2021 (capital)	2021 (annual)	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	NPV
Costs (£m)																						
Option 2a	206.4	17.0	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	
Option 3a	30.3	0.8	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	
Option 4a	206.4	-3.4	-10.9	-10.9	-10.9	-10.9	-10.9	-10.9	-10.9	-10.9	-10.9	-10.9	-10.9	-10.9	-10.9	-10.9	-10.9	-10.9	-10.9	-10.9	-10.9	
Benefits (£m)																						
Option 2a		12.5	12.6	12.7	12.8	12.9	13.0	13.2	13.3	13.4	13.5	14.2	14.9	15.6	16.3	17.0	17.8	18.5	19.2	19.9	20.6	
Option 3a		1.2	1.2	1.2	1.2	1.3	1.3	1.3	1.3	1.3	1.3	1.4	1.5	1.5	1.6	1.7	1.7	1.8	1.9	1.9	2.0	
Option 4a		10.7	10.8	10.9	11.0	11.1	11.2	11.3	11.4	11.5	11.6	12.2	12.8	13.5	14.1	14.8	15.4	16.0	16.7	17.3	18.0	
NPV (Benefits-Costs)																						
Option 2a	-206.4	-4.4	2.9	2.9	2.9	2.9	2.9	2.8	2.8	2.8	2.8	3.2	3.6	3.9	4.2	4.5	4.7	5.0	5.2	5.4	5.6	**-140.0**
Option 3a	-30.3	0.4	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.7	0.7	0.7	0.7	0.7	0.7	0.7	**-17.7**
Option 4a	-206.4	13.6	20.2	19.6	19.0	18.5	17.9	17.4	16.9	16.4	15.9	15.8	15.7	15.6	15.4	15.3	15.1	15.0	14.8	14.7	14.5	**120.7**

Table 2-18: NPV calculations (£m) using central estimates, for 'b' options

	2021 (capital)	2021 (annual)	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	NPV
Costs (£m)																						
Option 2b	206.4	4.8	-2.7	-2.7	-2.7	-2.7	-2.7	-2.7	-2.7	-2.7	-2.7	-2.7	-2.7	-2.7	-2.7	-2.7	-2.7	-2.7	-2.7	-2.7	-2.7	
Option 3b	30.30	-0.1	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	
Option 4b	206.4	-4.3	-11.8	-11.8	-11.8	-11.8	-11.8	-11.8	-11.8	-11.8	-11.8	-11.8	-11.8	-11.8	-11.8	-11.8	-11.8	-11.8	-11.8	-11.8	-11.8	
Benefits (£m)																						
Option 2b		12.1	12.2	12.4	12.5	12.6	12.7	12.8	12.9	13.0	13.1	13.8	14.5	15.3	16.0	16.7	17.4	18.1	18.8	19.5	20.2	
Option 3b		1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.3	1.3	1.3	1.4	1.5	1.5	1.6	1.7	1.7	1.8	1.9	2.0	
Option 4b		10.6	10.7	10.8	10.9	11.0	11.1	11.2	11.3	11.4	11.5	12.2	12.8	13.5	14.1	14.7	15.4	16.0	16.7	17.3	17.9	
NPV (Benefits-Costs)																						
Option 2b	-206.4	7.1	13.9	13.5	13.2	12.8	12.5	12.1	11.8	11.5	11.2	11.3	11.4	11.5	11.5	11.5	11.6	11.6	11.6	11.5	11.5	28.2
Option 3b	-30.3	1.2	1.4	1.4	1.4	1.3	1.3	1.3	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	-5.6

Affordability

Table 3-10 shows that in the medium cost scenario, additional annual operating costs across farm businesses is estimated to range from £9.5m (Option 2) to -£11m (a cost-saving in Option 4). To put these figures into context, the latest Aggregate Agricultural Account[6] shows Total Income from Farming in Wales in 2019 was £261m.

While looking at the aggregate impact may provide an indication of affordability, it will ultimately be decided at the individual farm level. Data from the annual Farm Business Survey[7] shows there is significant variation in annual income levels both between and within farm types. Table 4.1 shows average farm business income across Wales by main farm type for the period 2012-13 to 2018-19. Throughout the period, farm incomes have tended to be highest (on average) across dairy farms, although even here there have been significant variations across the period reflecting milk price fluctuations.

Table 4.1 Average Farm Incomes in Wales, 2012-13 to 2018-19

Average farm business income per farm *£ per farm*

Farm type	2012-13	2013-14	2014-15	2015-16	2016-17	2017-18	2018-19	% change (2017-18 to 2018-19)
At current prices								
Dairy	45,100	77,000	70,200	32,800	31,300	82,400	46,600	-43%
Cattle & sheep (LFA)	21,600	19,200	22,100	21,900	23,100	26,900	18,900	-30%
Cattle & sheep (lowland)	27,200	28,600	27,000	16,300	22,700	24,000	17,100	-29%
All farm types	26,600	29,300	29,000	22,200	24,500	34,600	23,600	-32%
In real terms at 2017-18 prices (a)								
Dairy	49,900	83,600	74,900	34,800	32,500	83,900	46,600	-44%
Cattle & sheep (LFA)	23,900	20,900	23,600	23,200	24,000	27,400	18,900	-31%
Cattle & sheep (lowland)	30,000	31,000	28,800	17,300	23,600	24,400	17,100	-30%
All farm types	29,400	31,900	30,900	23,600	25,400	35,300	23,600	-33%

Source: Farm Business Survey

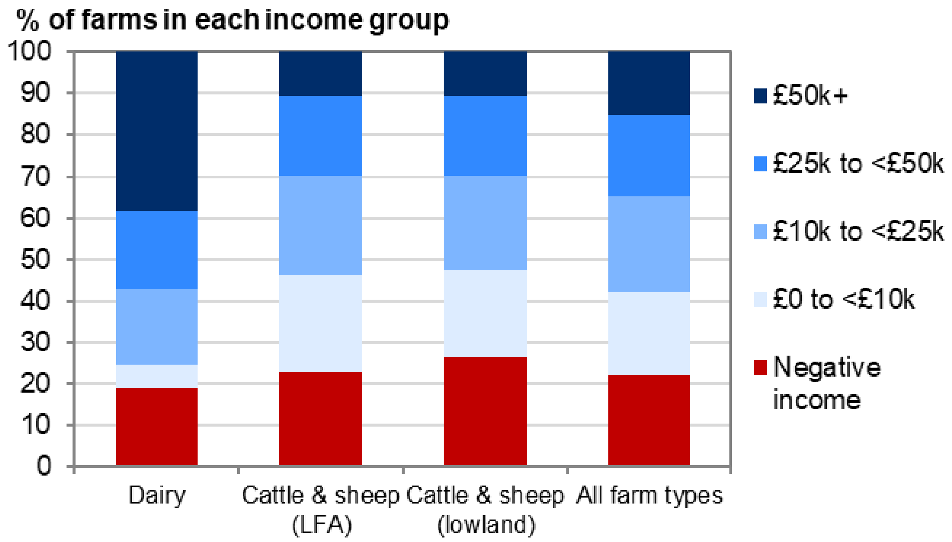
(a) GDP deflators are used here to uprate figures for 2017-18 (and earlier) to 2018-19 prices.

Chart 5.1 splits average farm business income for each of the main farm types into broad income bands. As the table shows, there are farms from each farm type in each of the income bands. The percentage of farms making £50,000+ is highest amongst dairy farms (38%), however, 19% of dairy farms were also reported to have negative farm business income in 2018-19.

Chart 5.1 Variation in farm business income by farm type, 2018-19

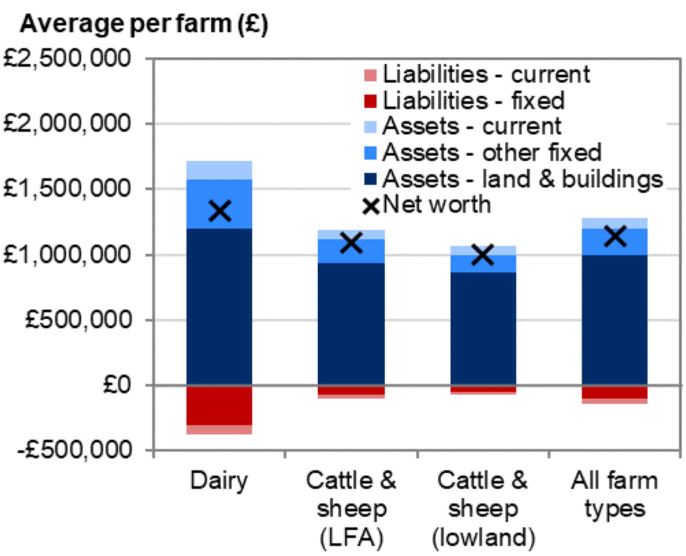
[6] https://llyw.cymru/sites/default/files/statistics-and-research/2020-04/allbwn-ac-incwm-cyfun-amaethyddol-2019-924.pdf

[7] https://gov.wales/sites/default/files/statistics-and-research/2019-12/farm-incomes-april-2018-march-2019-209.pdf



Another potential indicator of affordability is net worth. Net worth subtracts the value of total liabilities from total assets, and represents the wealth of a farm if all of their liabilities were called in. Businesses with a higher net worth are likely to be more resilient, at least in the short term, to fluctuations in their income. Such farms can draw on these reserves, or borrow against them, to support the business if the financial position of the farm deteriorates. As with farm income, average net worth is higher on dairy farms than other farm types. It is worth making the point again however that there is a likely to be significant variation in the net worth of individual farm businesses within each farm type. Chart 5.2 shows the average net worth by farm type.

Chart 5.2 Average net worth by farm type, 2018-19



LFA farms tend to be extensive and the costs associated with not being able to spread in high risk areas and at high risk times, the two greatest costs aside from storage, are less relevant as the use of manufactured fertiliser tends to be lower and they have less manure to spread and an increased area on which to apply it. The cost of slurry storage isn't applicable to sheep farms in the main. If cattle are housed then slurry storage will be needed but at reduced cost as stocking levels tend to be lower.

The greater costs will be associated with dairy and more intensive beef due to bigger stores to accommodate increased slurry production. The yield penalties associated with the spreading restrictions are likely to be greater as these farms are more dependent on maximising the utilisation of grass as opposed to feed imports which increase costs.

In summary, the greatest costs will be associated with dairy, which, the data suggests, is the sector best able to accommodate those costs (on average). Intensive lowland sheep and in particular beef, because of storage requirements, may face greater pressures due to lower incomes. LFA beef will also be impacted by storage costs but less so by yield penalties.

As stated above, there are large variances in farm incomes both between farm types and within farm types, this affects a farms ability to absorb the additional capital cost and/or ongoing operating cost.

The RIA has assumed that the full capital cost of increasing slurry storage will be incurred by the farm business, however, this does not reflect the funding which may be provided through the Rural Development Programme for Wales. While regulatory compliance cannot be funded, it is possible to provide funding for investments in advance. The Welsh Government has already provided funding for investments which would aid compliance with the proposed regulations. If additional funding is provided, it would be possible to grant aid up to 40% of the costs associated with the slurry storage requirements. While this would not affect the NPV calculation, it could shift between £10.4m and £12.8m of the upfront capital cost from farm businesses to Government for Option 2.

Infraction risk

Due to the obligation to remain compliant with European Union Directives and Water Framework Directive, while the United Kingdom remains a Member State, risks are associated with non-compliance in respect of Options 1 and 4. An infraction risk is also associated with Option 2 in relation to compliance and enforcement risks.

Under the Treaty on the Functioning of the European Union (TFEU), when the Commission refers a Member State to the Court of Justice of the European Union for having infringed EU law, the Court may impose financial sanctions in two situations (Brussels, 20.2.2019 C(2019) 1396 final):

- When the Court has ruled that a Member State infringing EU law has not yet complied with an earlier judgment finding that infringement (Article 260(2) TFEU);
- When a Member State has failed to fulfil its obligation to notify measures transposing a Directive adopted under a legislative procedure (Article 260(3) TFEU).

In both cases, the sanction is made up of a lump sum payment, to penalise the existence of the infringement itself, and a daily penalty payment, to penalise the continuation of the infringement after the Court's judgment. The Commission proposes an amount for the financial sanctions to the Court, which takes the final decision.

Infraction penalties take into consideration the following key factors:

- importance of the rules breached and the impact of the infringement on general and particular interests;
- the period the EU law has not been applied; and
- the country's ability to pay, ensuring that the fines have a deterrent effect.

The resulting method of calculation is summed up by the following general formula:

Dp = (Bfrap x Cs x Cd) x n

where: Dp = daily penalty payment; Bfrap = basic flat-rate amount "penalty payment" (3,105 EUR); Cs = coefficient for seriousness (from 1 to 20); Cd = coefficient for duration (from 1 to 3); n = factor taking into account the capacity to pay of the Member State concerned (n = 3.5).

The potential daily penalty for Wales ranges from 10,868 EUR to 652,050 EUR.

The potential lump sum penalty for Wales is 8,987,000 EUR.

Over a 20 year period the total penalty could range from 88,323,400 EUR to 4,768,952,000 EUR.

The Welsh Government has no contingency budget in place to deal with infraction penalties and would need to pay any fines in accordance with the rates applicable to the UK as a MS. It is UK Government policy that any non-compliance issue which fall under Wales' responsibility would need to be paid by the Welsh Government.

Example of infraction penalties applied:

Case C-304/02, Commission v French Republic. In this judgment of 12 July 2005, the ECJ ordered a Member State to pay both a periodic penalty payment and a lump sum fine for a serious and persistent failure to comply with Community law.

The case concerned compliance by France with Community measures for fisheries conservation. France had infringed Community law by letting undersized fish be offered for sale. Following inspection at certain French ports in the course of 11 years, the Commission took the view that France was still not yet complying fully with its obligations. Undersized fish were still offered for sale, and the French authorities maintained a lax attitude in enforcing EC rules.

The ECJ ordered France to pay a penalty payment of EUR 57 761 250 for each period of six months, from the 12 July 2005 onwards, taking into account the duration and the seriousness of the infringement and its ability to pay, and a lump sum of EUR 20 000 000. With this amount, the ECJ took into account the persistence of the breach of obligations and the public and private interests at issue.

Additional impacts

The proposed measures have the potential to impact upon individuals, communities, tenant farmers, allied industries. These impacts are discusses further in the Welsh Government's Integrated Impact Assessment. A summary is included in Appendix 6.

3 SUMMARY

Improvements in slurry management are likely to require significant capital investment (ranging between £8million and £360 million for the different options) to achieve compliance with the measures 'improve slurry storage capacity' and do not spread slurry and poultry manure at high risk times.

Slurry storage requirement can be reduced by improving the management of dirty water e.g. by roofing dirty yards and by covering slurry stores (which can also reduce ammonia emissions). The outputs from this study suggest that capital costs of roofing yards are not balanced by reductions in slurry storage requirement or savings in slurry spreading costs. There are other benefits from roofing yards such as reduced risks of yard runoff directly polluting surface waters and improvements in production efficiency which are not included in this study.

The modelled outputs suggest that the measures 'Use a Fertiliser Recommendation System' and 'Integrate fertiliser and manure nutrient supply' will lead to savings in operational costs as a result of savings in manufactured fertiliser use and increased crop yields. The savings are predicted to outweigh the additional time and administrative costs associated with setting up and maintaining nutrient management plans.

The measure 'Do not apply fertilisers to high risk areas' was predicted to have high operational costs largely reflecting reduced crop yields as a result of sub-optimal nutrient supply to these areas.

Operational costs associated with Option 'a' were predicted to be high as a result of potential impacts on crop yields of delaying fertiliser applications until April. Operational costs associated with Option 'b' were predicted to increase only under the high cost scenarios, reflecting the lower impact of delaying fertiliser applications until the end of February on crop yields

In this study 'high risk times' for slurry and manufactured fertiliser applications were defined as the beginning of October (to reduce risks of nitrate leaching losses), until soils had a moisture deficit of greater than 10 mm in the spring to reduce the risk of P and ammonium contamination of surface and drainage waters. Information from modelling work carried out as part of this study indicates that soils across Wales typically do not have soil moisture deficits until late March/ early April. Consequently, the measure 'do not apply slurry at high risk times' required 6 months slurry storage capacity (October to March).

Net present values (NPVs) were calculated for all three policy options using high, medium and low estimates for both environmental benefit values (prices for environmental pollutants) and costs (including capital costs and annual operational costs). This is to illustrate the impact of uncertainty on NPVs and how they will change when estimates for costs and benefits move from central values to upper and lower bounds.

The central estimates (both costs and environmental benefit prices at medium levels) suggest a total NPV of £28 million (net benefit) for option 2b, £121 million for Option

4a and £133m for Option 4b, compared to net costs of £17.7m for Option 3a and £5.6m for 3b, and £140 million for Option 2a. The higher NPV of ‘b’ options reflect the lower operational costs compared with ‘a’ options.

Option 4 shows the highest NPV benefits as a result of not including the measures do not apply fertilisers at high risk times and to high risk areas outside the proposed NVZ areas which have significant annual operational costs (central estimates of £9.8 million and £12.2 million respectively for whole Wales).

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APPENDIX 1. DETAILS ON FARMSCOPER

Description

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.

Pollutant loss coefficients were calculated using a suite of existing national model frameworks used for government policy support (including PSYCHIC (Davison et al., 2008) and NEAP-N (Lord and Anthony, 2000)) applied at 1km^2 resolution using local soil, climate and other environmental data and required assumptions on farm management. The results were then summarised for 3 soil types and 6 climate zones to populate the database that underpins Farmscoper. Farmscoper queries this database to determine the pollutant losses and apportionment for the farming system being represented, multiplying the relevant coefficients by the cropping area, volume or livestock excreta or fertiliser used as appropriate. A simplified description of Farmscoper is shown in Figure . The coefficients are expressed as a function of a complex coordinate system that allows for the quantification of the impacts of mitigation methods on the calculated pollutant loads, for example a mitigation method may only reduce losses of dairy slurry in the surface runoff pathway. The NEAP-N losses were 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 (Nicholson et al., 2013) and EDEN (Gooday et al., 2008)).

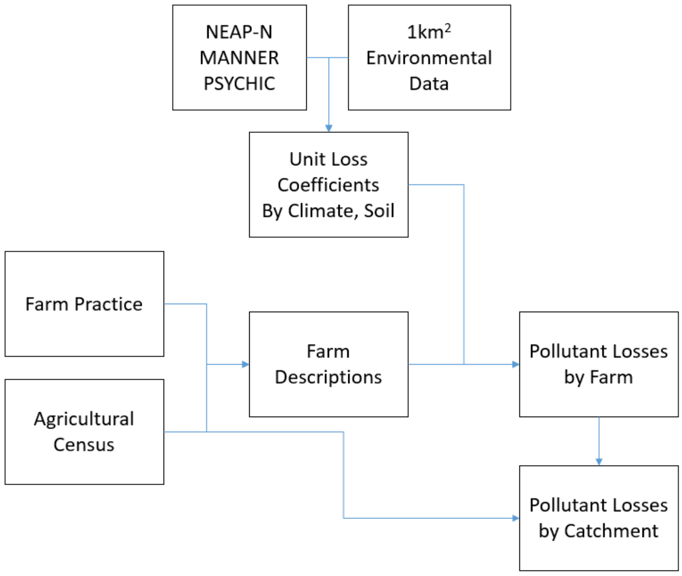

Figure A1-1: A simplified description of how pollutant export coefficients were calculated for use in Farmscoper and then used to calculate pollutant losses.

Table A1-1: The coordinate system used within Farmscoper to provide source apportionment and allow the targeting of mitigation methods.

Source	Area	Pathway	Type	Timescale	Form
Dairy	Arable	Runoff	Soil	Short	Particulate
Beef	Grass	Preferential	Fertiliser	Medium	Dissolved
Sheep	Rough	Leaching	FYM	Long	Gas
Pigs	Yards	Gaseous	Slurry		Gas Indirect
Poultry	Housing	Direct	Litter		
Chemical	Tracks		Voided		
Land	Fords		Enteric		
	Field Storage		Dirty Water		
	Steading				
	Storage				
	Woodland				

Previous validation of Farmscoper

As Farmscoper is effectively a meta-model of the PSYCHIC and NEAP-N models, the accuracy of Farmscoper's predictions can be assessed by comparing outputs with those of the source models. This was undertaken for the Water Management Catchments in England using data for 2010 (Figure 2; Gooday et al., 2015). Farmscoper outputs have also been directly compared against monitored data (e.g. Zhang et al., 2015).

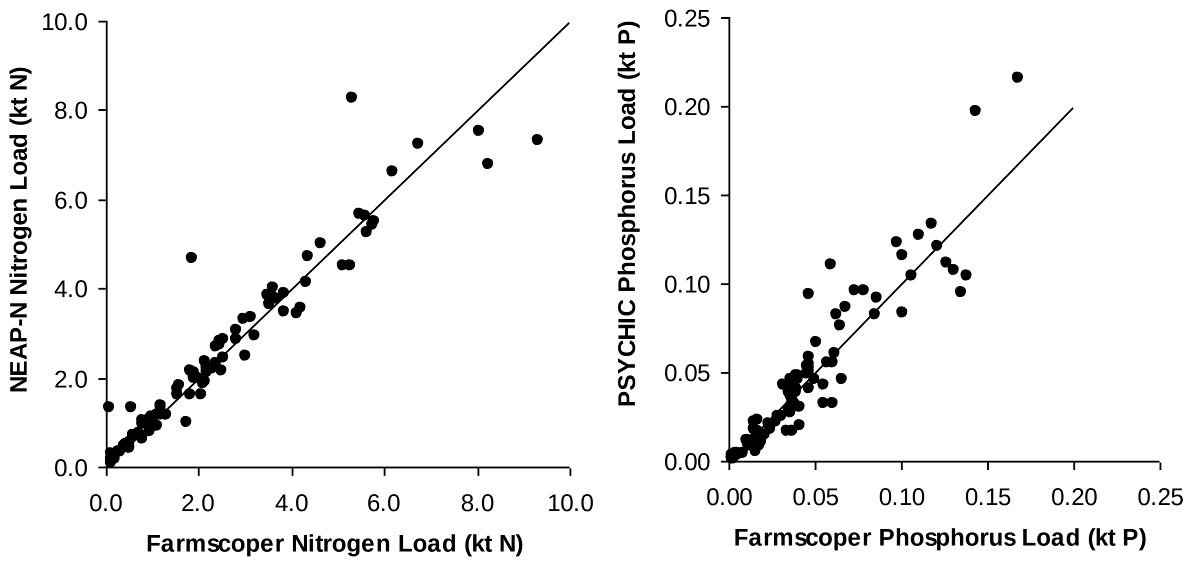

Figure A1-2: Comparison of agricultural nitrogen and phosphorus loads predicted by Farmscoper for the 91 Water Management Catchments in England against loads predicted by the NEAP-N and PSYCHIC models for those same catchments. All model simulations used 2010 June Agricultural Census data (from Gooday et al., 2015).

The equations within PSYCHIC were derived from, and calibrated against, experimental research data, but the catchment scale pollutant load predictions from PSYCHIC are not calibrated. Instead, these outputs have been verified against available catchment scale water quality measurements to show that outputs capture the spatial variations resulting from differences in input data. Initial verification of PSYCHIC was included in Stromqvist et al., 2008. Subsequent verification of outputs has included comparison of pollutant loads against data from the Harmonised Monitoring Scheme (Figure ; Gooday et al., 2015) and Environment Agency monitoring data.

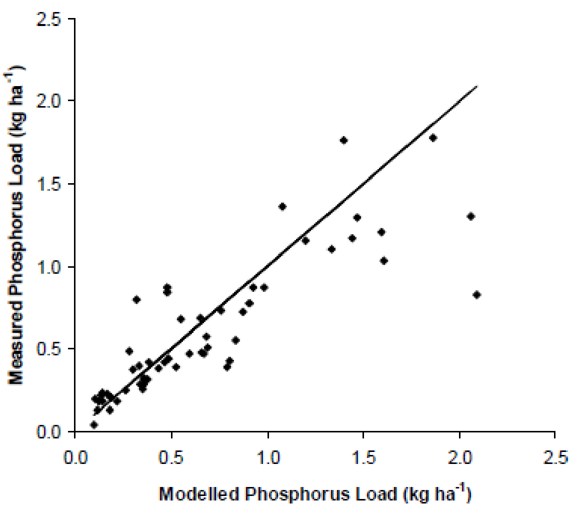

Figure A1-3: Comparison of modelled and measured phosphorus loads for the HMS monitoring catchments in Scotland (from Gooday et al., 2015).

The accumulated catchment scale predictions of nitrate loss from NEAP-N have been validated against observed water quality data (e.g. Anthony et al., 2011; Gooday et al., 2015). The most recent validation of NEAP-N outputs was undertaken in the generation of data for 2014, with nitrate loads compared against Harmonised Monitoring Scheme data for the period 2008-2012 and a regression equation derived to allow a comparison of predicted nitrate concentrations with Environment Agency data covering the period 2008-2012 for a further 301 sites.

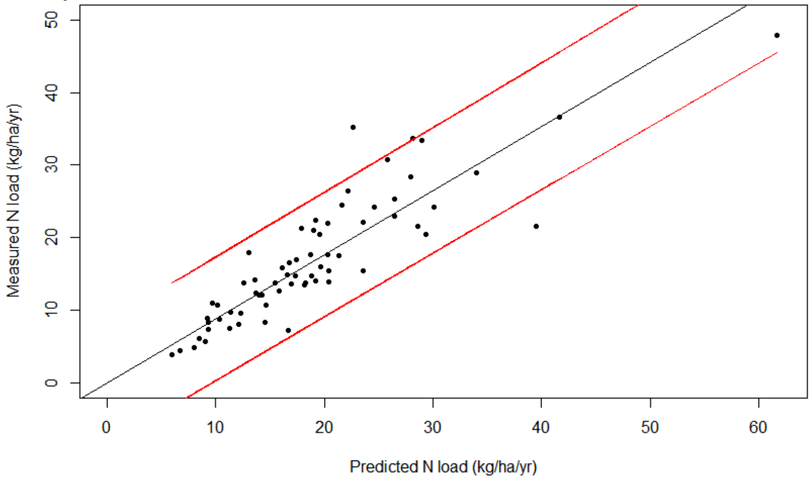

Figure A1-4: Comparison of annual average measured nitrate loads (2008-2012) and predicted loads (2014) for 66 HMS sites across England and Wales (from Lee et al., 2017)

APPENDIX 2. MANNER-*NPK* MODELLING

Methodology

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 nitrate, nitrous oxide and ammonia losses due to changes in application timing of high N available manure (cattle slurry, pig slurry, broiler litter and layer litter). MANNER has been used previously to model the impacts of introducing a manure spreading closed period in England using a similar methodology to that described below (DEFRA project WT0932).

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 methods) at a 5x5 km scale and a weighting of the results of these outputs to represent management under current practice and modified practice due to avoiding high risk times.

The batch runs of MANNER were performed using local climate for each 5km square in Wales, for:

- 3 land use types (spring sown, winter sown and grass)
- 2 soil types (sandy/shallow and other)
- 4 application methods (bandspread, broadcast, deep injection, shallow injection)
- 4 incorporation delays (not incorporated, < 1 week, < 24 hours, < 2 Hours)

The crop choices reflect the major land uses in Wales and represent different risks due to crop cover and over-winter nitrogen uptake. The soil types reflect those used in the definitions of NVZ closed periods.

MANNER simulations were undertaken for a unit of manure applied on the 1st and 15th of each month to give a predicted pollutant loss under each combination of month, 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, and the proportion of each soil type in each square. They were also weighted according to the proportion of each manure type applied by crop type by each of the four application methods and incorporation delays using data derived from the British Survey of Fertiliser Practice (BSFP; Table A2-1 and Table A2-2), using data for 2008-2010. Data on timings of manure application by month and crop type were also derived from the same source (Table **Table** A2-3). For cattle slurry, data specifically for Wales was used, but for other manure types results were based on data for England and Wales (due to there being very few records of application in Wales alone).

Manure volumes were derived from the results of the Farmscoper modelling, with volumes totalled for each 5 km square, including the proportions inside and outside of the proposed NVZ areas.

High risk times were defined as the NVZ closed periods for sandy/shallow soils and the NVZ closed periods and the months of February and March for other soils (reflecting the high risks of phosphorus loss in these month as described in Section 1.2.7). In order to model the impacts of avoiding high risk times, the timing data in Table **Table** A2-3 was adjusted so that any slurry or poultry manure currently spread during these times 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 A2-4 and Table A2-5)

Table A2-1: Current manure application methods by manure type and crop types (%).

Application Method	Band spread	Broadcast *	Deep injection	Shallow injection
Broiler/Turkey Litter				
Winter	0	100	0	0
Spring	0	100	0	0
Grass	0	100	0	0
Cattle slurry				
Winter	0	100	0	0
Spring	2	95	1	2
Grass	5	87	3	5
Layer Hen Manure				
Winter	0	1	0	0
Spring	0	1	0	0
Grass	0	1	0	0
Pig slurry				
Winter	45	55	0	0
Spring	11	87	0	2
Grass	16	85	0	0

*For Cattle Slurry spread on Grass, Broadcast is the sum of Broadcast, Rotating boom and Not available

Table A2-2: Current manure incorporation rates (%) for winter and spring sown crops receiving manure in either the winter or spring. Manure applied to grassland is never incorporated.

Incorporation Delay	Broiler / Turkey Litter	Cattle slurry	Layer Hen Manure	Pig slurry
	Winter Crop, Dec-Jun			
Over 1week or never*	97	61	62	85
Within 1 week of spreading†	3	0	0	10
Within 24 hours of spreading‡	0	39	36	5
Within 6 hours of spreading§	0	0	1	0.00
	Winter Crop, July-Nov			
Over 1week or never*	7	7	7	7
Within 1 week of spreading†	15	15	15	15
Within 24 hours of spreading‡	40	40	40	40
Within 6 hours of spreading§	38	38	38	38
	Spring Crop, Dec-Jun			
Over 1week or never*	17	34	4	11
Within 1 week of spreading†	17	25	24	55
Within 24 hours of spreading‡	41	35	47	30
Within 6 hours of spreading§	26	7	25	3
	Spring Crop, Jul-Nov			
Over 1week or never*	96	96	96	96
Within 1 week of spreading†	3	3	3	3
Within 24 hours of spreading‡	0	0	0	0
Within 6 hours of spreading§	0	0	0	0

*Survey results not incorporated, incorporated more than 1 week after spreading and don’t know
†Survey result: 3-5 days
‡Survey result: 6-12 hours
§Survey result: Less than 2 hours

Table A2-3: 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												
Spring sown	1	34	14	45	4							2
Winter sown		26	17	3				17	30	7		
Grass	12	19	23	13	6	9	6	4	2	3	2	2
Pig Slurry												
Spring sown	36	5	12	37	2					1	5	2
Winter sown	0		8	32	6	0	6	13	22	11	1	0
Grass	2	23	9	29	6	6	12	1		6	3	2
Layer Manure												
Spring sown	7	8	36	38	1			1		0	9	0
Winter sown	0	1	2	0		0	2	45	40	9		
Grass			35	20		19	7	5	13			1
Broiler Litter												
Spring sown	10	16	34	23	9			4	2		1	1
Winter sown		10	10	0			0	38	29	12		
Grass		29	46	9	1	11			2	2		

Table A2-4: Predicted manure application timings (%) to avoid high risk times 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												
Spring sown	1	35	14	46	4				1			
Winter sown		57	36	6								
Grass	13	21	25	14	6	10	6	4	13			
Pig Slurry												
Spring sown	40	5	13	40	3				40			
Winter sown	1		16	61	11	1	11		1			
Grass	2	26	11	33	7	7	14	1	2			
Layer Manure												
Spring sown	8	9	41	42	1				8			
Winter sown	1	21	28	6		5	40		1			
Grass			41	23		22	9	6				
Broiler Litter												
Spring sown	11	18	37	25	10				11			
Winter sown		49	51	0			0					
Grass		30	48	9	1	11						

Table A2-5: Predicted manure application timings (%) to avoid high risk times for other soils. Note that each row totals to 100%

	January	February	March	April	May	June	July	August	September	October	November	December
Cattle Slurry												
Spring sown				92	8							
Winter sown				6				34	60			
Grass				32	14	22	14	9	4	4		
Pig Slurry												
Spring sown				94	6							
Winter sown				40	7	0	7	17	28			
Grass				50	11	11	21	1		5		
Layer Manure												
Spring sown				96	2			2				
Winter sown				0		0	3	51	46			
Grass				31		30	11	7	21			
Broiler Litter												
Spring sown				61	23			10	5			
Winter sown				0			0	57	43			
Grass				39	4	46			7	4		

Table A2-6 summarises the changes in the nitrogen, ammonia and nitrous oxide losses due to avoiding applications at high risk times. Nitrate losses are reduced by almost 0.4 kt, which equates to 1.3% of national agricultural losses of nitrate. Nitrous oxide losses are also reduced, but are less significant as part of the overall total. Ammonia losses increase, as more manure is applied to dry soils in the summer and it cannot be incorporated (particularly poultry manure, where more is applied to arable crops and so could have been incorporated previously).

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, and that there will be no change in the proportions going to the different crop types or changes in application or incorporation method. This approach has been used in previous studies into the environmental impacts of introducing closed periods (DEFRA project WT0932; Lord *et al*. 2009).

Table A2-6: Total N applied in manure and change in pollutant losses from manure due to avoiding high risk times.

	N Applied (kg)	Change in Loss (kg)		
		NO_3	NH_3	N_2O
Proposed NVZ				
Cattle Slurry	13,199,534	264,368	-152	10,389
Pig slurry	82,134	4,051	-36	160
Broiler litter	2,379,625	44,040	-7,280	1,876
Layer litter	1,392,770	42,456	-3,197	1,732
Total	17,054,063	354,915	-10,665	14,156
Non-NVZ				
Cattle Slurry	2,075,685	44,446	-126	1,749
Pig slurry	5,752	269	-2	11
Broiler litter	31,714	819	-166	35
Layer litter	28,647	1,230	-113	51
Total	2,141,798	46,765	-407	1,845
Grand Total	19,195,862	401,680	-11,072	16,002

Appendix 3 Detailed slurry storage volumes and capital costs

Table A3-1: Slurry storage volumes and costs of additional slurry storage capacity (All Wales)

Livestock type	Slurry storage volumes (million m^3)			Additional storage capacity required (million m^3)		Additional costs Above ground tank (£m)		Additional costs Lagoon (£m)	
	Baseline*	5 months	6 months	5 months	6 months	5months	6 months	5months	6 months
Dairy	5.54	6.54	7.65	1.00	2.11	50.08	105.7	40.06	84.57
Beef	0.90	1.04	1.21	0.14	0.31	7.34	15.63	5.87	12.51
Pigs	0.01	0.02	0.02	<0.01	<0.01	0.12	0.27	0.10	0.22
Total	6.45	7.60	8.88	1.15	2.43	57.54	121.7	46.03	97.30

* Assumes compliance with SSAFO regs.

Table A3-2: Slurry storage volumes and costs of additional slurry storage capacity across non NVZ areas (92% of Wales)

Livestock type	Slurry storage volumes (million m^3)			Additional storage capacity required (million m^3)		Additional costs Above ground tank (£m)		Additional costs Lagoon (£m)	
	Baseline*	5 months	6 months	5 months	6 months	5months	6 months	5months	6 months
Dairy	4.69	5.53	6.47	0.84	1.78	42.11	88.98	33.69	71.19
Beef	0.83	0.97	1.12	0.14	0.29	6.79	14.47	5.43	11.57
Pigs	0.01	0.01	0.02	<0.01	<0.01	0.12	0.25	0.09	0.20
Total	5.53	6.51	7.61	0.98	2.07	49.02	103.7	39.21	82.96

* Assumes compliance with SSAFO regs

Table A3-3: Slurry storage volumes and costs of additional slurry storage capacity across proposed NVZ areas (8% of Wales)

Livestock type	Slurry storage volumes (million m^3)			Additional storage capacity required (million m^3)		Additional costs Above ground tank (£m)		Additional costs Lagoon (£m)	
	Baseline*	5 months	6 months	5 months	6 months	5months	6 months	5months	6 months
Dairy	0.85	1.01	1.19	0.16	0.33	7.97	16.74	6.37	13.39
Beef	0.06	0.07	0.08	0.01	0.02	0.55	1.16	0.44	0.91
Pigs	<0.01	<0.01	<0.01	<0.01	<0.01	0.01	0.02	0.01	0.02
Total	0.91	1.08	1.27	0.17	0.35	8.53	17.92	6.82	14.32

* Assumes compliance with SSAFO regs.

Table A3-4: Slurry storage volumes and costs of additional slurry storage capacity (All Wales)

Livestock type	Slurry storage volumes (million m^3)			Additional storage capacity required (million m^3)		Additional costs Above ground tank (£m)		Additional costs Lagoon (£m)	
	Baseline*	5 months	6 months	5 months	6 months	5months	6 months	5months	6 months
Dairy	5.49	6.23	7.29	0.74	1.80	37.11	90.15	29.69	72.12
Beef	0.89	0.93	1.09	0.04	0.20	2.33	10.22	1.86	8.17
Pigs	0.01	0.02	0.02	0.01	0.01	0.13	0.27	0.10	0.22
Total	6.39	7.18	8.41	0.79	2.01	39.55	100.6	31.65	80.49

* Assumes compliance with SSAFO regs.

Table A3-5: Slurry storage volumes and costs of additional slurry storage capacity across non NVZ areas (92% of Wales)

Livestock type	Slurry storage volumes (million m^3)			Additional storage capacity required (million m^3)		Additional costs Above ground tank (£m)		Additional costs Lagoon (£m)	
	Baseline*	5 months	6 months	5 months	6 months	5months	6 months	5months	6 months
Dairy	4.65	5.26	6.15	0.62	1.51	30.80	75.40.	24.64	60.32
Beef	0.82	0.87	1.02	0.04	0.19	2.45	9.75	1.96	7.80
Pigs	<0.01	<0.01	0.02	<0.01	<0.01	0.12	0.25	0.09	0.20
Total	5.47	6.13	7.19	0.66	1.70	33.37	85.40	26.79	68.32

* Assumes compliance with SSAFO regs

Table A3-6: Slurry storage volumes and costs of additional slurry storage capacity across proposed NVZ areas (8% of Wales)

Livestock type	Slurry storage volumes (million m^3)			Additional storage capacity required (million m^3)		Additional costs Above ground tank (£m)		Additional costs Lagoon (£m)	
	Baseline*	5 months	6 months	5 months	6 months	5months	6 months	5months	6 months
Dairy	0.81	0.96	1.13	0.15	0.32	7.65	16.10	6.13	12.88
Beef	0.05	0.07	0.08	0.01	0.02	0.50	1.09	0.40	0.87
Pigs	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Total	0.86	1.03	1.21	0.16	0.34	8.15	17.19	6.54	13.75

* Assumes compliance with SSAFO regs.

APPENDIX 4. DETAILED NPV TABLES

Table A4-1: Detailed NPV calculations for 'a' options, high capital and operational costs, low environmental values

	2021 (capital)	2021 (annual)	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	NPV
Costs (£m)																						
Option 2a	360.0	42.0	34.5	34.5	34.5	34.5	34.5	34.5	34.5	34.5	34.5	34.5	34.5	34.5	34.5	34.5	34.5	34.5	34.5	34.5	34.5	
Option 3a	51.50	3.1	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	
Option 4a	360.0	6.9	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6	
Benefits (£m)																						
Option 2a		6.3	6.4	6.4	6.5	6.5	6.6	6.7	6.7	6.8	6.8	7.2	7.5	7.9	8.2	8.6	9.0	9.3	9.7	10.0	10.4	
Option 3a		0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.7	0.7	0.7	0.7	0.7	0.8	0.8	0.8	0.9	0.9	0.9	1.0	1.0	
Option 4a		5.5	5.6	5.6	5.7	5.7	5.8	5.8	5.9	5.9	6.0	6.3	6.6	6.9	7.3	7.6	7.9	8.2	8.5	8.9	9.2	
NPV (Benefits-Costs)																						
Option 2a	-360.0	-34.5	-26.3	-25.4	-24.4	-23.6	-22.7	-21.9	-21.1	-20.4	-19.7	-18.7	-17.9	-17.0	-16.2	-15.5	-14.8	-14.1	-13.4	-12.8	-12.1	**-752.5**
Option 3a	-51.5	-2.4	-2.1	-2.0	-1.9	-1.8	-1.8	-1.7	-1.7	-1.6	-1.5	-1.5	-1.4	-1.3	-1.3	-1.2	-1.1	-1.1	-1.0	-1.0	-0.9	**-81.7**
Option 4a	-360.0	-1.4	5.7	5.6	5.4	5.3	5.1	5.0	4.9	4.8	4.6	4.7	4.7	4.8	4.8	4.9	4.9	4.9	4.9	4.9	4.9	**-266.6**

Table A4-2: Detailed NPV calculations for ‘b’ options, high capital and operational costs, low environmental values

	2021 (capital)	2021 (annual)	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	NPV
Costs (£m)																						
Option 2b	360.0	29.8	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	22.3	22.3	
Option 3b	51.5	2.2	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	
Option 4b	360.0	6.0	-1.5	-1.5	-1.5	-1.5	-1.5	-1.5	-1.5	-1.5	-1.5	-1.5	-1.5	-1.5	-1.5	-1.5	-1.5	-1.5	-1.5	-1.5	-1.5	
Benefits (£m)																						
Option 2b		6.2	6.2	6.3	6.3	6.4	6.4	6.5	6.5	6.6	6.6	7.0	7.4	7.7	8.1	8.4	8.8	9.1	9.5	9.8	10.2	
Option 3b		0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.7	0.7	0.7	0.8	0.8	0.8	0.9	0.9	0.9	1.0	
Option 4b		5.5	5.6	5.6	5.7	5.7	5.8	5.8	5.9	5.9	6.0	6.3	6.6	6.9	7.2	7.6	7.9	8.2	8.5	8.8	9.2	
NPV (Benefits-Costs)																						
Option 2b	-360.0	-22.9	-15.1	-14.5	-14.0	-13.4	-12.9	-12.5	-12.0	-11.6	-11.1	-10.5	-9.9	-9.4	-8.8	-8.3	-7.8	-7.4	-6.9	-6.5	-6.1	-581.5
Option 3b	-51.5	-1.5	-1.2	-1.2	-1.2	-1.1	-1.1	-1.0	-1.0	-1.0	-0.9	-0.9	-0.8	-0.8	-0.7	-0.7	-0.6	-0.6	-0.5	-0.5	-0.5	-69.3
Option 4b	-360.0	-0.5	6.6	6.4	6.2	6.0	5.9	5.7	5.6	5.4	5.3	5.3	5.3	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.3	-253.9

Table A4-3: Detailed NPV calculations for 'a' options, high capital and operational costs, medium environmental values

	2021 (capital)	2021 (annual)	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	NPV
Costs (£m)																						
Option 2a	360.0	42.0	34.5	34.5	34.5	34.5	34.5	34.5	34.5	34.5	34.5	34.5	34.5	34.5	34.5	34.5	34.5	34.5	34.5	34.5	34.5	
Option 3a	51.50	3.1	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	
Option 4a	360.0	6.9	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6	
Benefits (£m)																						
Option 2a		12.5	12.6	12.7	12.8	12.9	13.0	13.2	13.3	13.4	13.5	14.2	14.9	15.6	16.3	17.0	17.8	18.5	19.2	19.9	20.6	
Option 3a		1.2	1.2	1.2	1.2	1.3	1.3	1.3	1.3	1.3	1.3	1.4	1.5	1.5	1.6	1.7	1.7	1.8	1.9	1.9	2.0	
Option 4a		10.7	10.8	10.9	11.0	11.1	11.2	11.3	11.4	11.5	11.6	12.2	12.8	13.5	14.1	14.8	15.4	16.0	16.7	17.3	18.0	
NPV (Benefits-Costs)																						
Option 2a	-360.0	-28.5	-20.5	-19.7	-18.9	-18.2	-17.5	-16.8	-16.2	-15.5	-14.9	-13.9	-13.0	-12.1	-11.2	-10.4	-9.7	-9.0	-8.3	-7.6	-7.0	**-648.9**
Option 3a	-51.5	-1.8	-1.5	-1.4	-1.4	-1.3	-1.3	-1.2	-1.2	-1.1	-1.1	-1.0	-0.9	-0.8	-0.8	-0.7	-0.6	-0.6	-0.5	-0.5	-0.4	**-71.6**
Option 4a	-360.0	3.6	10.6	10.3	10.0	9.8	9.5	9.3	9.0	8.8	8.6	8.7	8.9	9.0	9.1	9.1	9.2	9.3	9.3	9.3	9.3	**-179.3**

Table A4-4: Detailed NPV calculations for 'b' options, high capital and operational costs, medium environmental values

	2021 (capital)	2021 (annual)	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	NPV
Costs (£m)																						
Option 2b	360.0	29.8	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	22.3	22.3	
Option 3b	51.50	2.2	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	
Option 4b	360.0	6.0	-1.5	-1.5	-1.5	-1.5	-1.5	-1.5	-1.5	-1.5	-1.5	-1.5	-1.5	-1.5	-1.5	-1.5	-1.5	-1.5	-1.5	-1.5	-1.5	
Benefits (£m)																						
Option 2b		12.1	12.2	12.4	12.5	12.6	12.7	12.8	12.9	13.0	13.1	13.8	14.5	15.3	16.0	16.7	17.4	18.1	18.8	19.5	20.2	
Option 3b		1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.3	1.3	1.3	1.4	1.5	1.5	1.6	1.7	1.7	1.8	1.9	2.0	
Option 4b		10.6	10.7	10.8	10.9	11.0	11.1	11.2	11.3	11.4	11.5	12.2	12.8	13.5	14.1	14.7	15.4	16.0	16.7	17.3	17.9	
NPV (Benefits-Costs)																						
Option 2b	-360.0	-17.1	-9.4	-9.0	-8.6	-8.2	-7.9	-7.5	-7.2	-6.8	-6.5	-5.8	-5.2	-4.5	-3.9	-3.4	-2.9	-2.4	-1.9	-1.5	-1.1	-360.0
Option 3b	-51.5	-1.0	-0.7	-0.7	-0.6	-0.6	-0.6	-0.6	-0.5	-0.5	-0.5	-0.4	-0.4	-0.3	-0.2	-0.2	-0.1	-0.1	-0.1	-0.0	0.0	-51.5
Option 4b	-360.0	4.5	11.4	11.1	10.8	10.5	10.2	10.0	9.7	9.5	9.2	9.3	9.4	9.5	9.6	9.7	9.7	9.7	9.8	9.8	9.8	-360.0

Table A4-5: Detailed NPV calculations for ‘a’ options, high capital and operational costs, high environmental values

	2021 (capital)	2021 (annual)	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	NPV
Costs (£m)																						
Option 2a	360.0	34.5	34.5	34.5	34.5	34.5	34.5	34.5	34.5	34.5	34.5	34.5	34.5	34.5	34.5	34.5	34.5	34.5	34.5	34.5	34.5	
Option 3a	51.50	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	
Option 4a	360.0	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6	
Benefits (£m)																						
Option 2a		22.2	22.4	22.6	22.7	22.9	23.1	23.2	23.4	23.6	23.7	24.8	25.9	26.9	28.0	29.1	30.1	31.2	32.3	33.3	34.4	
Option 3a		2.1	2.2	2.2	2.2	2.2	2.2	2.2	2.3	2.3	2.3	2.4	2.5	2.6	2.7	2.8	2.9	3.0	3.1	3.2	3.3	
Option 4a		18.4	18.5	18.7	18.8	19.0	19.1	19.3	19.4	19.5	19.7	20.7	21.6	22.6	23.6	24.5	25.5	26.4	27.4	28.4	29.3	
NPV (Benefits-Costs)																						
Option 2a	-360.0	-11.9	-11.3	-10.8	-10.3	-9.8	-9.3	-8.9	-8.5	-8.1	-7.7	-6.7	-5.7	-4.9	-4.0	-3.3	-2.5	-1.9	-1.2	-0.6	-0.1	-487.4
Option 3a	-51.5	-0.7	-0.6	-0.6	-0.6	-0.5	-0.5	-0.5	-0.4	-0.4	-0.4	-0.3	-0.2	-0.1	-0.1	-0.0	0.1	0.1	0.2	0.2	0.3	-56.5
Option 4a	-360.0	18.3	17.8	17.3	16.9	16.4	16.0	15.6	15.2	14.8	14.4	14.5	14.7	14.8	14.9	15.0	15.0	15.0	15.1	15.0	15.0	-48.3

Table A4-6: Detailed NPV calculations for ‘b’ options, high capital and operational costs, high environmental values

	2021 (capital)	2021 (annual)	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	NPV
Costs (£m)																						
Option 2b	360.0	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	22.3	22.3	22.3	
Option 3b	51.50	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	
Option 4b	360.0	-1.5	-1.5	-1.5	-1.5	-1.5	-1.5	-1.5	-1.5	-1.5	-1.5	-1.5	-1.5	-1.5	-1.5	-1.5	-1.5	-1.5	-1.5	-1.5	-1.5	
Benefits (£m)																						
Option 2b		21.4	21.6	21.8	21.9	22.1	22.3	22.4	22.6	22.7	22.9	24.0	25.0	26.1	27.2	28.2	29.3	30.4	31.4	32.5	33.6	
Option 3b		2.1	2.1	2.1	2.1	2.1	2.1	2.2	2.2	2.2	2.2	2.3	2.4	2.5	2.6	2.7	2.8	2.9	3.0	3.1	3.2	
Option 4b		18.3	18.4	18.6	18.7	18.9	19.0	19.2	19.3	19.5	19.6	20.6	21.5	22.5	23.5	24.4	25.4	26.4	27.3	28.3	29.3	
NPV (Benefits-Costs)																						
Option 2b	-360.0	-0.9	-0.7	-0.5	-0.4	-0.2	-0.1	0.1	0.2	0.3	0.4	1.1	1.8	2.4	3.0	3.5	4.0	4.5	4.9	5.3	5.6	-325.7
Option 3b	-51.5	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.3	0.3	0.4	0.4	0.5	0.5	0.6	0.6	0.6	0.7	-45.1
Option 4b	-360.0	19.1	18.6	18.1	17.6	17.1	16.7	16.2	15.8	15.4	14.9	15.1	15.2	15.3	15.4	15.5	15.5	15.5	15.5	15.5	15.4	-36.6

Table A4-7: Detailed NPV calculations for ‘a’ options, low capital and operational costs, low environmental values

	2021 (capital)	2021 (annual)	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	NPV
Costs (£m)																						
Option 2a	109.5	-9.8	-17.3	-17.3	-17.3	-17.3	-17.3	-17.3	-17.3	-17.3	-17.3	-17.3	-17.3	-17.3	-17.3	-17.3	-17.3	-17.3	-17.3	-17.3	-17.3	
Option 3a	16.1	-1.5	-1.8	-1.8	-1.8	-1.8	-1.8	-1.8	-1.8	-1.8	-1.8	-1.8	-1.8	-1.8	-1.8	-1.8	-1.8	-1.8	-1.8	-1.8	-1.8	
Option 4a	109.5	-19.0	-26.5	-26.5	-26.5	-26.5	-26.5	-26.5	-26.5	-26.5	-26.5	-26.5	-26.5	-26.5	-26.5	-26.5	-26.5	-26.5	-26.5	-26.5	-26.5	
Benefits (£m)																						
Option 2a		6.3	6.4	6.4	6.5	6.5	6.6	6.7	6.7	6.8	6.8	7.2	7.5	7.9	8.2	8.6	9.0	9.3	9.7	10.0	10.4	
Option 3a		0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.7	0.7	0.7	0.7	0.7	0.8	0.8	0.8	0.9	0.9	0.9	1.0	1.0	
Option 4a		5.5	5.6	5.6	5.7	5.7	5.8	5.8	5.9	5.9	6.0	6.3	6.6	6.9	7.3	7.6	7.9	8.2	8.5	8.9	9.2	
NPV (Benefits-Costs)																						
Option 2a	-109.5	15.6	22.1	21.4	20.7	20.0	19.4	18.8	18.2	17.6	17.1	16.7	16.4	16.1	15.8	15.4	15.1	14.8	14.5	14.2	13.9	234.3
Option 3a	-16.1	2.1	2.2	2.2	2.1	2.0	2.0	1.9	1.8	1.8	1.7	1.7	1.7	1.6	1.6	1.6	1.5	1.5	1.5	1.4	1.4	19.1
Option 4a	-109.5	23.7	29.9	28.9	28.0	27.1	26.2	25.4	24.6	23.8	23.0	22.4	21.9	21.3	20.8	20.3	19.8	19.3	18.8	18.4	17.9	352.1

Table A4-8: Detailed NPV calculations for ‘b’ options, low capital and operational costs, low environmental values

	2021 (capital)	2021 (annual)	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	NPV
Costs (£m)																						
Option 2b	109.5	-15.9	-23.4	-23.4	-23.4	-23.4	-23.4	-23.4	-23.4	-23.4	-23.4	-23.4	-23.4	-23.4	-23.4	-23.4	-23.4	-23.4	-23.4	-23.4	-23.4	
Option 3b	16.1	-2.0	-2.3	-2.3	-2.3	-2.3	-2.3	-2.3	-2.3	-2.3	-2.3	-2.3	-2.3	-2.3	-2.3	-2.3	-2.3	-2.3	-2.3	-2.3	-2.3	
Option 4b	109.5	-19.5	-27.0	-27.0	-27.0	-27.0	-27.0	-27.0	-27.0	-27.0	-27.0	-27.0	-27.0	-27.0	-27.0	-27.0	-27.0	-27.0	-27.0	-27.0	-27.0	
Benefits (£m)																						
Option 2b		6.2	6.2	6.3	6.3	6.4	6.4	6.5	6.5	6.6	6.6	7.0	7.4	7.7	8.1	8.4	8.8	9.1	9.5	9.8	10.2	
Option 3b		0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.7	0.7	0.7	0.8	0.8	0.8	0.9	0.9	0.9	1.0	
Option 4b		5.5	5.6	5.6	5.7	5.7	5.8	5.8	5.9	5.9	6.0	6.3	6.6	6.9	7.2	7.6	7.9	8.2	8.5	8.8	9.2	
NPV (Benefits-Costs)																						
Option 2b	-109.5	21.3	27.6	26.7	25.9	25.0	24.2	23.5	22.7	22.0	21.3	20.8	20.3	19.9	19.4	19.0	18.5	18.1	17.7	17.3	16.9	318.5
Option 3b	-16.1	2.5	2.7	2.6	2.5	2.4	2.3	2.3	2.2	2.1	2.1	2.0	2.0	1.9	1.9	1.8	1.8	1.8	1.7	1.7	1.6	25.8
Option 4b	-109.5	24.1	30.4	29.4	28.4	27.5	26.6	25.8	24.9	24.1	23.3	22.8	22.2	21.7	21.1	20.6	20.1	19.6	19.1	18.6	18.2	359.1

Table A4-9: Detailed NPV calculations for ‘a’ options, low capital and operational costs, medium environmental values

	2021 (capital)	2021 (annual)	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	NPV
Costs (£m)																						
Option 2a	109.5	-9.8	-17.3	-17.3	-17.3	-17.3	-17.3	-17.3	-17.3	-17.3	-17.3	-17.3	-17.3	-17.3	-17.3	-17.3	-17.3	-17.3	-17.3	-17.3	-17.3	
Option 3a	16.14	-1.5	-1.8	-1.8	-1.8	-1.8	-1.8	-1.8	-1.8	-1.8	-1.8	-1.8	-1.8	-1.8	-1.8	-1.8	-1.8	-1.8	-1.8	-1.8	-1.8	
Option 4a	109.5	-19.0	-26.5	-26.5	-26.5	-26.5	-26.5	-26.5	-26.5	-26.5	-26.5	-26.5	-26.5	-26.5	-26.5	-26.5	-26.5	-26.5	-26.5	-26.5	-26.5	
Benefits (£m)																						
Option 2a		12.5	12.6	12.7	12.8	12.9	13.0	13.2	13.3	13.4	13.5	14.2	14.9	15.6	16.3	17.0	17.8	18.5	19.2	19.9	20.6	
Option 3a		1.2	1.2	1.2	1.2	1.3	1.3	1.3	1.3	1.3	1.3	1.4	1.5	1.5	1.6	1.7	1.7	1.8	1.9	1.9	2.0	
Option 4a		10.7	10.8	10.9	11.0	11.1	11.2	11.3	11.4	11.5	11.6	12.2	12.8	13.5	14.1	14.8	15.4	16.0	16.7	17.3	18.0	
NPV (Benefits-Costs)																						
Option 2a	-109.5	21.5	27.9	27.0	26.2	25.4	24.7	23.9	23.2	22.5	21.8	21.5	21.3	21.0	20.8	20.5	20.2	19.9	19.6	19.3	19.0	**337.8**
Option 3a	-16.1	2.6	2.8	2.7	2.6	2.5	2.5	2.4	2.3	2.3	2.2	2.2	2.1	2.1	2.1	2.0	2.0	2.0	2.0	1.9	1.9	**29.1**
Option 4a	-109.5	28.6	34.7	33.7	32.6	31.6	30.6	29.6	28.7	27.8	26.9	26.5	26.0	25.5	25.1	24.6	24.1	23.7	23.2	22.8	22.3	**439.4**

Table A4-10: Detailed NPV calculations for 'b' options, low capital and operational costs, medium environmental values

	2021 (capital)	2021 (annual)	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	NPV
Costs (£m)																						
Option 2b	109.5	-15.9	-23.4	-23.4	-23.4	-23.4	-23.4	-23.4	-23.4	-23.4	-23.4	-23.4	-23.4	-23.4	-23.4	-23.4	-23.4	-23.4	-23.4	-23.4	-23.4	
Option 3b	16.14	-2.0	-2.3	-2.3	-2.3	-2.3	-2.3	-2.3	-2.3	-2.3	-2.3	-2.3	-2.3	-2.3	-2.3	-2.3	-2.3	-2.3	-2.3	-2.3	-2.3	
Option 4b	109.5	-19.5	-27.0	-27.0	-27.0	-27.0	-27.0	-27.0	-27.0	-27.0	-27.0	-27.0	-27.0	-27.0	-27.0	-27.0	-27.0	-27.0	-27.0	-27.0	-27.0	
Benefits (£m)																						
Option 2b		12.1	12.2	12.4	12.5	12.6	12.7	12.8	12.9	13.0	13.1	13.8	14.5	15.3	16.0	16.7	17.4	18.1	18.8	19.5	20.2	
Option 3b		1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.3	1.3	1.3	1.4	1.5	1.5	1.6	1.7	1.7	1.8	1.9	2.0	
Option 4b		10.6	10.7	10.8	10.9	11.0	11.1	11.2	11.3	11.4	11.5	12.2	12.8	13.5	14.1	14.7	15.4	16.0	16.7	17.3	17.9	
NPV (Benefits-Costs)																						
Option 2b	-109.5	27.1	33.2	32.2	31.2	30.3	29.3	28.4	27.5	26.7	25.9	25.5	25.1	24.7	24.3	23.9	23.5	23.1	22.7	22.3	21.9	419.3
Option 3b	-16.1	3.1	3.2	3.1	3.0	2.9	2.8	2.8	2.7	2.6	2.5	2.5	2.4	2.4	2.4	2.3	2.3	2.2	2.2	2.2	2.1	35.5
Option 4b	-109.5	29.1	35.2	34.1	33.0	32.0	31.0	30.0	29.1	28.2	27.3	26.8	26.3	25.8	25.4	24.9	24.4	23.9	23.5	23.0	22.6	446.1

Table A4-11: Detailed NPV calculations for ‘a’ options, low capital and operational costs, high environmental values

	2021 (capital)	2021 (annual)	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	NPV
Costs (£m)																						
Option 2a	109.5	-17.3	-17.3	-17.3	-17.3	-17.3	-17.3	-17.3	-17.3	-17.3	-17.3	-17.3	-17.3	-17.3	-17.3	-17.3	-17.3	-17.3	-17.3	-17.3	-17.3	
Option 3a	16.14	-1.8	-1.8	-1.8	-1.8	-1.8	-1.8	-1.8	-1.8	-1.8	-1.8	-1.8	-1.8	-1.8	-1.8	-1.8	-1.8	-1.8	-1.8	-1.8	-1.8	
Option 4a	109.5	-26.5	-26.5	-26.5	-26.5	-26.5	-26.5	-26.5	-26.5	-26.5	-26.5	-26.5	-26.5	-26.5	-26.5	-26.5	-26.5	-26.5	-26.5	-26.5	-26.5	
Benefits (£m)																						
Option 2a		22.2	22.4	22.6	22.7	22.9	23.1	23.2	23.4	23.6	23.7	24.8	25.9	26.9	28.0	29.1	30.1	31.2	32.3	33.3	34.4	
Option 3a		2.1	2.2	2.2	2.2	2.2	2.2	2.2	2.3	2.3	2.3	2.4	2.5	2.6	2.7	2.8	2.9	3.0	3.1	3.2	3.3	
Option 4a	-	18.4	18.5	18.7	18.8	19.0	19.1	19.3	19.4	19.5	19.7	20.7	21.6	22.6	23.6	24.5	25.5	26.4	27.4	28.4	29.3	
NPV (Benefits-Costs)																						
Option 2a	-109.5	38.2	37.0	35.9	34.9	33.8	32.8	31.8	30.9	30.0	29.1	28.8	28.5	28.3	28.0	27.7	27.3	27.0	26.7	26.3	26.0	**499.4**
Option 3a	-16.1	3.8	3.7	3.6	3.5	3.4	3.3	3.2	3.1	3.0	2.9	2.9	2.8	2.8	2.8	2.7	2.7	2.7	2.6	2.6	2.6	**44.2**
Option 4a	-109.5	43.3	42.0	40.7	39.4	38.2	37.1	35.9	34.8	33.8	32.7	32.3	31.8	31.4	30.9	30.4	30.0	29.5	29.0	28.5	28.0	**570.3**

Table A4-12: Detailed NPV calculations for ‘b’ options, low capital and operational costs, high environmental values

	2021 (capital)	2021 (annual)	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	NPV
Costs (£m)																						
Option 2b	109.5	-23.4	-23.4	-23.4	-23.4	-23.4	-23.4	-23.4	-23.4	-23.4	-23.4	-23.4	-23.4	-23.4	-23.4	-23.4	-23.4	-23.4	-23.4	-23.4	-23.4	
Option 3b	16.14	-2.3	-2.3	-2.3	-2.3	-2.3	-2.3	-2.3	-2.3	-2.3	-2.3	-2.3	-2.3	-2.3	-2.3	-2.3	-2.3	-2.3	-2.3	-2.3	-2.3	
Option 4b	109.5	-27.0	-27.0	-27.0	-27.0	-27.0	-27.0	-27.0	-27.0	-27.0	-27.0	-27.0	-27.0	-27.0	-27.0	-27.0	-27.0	-27.0	-27.0	-27.0	-27.0	
Benefits (£m)																						
Option 2b		21.4	21.6	21.8	21.9	22.1	22.3	22.4	22.6	22.7	22.9	24.0	25.0	26.1	27.2	28.2	29.3	30.4	31.4	32.5	33.6	
Option 3b		2.1	2.1	2.1	2.1	2.1	2.1	2.2	2.2	2.2	2.2	2.3	2.4	2.5	2.6	2.7	2.8	2.9	3.0	3.1	3.2	
Option 4b		18.3	18.4	18.6	18.7	18.9	19.0	19.2	19.3	19.5	19.6	20.6	21.5	22.5	23.5	24.4	25.4	26.4	27.3	28.3	29.3	
NPV (Benefits-Costs)																						
Option 2b	-109.5	43.3	42.0	40.7	39.5	38.3	37.1	36.0	34.9	33.8	32.8	32.4	32.0	31.6	31.2	30.8	30.4	29.9	29.5	29.1	28.6	574.4
Option 3b	-16.1	4.2	4.1	3.9	3.8	3.7	3.6	3.5	3.4	3.3	3.2	3.1	3.1	3.1	3.0	3.0	2.9	2.9	2.9	2.8	2.8	50.0
Option 4b	-109.5	43.7	42.4	41.1	39.8	38.6	37.4	36.3	35.2	34.1	33.0	32.6	32.1	31.6	31.2	30.7	30.2	29.7	29.2	28.7	28.3	576.3

Table A4-13: Detailed NPV calculations for ‘a’ options, medium capital and operational costs, low environmental values

	2021 (capital)	2021 (annual)	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	NPV
Costs (£m)																						
Option 2a	206.4	17.0	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	
Option 3a	30.3	0.8	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	
Option 4a	206.4	-3.4	-10.9	-10.9	-10.9	-10.9	-10.9	-10.9	-10.9	-10.9	-10.9	-10.9	-10.9	-10.9	-10.9	-10.9	-10.9	-10.9	-10.9	-10.9	-10.9	
Benefits (£m)																						
Option 2a		6.3	6.4	6.4	6.5	6.5	6.6	6.7	6.7	6.8	6.8	7.2	7.5	7.9	8.2	8.6	9.0	9.3	9.7	10.0	10.4	
Option 3a		0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.7	0.7	0.7	0.7	0.7	0.8	0.8	0.8	0.9	0.9	0.9	1.0	1.0	
Option 4a		5.5	5.6	5.6	5.7	5.7	5.8	5.8	5.9	5.9	6.0	6.3	6.6	6.9	7.3	7.6	7.9	8.2	8.5	8.9	9.2	
NPV (Benefits-Costs)																						
Option 2a	-206.4	-10.3	-3.0	-2.8	-2.7	-2.5	-2.4	-2.3	-2.2	-2.0	-1.9	-1.6	-1.3	-1.1	-0.8	-0.6	-0.3	-0.1	0.1	0.3	0.4	**-243.6**
Option 3a	-30.3	-0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	**-27.8**
Option 4a	-206.4	8.6	15.3	14.9	14.4	14.0	13.5	13.1	12.7	12.3	11.9	11.7	11.6	11.4	11.2	11.0	10.8	10.6	10.4	10.3	10.1	**33.4**

Table A4-14: Detailed NPV calculations for ‘b’ options, medium capital and operational costs, low environmental values

	2021 (capital)	2021 (annual)	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	NPV
Costs (£m)																						
Option 2b	206.4	4.8	-2.7	-2.7	-2.7	-2.7	-2.7	-2.7	-2.7	-2.7	-2.7	-2.7	-2.7	-2.7	-2.7	-2.7	-2.7	-2.7	-2.7	-2.7	-2.7	
Option 3b	30.3	-0.1	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	
Option 4b	206.4	-4.3	-11.8	-11.8	-11.8	-11.8	-11.8	-11.8	-11.8	-11.8	-11.8	-11.8	-11.8	-11.8	-11.8	-11.8	-11.8	-11.8	-11.8	-11.8	-11.8	
Benefits (£m)																						
Option 2b		6.2	6.2	6.3	6.3	6.4	6.4	6.5	6.5	6.6	6.6	7.0	7.4	7.7	8.1	8.4	8.8	9.1	9.5	9.8	10.2	
Option 3b		0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.7	0.7	0.7	0.8	0.8	0.8	0.9	0.9	0.9	1.0	
Option 4b		5.5	5.6	5.6	5.7	5.7	5.8	5.8	5.9	5.9	6.0	6.3	6.6	6.9	7.2	7.6	7.9	8.2	8.5	8.8	9.2	
NPV (Benefits-Costs)																						
Option 2b	-206.4	1.3	8.3	8.0	7.8	7.6	7.4	7.2	7.0	6.8	6.6	6.6	6.6	6.6	6.6	6.6	6.6	6.6	6.5	6.5	6.5	-72.6
Option 3b	-30.3	0.7	0.9	0.9	0.8	0.8	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	-15.4
Option 4b	-206.4	9.5	16.2	15.7	15.2	14.7	14.3	13.8	13.4	13.0	12.6	12.4	12.2	11.9	11.7	11.5	11.3	11.1	10.9	10.7	10.5	46.1

Table A4-15: Detailed NPV calculations for ‘a’ options, medium capital and operational costs, medium environmental values

	2021 (capital)	2021 (annual)	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	NPV
Costs (£m)																						
Option 2a	206.4	17.0	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	
Option 3a	30.30	0.8	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	
Option 4a	206.4	-3.4	-10.9	-10.9	-10.9	-10.9	-10.9	-10.9	-10.9	-10.9	-10.9	-10.9	-10.9	-10.9	-10.9	-10.9	-10.9	-10.9	-10.9	-10.9	-10.9	
Benefits (£m)																						
Option 2a		12.5	12.6	12.7	12.8	12.9	13.0	13.2	13.3	13.4	13.5	14.2	14.9	15.6	16.3	17.0	17.8	18.5	19.2	19.9	20.6	
Option 3a		1.2	1.2	1.2	1.2	1.3	1.3	1.3	1.3	1.3	1.3	1.4	1.5	1.5	1.6	1.7	1.7	1.8	1.9	1.9	2.0	
Option 4a		10.7	10.8	10.9	11.0	11.1	11.2	11.3	11.4	11.5	11.6	12.2	12.8	13.5	14.1	14.8	15.4	16.0	16.7	17.3	18.0	
NPV (Benefits-Costs)																						
Option 2a	-206.4	-4.4	2.9	2.9	2.9	2.9	2.9	2.8	2.8	2.8	2.8	3.2	3.6	3.9	4.2	4.5	4.7	5.0	5.2	5.4	5.6	**-140.0**
Option 3a	-30.3	0.4	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.7	0.7	0.7	0.7	0.7	0.7	0.7	**-17.7**
Option 4a	-206.4	13.6	20.2	19.6	19.0	18.5	17.9	17.4	16.9	16.4	15.9	15.8	15.7	15.6	15.4	15.3	15.1	15.0	14.8	14.7	14.5	**120.7**

Table A4-16: Detailed NPV calculations for ‘b’ options, medium capital and operational costs, medium environmental values

	2021 (capital)	2021 (annual)	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	NPV
Costs (£m)																						
Option 2b	206.4	4.8	-2.7	-2.7	-2.7	-2.7	-2.7	-2.7	-2.7	-2.7	-2.7	-2.7	-2.7	-2.7	-2.7	-2.7	-2.7	-2.7	-2.7	-2.7	-2.7	
Option 3b	30.30	-0.1	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	
Option 4b	206.4	-4.3	-11.8	-11.8	-11.8	-11.8	-11.8	-11.8	-11.8	-11.8	-11.8	-11.8	-11.8	-11.8	-11.8	-11.8	-11.8	-11.8	-11.8	-11.8	-11.8	
Benefits (£m)																						
Option 2b		12.1	12.2	12.4	12.5	12.6	12.7	12.8	12.9	13.0	13.1	13.8	14.5	15.3	16.0	16.7	17.4	18.1	18.8	19.5	20.2	
Option 3b		1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.3	1.3	1.3	1.4	1.5	1.5	1.6	1.7	1.7	1.8	1.9	2.0	
Option 4b		10.6	10.7	10.8	10.9	11.0	11.1	11.2	11.3	11.4	11.5	12.2	12.8	13.5	14.1	14.7	15.4	16.0	16.7	17.3	17.9	
NPV (Benefits-Costs)																						
Option 2b	-206.4	7.1	13.9	13.5	13.2	12.8	12.5	12.1	11.8	11.5	11.2	11.3	11.4	11.5	11.5	11.5	11.6	11.6	11.6	11.5	11.5	28.2
Option 3b	-30.3	1.2	1.4	1.4	1.4	1.3	1.3	1.3	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	-5.6
Option 4b	-206.4	14.4	21.0	20.4	19.8	19.2	18.6	18.1	17.5	17.0	16.5	16.4	16.3	16.1	16.0	15.8	15.6	15.5	15.3	15.1	14.9	133.1

Table A4-17: Detailed NPV calculations for ‘a’ options, medium capital and operational costs, high environmental values

	2021 (capital)	2021 (annual)	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	NPV
Costs (£m)																						
Option 2a	206.4	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	
Option 3a	30.30	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	
Option 4a	206.4	-10.9	-10.9	-10.9	-10.9	-10.9	-10.9	-10.9	-10.9	-10.9	-10.9	-10.9	-10.9	-10.9	-10.9	-10.9	-10.9	-10.9	-10.9	-10.9	-10.9	
Benefits (£m)																						
Option 2a		22.2	22.4	22.6	22.7	22.9	23.1	23.2	23.4	23.6	23.7	24.8	25.9	26.9	28.0	29.1	30.1	31.2	32.3	33.3	34.4	
Option 3a		2.1	2.2	2.2	2.2	2.2	2.2	2.2	2.3	2.3	2.3	2.4	2.5	2.6	2.7	2.8	2.9	3.0	3.1	3.2	3.3	
Option 4a	-	18.4	18.5	18.7	18.8	19.0	19.1	19.3	19.4	19.5	19.7	20.7	21.6	22.6	23.6	24.5	25.5	26.4	27.4	28.4	29.3	
NPV (Benefits-Costs)																						
Option 2a	-206.4	12.3	12.0	11.8	11.5	11.3	11.0	10.8	10.5	10.3	10.1	10.4	10.8	11.1	11.4	11.7	11.9	12.1	12.2	12.4	12.5	**21.6**
Option 3a	-30.3	1.6	1.5	1.5	1.5	1.4	1.4	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.4	1.4	1.4	1.4	1.4	1.4	1.4	**-2.6**
Option 4a	-206.4	28.2	27.4	26.6	25.9	25.1	24.4	23.7	23.0	22.3	21.7	21.6	21.5	21.4	21.3	21.1	21.0	20.8	20.6	20.4	20.2	**251.6**

Table A4-18: Detailed NPV calculations for 'b' options, medium capital and operational costs, high environmental values

	2021 (capital)	2021 (annual)	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	NPV
Costs (£m)																						
Option 2b	206.4	-2.7	-2.7	-2.7	-2.7	-2.7	-2.7	-2.7	-2.7	-2.7	-2.7	-2.7	-2.7	-2.7	-2.7	-2.7	-2.7	-2.7	-2.7	-2.7	-2.7	
Option 3b	30.30	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	
Option 4b	206.4	-11.8	-11.8	-11.8	-11.8	-11.8	-11.8	-11.8	-11.8	-11.8	-11.8	-11.8	-11.8	-11.8	-11.8	-11.8	-11.8	-11.8	-11.8	-11.8	-11.8	
Benefits (£m)																						
Option 2b		21.4	21.6	21.8	21.9	22.1	22.3	22.4	22.6	22.7	22.9	24.0	25.0	26.1	27.2	28.2	29.3	30.4	31.4	32.5	33.6	
Option 3b		2.1	2.1	2.1	2.1	2.1	2.1	2.2	2.2	2.2	2.2	2.3	2.4	2.5	2.6	2.7	2.8	2.9	3.0	3.1	3.2	
Option 4b		18.3	18.4	18.6	18.7	18.9	19.0	19.2	19.3	19.5	19.6	20.6	21.5	22.5	23.5	24.4	25.4	26.4	27.3	28.3	29.3	
NPV (Benefits-Costs)																						
Option 2b	-206.4	23.3	22.6	22.0	21.4	20.8	20.3	19.7	19.2	18.6	18.1	18.2	18.3	18.4	18.4	18.4	18.4	18.4	18.4	18.3	18.2	183.3
Option 3b	-30.3	2.3	2.3	2.2	2.2	2.1	2.0	2.0	1.9	1.9	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	8.8
Option 4b	-206.4	29.0	28.2	27.4	26.6	25.8	25.0	24.3	23.6	22.9	22.2	22.2	22.0	21.9	21.8	21.6	21.4	21.2	21.0	20.8	20.6	263.4

Summary

Options 1 and 3 are not considered viable options to tackle the issue of agricultural pollution affecting waterbodies across Wales. These options have no impact upon waterbodies failing to meet good status under the Water Framework Directive outside of designated or recommended NVZs. Due to the scale of NVZ areas, the majority of Welsh waterbodies not meeting good status are located outside of these areas. This presents an increased risk of infraction and fails to address Section 6 of the Environment Act (Wales) which places a duty on public authorities to ‘seek to maintain and enhance biodiversity’. Options 1 and 3 are therefore incompatible with this duty.

An all Wales approach is considered proportionate and ensures a level playing field for all farms in Wales, while reducing levels of pollutants on all areas of the country.

Option 4 provides some flexibility in the measures which could be applied. Deselecting specific measures reduces the costs but also the associated benefits, while the risk of infraction and non-compliance and complexity is increased. Other than reduced costs and benefits, there is little benefit to this option compared to Option 2.

Although Option 2 does not present a positive NPV it is the preferred option. It is designed to reduce pollution from agriculture across the whole of Wales, addresses failure of water quality standards under the Nitrates Directive and Water Framework Directive, minimises the risk of infraction and provides a level playing field for farm businesses. This option is also compatible with domestic obligations in respect of biodiversity and contributes to tackling climate change compared to the alternative options.

APPENDIX 6: WELSH GOVERNMENT INTEGRATED IMPACT ASSESSMENT

WHAT ACTION IS THE WELSH GOVERNMENT CONSIDERING AND WHY?

Wales' natural resources are among our most valuable assets. They provide essential services including food, water and land. These are as fundamental to the long-term success of our economy as they are to the quality of our natural environment and the well-being of our communities.

Our resources are under pressure from challenges, including extreme weather, pollution and climate change. Over the past fifty years, more intensive farming methods have led to an increase in overall loadings of nutrients to land, and the loss of some of those nutrients into the environment which has detrimental consequences.

A significant proportion of Wales' nutrient input to the environment originates from diffuse pollution, individual small sources of pollution which collectively cause a significant impact. Agricultural activities are one of the main causes of water pollution and ammonia emissions which are detrimental to public health, the environment, biodiversity and the economy.

Acute point-source pollution incidents also effect water quality and can cause significant losses in biodiversity in large stretches of the aquatic ecosystem. It can take many years for full recovery to be achieved following large scale incidents, if at all. While many farms in Wales operate to high standards, comply with the regulatory baseline and follow good practice guidance, many do not. It is those businesses, which risk the reputation of responsible farmers and cause damage to our environment, the proposed measures are targeted at.

While the primary intention of the proposal is to reduce water pollution from agriculture the approach should not be detrimental to other policy aims, such as reduced atmospheric emissions. The Clean Air Plan for Wales, Healthy Air, Heathy Wales, was published earlier this year. The Plan highlights the importance of clean air for public heath, which has been highlighted by the Covid-19 pandemic, due to the detrimental impact of air pollution on fatality rates and recovery The proposed measures are designed to avoid pollution swapping, to prevent or minimise increased losses of nutrients to the environment, including greenhouse gases, phosphorus and ammonia as a result of measures primarily focussed on reducing losses of nitrogen.

The proposal also recognises a regulatory approach alone will not achieved the desired outcome. The provision of advice and guidance, financial support and voluntary measures will all play a role in minimising pollution from agriculture. A regulatory baseline which underpins these key factors is necessary to facilitate further improvement and protect the environment from detrimental activities.

The proposal moves to a preventative approach, as opposed to taking action once pollution has already occurred and the damage has been done. This approach will improve the enforcement capability of the regulator as a prohibited activity is more easily identifiable than determining the cause of pollution, particularly in respect of diffuse pollution. It will also prevent pollution occurring before action can be taken.

The Nitrates Directive (1991) (The Directive) aims to protect water quality across Europe by preventing nitrates from agricultural sources polluting ground and surface waters and by promoting the use of good farming practices. The Directive forms an integral part of the Water Framework Directive and is one of the key instruments in the protection of waters against agricultural pressures.

More widely, the Water Framework Directive requires member states to take action to address agricultural pollution and expands the scope of water protection to all waters and requires good status to be achieved for all waterbodies.

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The UK Committee on Climate Change issued its report on Land use: Policies for a Net Zero on 23 January 2020. The report highlights the UK's net-zero target will not be met without changes in how we use our land, which must be made now. The Committee's previous work has shown it is possible to reduce land-based emissions of greenhouse gases while contributing to other strategic priorities for land such as food production, climate change adaptation and biodiversity. This report focuses on the policies to drive that change. One of the key recommendations of the report is to extend coverage of NVZs to all of the UK.

The outcome of the referendum held on 23 June 2016 was that the UK should leave the European Union. Importantly before, and during the negotiations and the transitional period, the UK continues to participate in EU activities, the EU institutions, and abides by EU law. Welsh Ministers are obliged to continue to make legislation to transpose the requirements of the European Directives prior to the end of the Implementation Period and, beyond, retained EU law provides continuity in our obligations.

The issue of agricultural pollution will still need to be tackled whatever the outcome of the EU negotiations. Safeguarding drinking water, biodiversity and the rural economy from detrimental agricultural activities requires an approach which provides adequate protection from an industry adapting to market pressures and opportunities through changing practices.

The Welsh Government's aim is to provide a mechanism to protect the environment from losses of nutrients, in a climate of changing agricultural practices related to leaving the EU or otherwise. We want to take a proportionate, targeted approach which facilitates entry into land management schemes and provides opportunities for payments for ecosystem services, for the benefit of agricultural businesses and the environment.

The Welsh Government recognises an approach which integrates good practice within the regulatory framework may represent significant change, particularly for those not already following good practice advice. The need to address pollution issues affecting the environment now, with protection in the long term, while providing sufficient time and support for such change to be adopted, will require a balanced approach.

Responses to consultations on the implementation of the Nitrates Directive, the regulations governing the storage of silage and slurry and the sustainable management of natural resources have all been considered in the development of the proposal. Stakeholder engagement has also informed the approach, including the work of the Wales Land Management Forum sub-group on agricultural pollution, which has also informed the development of this impact assessment. In addition, stakeholders have been afforded the opportunity to submit further evidence which they believe the Minister should consider when making a decision on the proposal.

The measures the Welsh Government proposes are designed to improve the baseline regulations to increase the capability of farms to manage nutrients more effectively. While it is not possible to establish the exact scale of the impact this will have due to limited data on land-spreading activities, the measures will provide the foundation upon which additional losses of nutrients can be prevented through further measures, including through payments for environmental outcomes. The potential of earned autonomy may also provide flexibility for farms to achieve the same outcomes in ways which are better suited to individual businesses.

Further work will be undertaken with stakeholders, including the Wales Land Management Forum sub-group on agricultural pollution on the delivery of the proposal. This will include building upon the work facilitated by Farming Connect, to ensure farm infrastructure improvements are approached in the most cost effective way, which has the potential to reduce the economic impact on farm businesses.

Funding for measures to aid compliance with the proposals has already been provided through the Rural Development Programme. Additional funding will be considered as part of the delivery of any resulting regulations.

The Covid-19 pandemic has been considered carefully as part of the proposal, to ensure the industry is able to implement the necessary changes with minimal disruption. As the risks associated with the impact of the pandemic can change at any time, transitional periods have been proposed to ensure the burden of implementation is spread over a number of years, providing a balance of providing positive environmental outcomes, whilst giving farmers time to understand and comply with the requirements.

The measures have been designed to contribute to the delivery of the Well-being of Future Generations Act and the principles embedded with Prosperity for All.

CONCLUSION

The development of the proposal has been informed by a number of consultations including on the storage of silage and slurry, the sustainable management of natural resources and on Nitrate Vulnerable Zones in Wales. Stakeholder engagement and the work of the Wales Land Management Forum sub-group on agricultural pollution has also been considered and taken into account. Welsh Government officials of relevant policy areas have been consulted during the development of the proposal to ensure co-ordinated approach with other policies, particularly in relation to water quality and the development of future land management schemes.

The proposal has the potential to impact upon the people, culture, Welsh language, economy and environment of Wales. The most significant impacts relate to the effect of the proposals on farm businesses and the environment. Agricultural businesses have identified concerns regarding the implementation of regulatory requirements. There are many agricultural businesses operating to very high, environmentally sustainable standards of production. The burden of paperwork and the economic impact were raised as significant challenges. The greatest economic issue raised relates to the investment in achieving compliance with the proposed slurry storage standards. These costs vary from minor clean and dirty separation actions to replacement stores requiring substantial investment. This is a commercial decision for the farmer but these types of capital investments can be financially supported through the Rural Development Programme. Where shortfalls in slurry storage exist, this investment is necessary to manage manures in a way which prevents pollution and replacement costs are inevitable when stores reach the end of their lifespan.

Where good practice guidance is already being followed and existing regulatory requirements are being met, the proposed measures will have minimal impact. A high level of non-compliance with regulatory standards relating to storage has been observed on farms producing slurry. Those businesses will face the greatest challenge as the most significant costs associated with the proposal relate to the additional storage needed by those not meeting existing requirements. Some tenant farmers may face particular challenges due to restrictive clauses in their tenancy agreements. The Welsh Government recognises this issue and is committed to modernise tenancy law to facilitate longer-term investments in sustainable land management practices and productivity improvements.

The other main cost attributed to the proposal is an annual reduction in yield due to the avoidance of spreading fertiliser at high risk times and in high risk areas. The economic impact will depend on the ability of farms to utilise nutrients more efficiently, to increase yields, such as through the use of precision spreading technology. Agricultural contractor businesses may also face particular challenges, where measures restrict activities during the winter when nutrient losses are greater, due to the ability to retain staff during these periods.

The impact of non-conformity could have detrimental implications in respect of infraction costs and for future trade with European and worldwide markets, where the competitive advantage of a lower regulatory baseline may attract consequences which negate that cost benefit. There is uncertainty on these issues due to the negotiations on leaving the European Union but the associated risks for certain elements of the agriculture sector are considered to be high.

The economic impact on other sectors and individuals may also be significant. The viability of many rural businesses are dependent on water quality. Wales' fisheries provide jobs and incomes in commercial and recreational fishing, fisheries management and tourism. The economic benefits are particularly important in remote rural areas and areas with low income levels. The Water companies in Wales also benefit from improved water quality through reduced treatment costs, which can benefit household incomes through their water bills. The positive implications for rural populations supports the viability of Welsh culture and language. Whilst the Covid-19 pandemic continues the agricultural industry and related supply chains have responded positively and continue to perform comparatively well against 5 years averages. The inclusion of increased transitional periods will further minimise the initial impact of the regulations and mitigate against the potential impacts associated with exiting the EU and the pandemic.

Ministers are required to have due regard to the United Nations Convention on the Rights of the Child when exercising any of their functions. Infants are more susceptible to the effects of elevated levels of pollutants in drinking-water, especially bottle-fed infants. Each year in Wales, private water supplies fail to meet standards due to microbial and chemical parameters, which puts the health and development of children at risk. The proposal aims to enhance the environment, providing clean water for drinking and for play, improving opportunities for healthy activities in a safe environment.

The proposal is expected to have a positive impact on public health more generally. The reduction of nutrient and faecal pathogen losses to the environment provides improved access to safe outdoor recreational activities, improved mental well-being and improved access to clean drinking water. There may be some negative consequences for health due to the cost implications for farm businesses, which has the potential to contribute to the detrimental economic conditions affecting health of individuals. The potential negative impact of additional regulatory requirements on mental well-being, particularly where other economic or health challenges already exist, is also recognised.

The natural environment is a key element of Welsh culture and heritage. It also provides significant opportunities for outdoor recreation. The health of the environment at landscape scale, catchment scale or individual waterbodies is crucially important in supporting enjoyment of the countryside. Reduced nutrient losses from agriculture to the environment will be beneficial in helping to reverse the decline in biodiversity. An all-Wales approach will enhance ecological networks. Ecosystem improvements will support climate change mitigation and adaptation.

Sustainable farming is crucial for food production, access to the countryside, supporting a healthy population and for the provision of clean air and water. Financial support through the Rural Development Programme has already been provided and promoted through Farming Connect for measures which will be necessary to tackle agricultural pollution. The Welsh Government will continue to support the agricultural industry through advice, guidance and capital investment.

The programme of measures will be reviewed every 4 years to ensure they are effective and reflect the latest evidence available. This process will involve consultation with affected individuals and representative organisations.