Penwith Moors Farmscoper Modelling Report

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Contents

1 INTRODUCTION

Natural England is currently considering the designation of land in Penwith Moors, Cornwall, as a Site of Special Scientific Interest (SSSI) under the Wildlife & Countryside Act 1981. The SSSI as proposed will be some 3,125 ha in extent. Within a wider habitat mosaic, it will include eleven valley fens and parts of their catchments (Figure 1-1) with a collective extent of 812 ha. An important factor in the condition of these fens is the quantity and quality of water supplying the wetland. Consequently, a written consent will be required from Natural England before land managers can legally undertake any land management operations, listed in the SSSI notification document, that may impact water quantity, chemistry or nutrient status. The amount of farmland and the type of farming taking place within the catchments varies but includes extensive livestock rearing with relatively low-input permanent pastures, more intensive livestock and dairy farming with silage production, and arable and horticultural production (e.g. brassicas and daffodils). In order to help Natural England undertake its regulatory role in an effective and proportionate manner, a better understanding of the impacts of these activities is needed in order to identify those which are compatible with achieving and/or maintaining favourable condition[1] in relation to water quality.

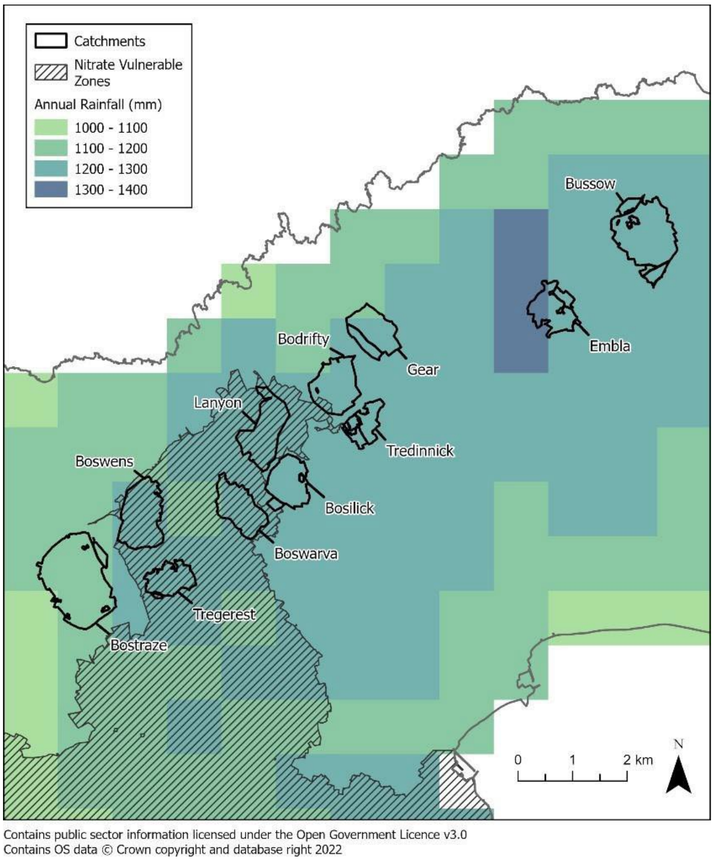

Figure 1-1 The Penwith Moors catchments (defined by including the steepest slopes within the wider catchments up to the first break-of-slope) and annual average rainfall (1990-2020) and Nitrate Vulnerable Zone boundaries.

The objective of this project was to predict which farming activities would achieve pollution concentrations at or below threshold annual concentrations of 1 mg l^{-1} NO_3-N and 2 mg l^{-1} NO_3-N. These threshold values are based on groundwater chemical concentrations that have been derived from empirical evidence. They were developed to ascertain whether or not there is a risk

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[1] Favourable condition is achieved when the designated features of an SSSI are in a healthy state and are being conserved by appropriate management. See: Sites of special scientific interest: managing your land (www.gov.uk)

to the health of groundwater-fed wetlands – such as the valley fens of the Penwith Moors – from chemical (nutrient) pressures in a groundwater body (UKTAG, 2014; report).

The key tasks within the project were:

1. Agree the farm management scenarios to be investigated, taking account of the range of current/possible future farm types in the catchments and the relatively low concentration threshold which will preclude some intensive farm systems. The inclusion and extent of any mitigation measures that would help to achieve the threshold concentrations would also be considered.
2. Use the Farmscoper model to predict the nitrate concentrations for these farm management scenarios.
3. Report on the farm management scenarios and predicted concentrations, and document the modelling methodology undertaken, so that the specific results or the general approach could be replicated if required.

2 METHODOLOGY

Farmscoper (Gooday et al., 2014) was developed by ADAS in 2010 under Defra Project WQ0106(3), initially as a farm-scale decision support tool to predict the losses of nine different pollutants, to quantify the effect of implementation of one or more mitigation measures on those pollutant losses and to estimate the cost of measure implementation. As part of the calculations, Farmscoper predicts both pollutants losses and drainage volumes, allowing the calculation of pollutant concentrations for the water-borne pollutants. Subsequent iterations of the tool with Defra and EA funding have included wider pollutant coverage, a catchment scale application and more explicit representation of the costs of mitigation. It is being extensively used by the Defra family for national policy development in the field of planning and evaluating the environmental impact of farming activities. This use is driven by legally binding requirements on the UK to reduce greenhouse gas emissions (by 80% by 2050; Climate Change Act, 2008), ammonia emissions (under the Gothenburg Protocol) and to meet standards for drinking water and good ecological status set by the Nitrates Directive (81/676/EEC) and the UK implementation of the Water Framework Directive (2000/60/EC).

Farmscoper was used to determine long term annual average nitrate concentrations for a number of different field management scenarios, as described in the next sub-section. The scenarios were applied for each of the soil types and climate zones (based on annual average rainfall (AAR)), relevant to the Penwith Moors catchments. Figure 1-1 shows that the relevant climate zones are 900-1200 and 12001500 mm AAR. Farmscoper has three soil types, which are designed to reflect the pathways by which water and pollutants move:

1. Free-draining soils, where water can move freely down through the soil;
2. Slowly permeable soils, where vertical movement of water through the soil profile is impeded and there is some lateral flow. Artificial drainage is required to reduce waterlogging sufficiently for effective arable farming; and
3. Slowly permeable soils as per 2, but artificial drainage is required to reduce waterlogging sufficiently for effective arable and grassland farming.

The soils in the Penwith catchments are a mixture of freely draining loam (type 1) and wet peat dominant (likely to be type 3).

Further details of the methodology used are described in Annex 1.

2.1 Field Management Scenarios

Farmscoper allows the user to create a farm system by specifying the number of livestock and area of cropping based on the livestock and crop categories in the Defra June Agricultural Survey when Farmscoper was first created. For the livestock, users can then specify what proportion of the manure is managed as slurry or FYM (and how much is applied on farm), whilst other parameters (e.g. excreta volume, duration of grazing and manure storage) are fixed [2] . For cropping, users can specify fertiliser rates and how much FYM and slurry is applied.

A selection of 20 field management scenarios were created, based upon current farming within Penwith Moors but adjusted if needed so that the predicted annual average concentrations were close to 1-2 mg l^{-1} nitrate-N where possible. Fertiliser rates were taken from the British Survey of Fertiliser Practice for 2020 (BSFP) and agri-environment scheme data for low input pasture[3] .

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[2] Farmscoper is a meta-model of a number of different pollutant models, so it was necessary to fix certain parameters to allow these models to be applied, and also to allow the specification of the potential impacts of mitigation measures.

[3] ELS Handbook 2010: Permanent grassland with low inputs

Other farm practices are specified below or used the default data within Farmscoper. The scenarios are also described in detail in Table 2-1.

1. Winter wheat, BSFP fertiliser rates, receiving no manure applications.
2. Spring barley, BSFP fertiliser rates, receiving no manure applications.
3. Brassica crop, BSFP fertiliser rates, receiving no manure applications.
4. Grassland with the equivalent of 3.5 sheep per ha present all year and 3.5 lambs for ~ 8 months, low input pasture fertiliser rates.
5. Grassland with the equivalent of 7 sheep per ha present all year and 7 lambs for ~8 months, BSFP fertiliser rates for ‘Grass 5 years and over’ for ‘Other livestock farms’.
6. Grassland for silage, low input pasture fertiliser rates.
7. Grassland for silage, low input pasture fertiliser rates, receiving FYM 1 year in 3.
8. Grassland for silage, low input pasture fertiliser rates, receiving slurry 1 year in 3.
9. Grassland for silage, BSFP fertiliser rates for ‘Grass under 5 years old’ for ‘Dairy farm’.
10. Grassland for silage, BSFP fertiliser rates for ‘Grass under 5 years old’ for ‘Dairy farm’, receiving FYM 1 year in 3.
11. Grassland for silage, BSFP fertiliser rates for ‘Grass under 5 years old’ for ‘Dairy farm’, receiving slurry 1 year in 3.
12. Grassland with the equivalent of 1 adult beef cow per ha grazing for ~6 months, low input pasture fertiliser rates.
13. Grassland with the equivalent of 1 adult beef cow per ha grazing for ~6 months, low input pasture fertiliser rates, receiving the FYM generated by the cow 1 year in 3.
14. Grassland with the equivalent of 1 adult beef cow per ha grazing for ~6 months, low input pasture fertiliser rates, receiving the slurry generated by the cow 1 year in 3.
15. Grassland with the equivalent of 2 adult beef cows per ha grazing for ~6 months, BSFP fertiliser rates for ‘Grass 5 years and over’ for ‘Other livestock farms’.
16. Grassland with the equivalent of 2 adult beef cows per ha grazing for ~6 months, BSFP fertiliser rates for ‘Grass 5 years and over’ for ‘Other livestock farms’, receiving the FYM generated by the cows 1 year in 3.
17. Grassland with the equivalent of 2 adult beef cows per ha grazing for ~6 months, BSFP fertiliser rates for ‘Grass 5 years and over’ for ‘Other livestock farms’, receiving the slurry generated by the cows 1 year in 3.
18. Grassland with the equivalent of 1.5 adult dairy cows per ha grazing for ~6 months, BSFP fertiliser rates for ‘Grass 5 years and over’ for ‘Other livestock farms’.
19. Grassland with the equivalent of 1.5 adult dairy cows per ha grazing for ~6 months, BSFP fertiliser rates for ‘Grass 5 years and over’ for ‘Other livestock farms’, receiving the FYM generated by the cows 1 year in 3.
20. Grassland with the equivalent of 1.5 adult dairy cows per ha grazing for ~6 months, BSFP fertiliser rates for ‘Grass 5 years and over’ for ‘Other livestock farms’, receiving the slurry generated by the cows 1 year in 3.

The amount of manure for the low input (7-8 above) and high input (10-11 above) silage scenarios were the same as the extensive (13-14 above) and intensive (16-17 above) beef grazing scenarios respectively.

The fertiliser rates for nitrogen were adjusted to reflect the crop available manure nitrogen which was assumed to be 10% for FYM and 35% for slurry (based on RB209 Nutrient Management Guidance (AHDB, 2022)).

The fertiliser rates in scenarios 18-20 were originally the BSFP rates for 'Dairy farms'. However, these were altered to those of 'Other livestock farms' in order to reduce the predicted nitrate concentrations and reflect the slightly lower stocking density assumed in the scenario than is typical of dairy farming.

The 'Excreta at grazing' values in Table 2-1 are lower in scenarios 18-20 than 15-17 as they reflect the fact the although the dairy cows are grazing for ~6 months, they still spend a sizeable proportion of that time away from the fields due to milking (and thus there is more manure to be applied).

For all scenarios, the following data were used in Farmscoper: Fields by watercourses 100%; Percentage of fields at high P index 20%; surface connectivity for free draining fields 60%. The impacts of these choices are minor on losses of nitrate but would be more important if the results for phosphorus or sediment (not shown in this report) are used in other work.

Table 2-1. Field management scenarios. Livestock are assumed to be present every year. Manure is applied 1 year in 3, but the results presented are for the year of application.

No.	Name	Crop	Fertiliser N (kg ha^{-1})	Fertiliser P (kg ha^{-1})	Livestock	Excreta whilst grazing (kg ha^{-1})	Manure Type	Manure Total N (kg ha^{-1})
1	Winter Wheat	Winter Wheat	179	24	-	-	-	
2	Spring Barley	Spring Barley	102	25	-	-	-	
3	Brassica	Brassica	106	24	-	-		
4	Extensive sheep grazing	Permanent Pasture	50	18	Sheep	45		
5	Intensive sheep grazing	Permanent Pasture	69	18	Sheep	90		
6	Low input silage	Rotational grassland	50	18	-	-	-	
7	Low input silage with FYM	Rotational grassland	47	18	-	-	Solid	29
8	Low input silage with slurry	Rotational grassland	40	18	-	-	Slurry	28
9	High input silage	Rotational grassland	165	18	-	-	-	-
10	High input silage with FYM	Rotational grassland	160	18	-	-	Solid	58
11	High input silage with slurry	Rotational grassland	146	18	-	-	Slurry	56
12	Extensive beef grazing	Permanent Pasture	50	7	Beef	30	-	-
13	Extensive beef grazing with FYM	Permanent Pasture	47	7	Beef	30	Solid	29
14	Extensive beef grazing with slurry	Permanent Pasture	40	7	Beef	30	Slurry	28

15	Intensive beef grazing	Permanent Pasture	69	7	Beef	61	-	-
16	Intensive beef grazing with FYM	Permanent Pasture	63	7	Beef	61	Solid	58
17	Intensive beef grazing with slurry	Permanent Pasture	58	7	Beef	61	Slurry	56
18	Dairy grazing	Permanent Pasture	69	7	Dairy	72	-	-
19	Dairy grazing with FYM	Permanent Pasture	61	8	Dairy	72	Solid	80
20	Dairy grazing with slurry	Permanent Pasture	53	8	Dairy	72	Slurry	87

2.2 Mitigation measure uptake

Farmscoper includes a library of over 100 diffuse pollution control measures, based upon the Mitigation Method User Guide (Newell-Price et al., 2011), agri-environment scheme options and others that have been added during updates to the tool. For each of these measures, Farmscoper contains a default implementation rate based upon national farm practice survey data, which varies by soil type, farm type and whether or not a farm is within a nitrate vulnerable zone. For each measure, it also shows which policy mechanisms are relevant. The Farming Rules for Water (FRfW) states some activities that must be undertaken or avoided, but also lists some activities that could be undertaken as a ‘reasonable precaution’ to avoid pollution. The relevant measures in the Farmscoper library are identified as either FRfW required or FRfW reasonable respectively.

Two scenarios of mitigation measure uptake were modelled:

1. Full compliance with the measures associated with the NVZ action programme (for land inside NVZ area) and the ‘required’ aspects of the FRfW (for all land). Uptake of all other measures were left at the default rates.

2. As per item 1, but also with full implementation of all the ‘reasonable’ FRfW measures on all land.

The measures in the Farmscoper library that correspond to items 1 and 2 are listed in Table 2-2. Farmscoper restricts application of mitigation measures so they are only applied to land with applicable management (i.e. livestock measures would not be applied to arable fields).

Table 2-2 The scenarios assumed 100% compliance with the following Farmscoper mitigation measures, which are considered to reflect the NVZ regulations and the Farming Rules for Water. Note that the Farming Rules for Water are separated into those that are required, and those that could be considered a ‘reasonable precaution’ to avoid pollution.

Name	NVZ	FRfW Required	FRfW Reasonable
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	✓	✓	
Site solid manure heaps away from watercourses/field drains	✓	✓	
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	✓	✓	
Fertiliser spreader calibration	✓		✓
Incorporate manure into the soil	✓		✓

Minimise the volume of dirty water produced	✓		
Manure Spreader Calibration	✓		
Do not apply P fertilisers to high P index soils		✓	
Establish cover crops in the autumn			✓
Early harvesting and establishment of crops in the autumn			✓
Cultivate land for crops in spring rather than autumn			✓
Cultivate compacted tillage soils			✓
Leave autumn seedbeds rough			✓
Manage over-winter tramlines			✓
Establish riparian buffer strips			✓
Loosen compacted soil layers in grassland fields			✓
Reduce field stocking rates when soils are wet			✓
Move feeders at regular intervals			✓
Fence off rivers and streams from livestock			✓
Name	**NVZ**	**FRfW Required**	**FRfW Reasonable**
Use correctly inflated low ground pressure tyres on machinery			✓
Locate out-wintered stock away from watercourses			✓

2.3 Other farming systems

The field management scenarios focus on the dominant agricultural management systems within Penwith Moors. The text below lists some of the other systems that are relevant to the area but have not been modelled, briefly describing why and where the results that have been produced may be an appropriate proxy.

- Horses: these are not included as a livestock category within Farmscoper but could be considered as equivalent to beef cattle assuming they are only grazed for ~6 months of the year. It would be necessary to account for differences in the amount of excreta produced by a horse compared to cattle (NVZ guidance states a horse produces 21 kg N yr^{-1} whilst an adult beef cow weighting up to 500 kg produces 61 kg N yr^{-1}).

- Outdoor pig rearing: pollutant losses from commercial outdoor pig units would exceed the nitrate targets due to the large amounts of excreta deposited on bare soil (e.g. Williams et al. 2000 measured concentrations between 8 and 116 mg l^{-1} of nitrate-N for different management systems on a site in Berkshire). The stocking levels and/or management that would be required to maintain sufficient ground cover and limit nitrate losses would need to be different from the typical commercial practice assumed in Farmscoper and for which limited empirical evidence is available. Although non-commercial farming may have lower losses, they would not necessarily be below the required nitrate threshold concentrations and there would be significant uncertainty on any predictions.

- Outdoor poultry: losses would depend upon the amount of time the birds actually spent outside, the stocking density and the extent of ground cover and crop growth to utilise the nutrients in the excreta. Given the low nitrate concentration thresholds, management is likely to be different to typical commercial practice, with much lower stocking rates. Any manure produced would need to be spread outside of the catchments.

- Daffodils: Farmscoper does not include an appropriate category for daffodils. Fertiliser rates are typically around 100 kg N ha^{-1} (based on RB209 Nutrient Management Guide (AHDB, 2022)), and with a spring-summer growing season, the losses for spring barley may be appropriate. However, daffodils are grown in ridges or beds, which could alter the potential for surface runoff, but this factor is more important for sediment and phosphorus than nitrate.

- Alternative cattle grazing systems: Farmscoper assumes cattle are outside for approximately six months. It is not possible to represent significantly different grazing patterns, although zerograzed livestock (i.e. cattle housed all year round) would only require use of the silage and silage + manure scenarios (assuming any losses from the farm steading were suitably controlled). • Organic farming: Farmscoper is based on conventional farming and does not properly reflect the nitrogen dynamics in organic farming. However, losses for organic systems are generally comparable to those of conventional systems where yields and intensity of production are similar (e.g. Stopes et al., 2002).

3 RESULTS

Farmscoper has been used to determine the annual average nitrate concentrations for the different management scenarios shown in Table 2-1, assuming compliance with regulations inside/outside the NVZ (defined by the measures listed in Table 2-2).

Table 3-1 shows that concentrations from arable land always significantly exceed the 2 mg l^{-1} annual nitrate-N concentration threshold. Concentrations are lower in the higher rainfall band (as there is only so much nitrogen to be lost, so the dilution due to more rainfall has more impact on the concentration than a slightly higher load) and lower on slowly permeable soils (where denitrification within the soil profile is more likely, which reduces the amount of nitrate available to be lost). However, even the lowest concentrations are still over 3 mg l^{-1}, which suggests it would only be possible to be below the 2mg l^{-1} thresholds by turning 50% or more of the field over to zero-input grassland or equivalent or by using significantly reduced fertiliser inputs.

The only scenarios that are below the 1 mg l^{-1} threshold are the silage scenarios (which sometimes remain below the threshold even with manure N being applied) and some of the extensive grazing scenarios (but never with manure N being applied). Intensive grassland systems, particularly those with manure being applied, typically exceed the 2 mg l^{-1} threshold.

There are limited differences in the annual average concentrations shown in Table 3-1 for farms inside and outside the NVZ area (typically less than 1%). This is because: i) there are only 4 additional measures within the NVZ area and ii) full compliance has been assumed rather than 'current uptake' (which would be higher within the NVZ area, as the NVZ regulations having been in place for longer than the FRfW). The results in Table 3-2 include full compliance with all of the FRfW 'reasonable precaution' measures – concentrations are typically 3% lower than in Table 3-1, but this is not enough to change the general conclusion that the nitrate concentrations shown are primarily controlled by farming system and the environment, rather than compliance with regulation. The greatest changes due to measures are for spring barley and brassicas, where covers crops included as part of the FRfW 'reasonable precaution' measures result in concentrations up to 10% lower, however concentrations still exceed the target thresholds.

3.1 Notes on interpretation of results

When using the results of this modelling work the following points are worthy of consideration:

- Farmscoper predicts long term annual average losses based on climate data. There could be significant variation in losses between years due a range of factors including weather - e.g. the total amount of rainfall and timing of rainfall relative to activities, particularly manure spreading and crop performance.
- Farmscoper is a meta-model of a suite of different pollutant models that were run for the whole of England and Wales, and then aggregated by area weighting by land use for the Farmscoper soil and climate zones. One of the advantages of this approach is that application of Farmscoper at regional to national scale will produce pollutant losses comparable to the original source models. However, it also means that the climate (rainfall) for each land use and soil type within a climate zone will not be the same (this is particularly true in the higher rainfall zones, where arable land is less common than grassland on wetter areas). Any potential differences will be slightly negated by the use of nitrate concentrations rather than loads, as greater loads from higher rainfall (and thus drainage) will be diluted by the higher drainage.
- It is unlikely that a land manager would need to carry out all of the 'reasonable precaution' measures in Table 2-2 appropriate to their land in order to be considered compliant with

the FRfW. • It is possible to interpolate between the results of the scenarios or - within reason – extrapolate, to determine the concentrations for alternative inputs. For example, the concentration from applying 110 kg N ha^{-1} for silage grassland would be halfway between the results of Scenarios 6 and 9. It is not possible to vary the fertiliser and manure inputs separately although an approximate value for more or less manure could be determined by differencing with the corresponding non-manure scenario.

- For scenarios with manure, the losses are for the year of manure application, but it is assumed that manure is only applied one year in three. More frequent application of manure will increase the soil organic matter content, resulting in greater nitrate losses. It is not possible to determine the impacts of more/less frequent manure application from the results shown in this report – it would be necessary to do some post-processing of the Farmscoper output files or rerun the application of Farmscoper Evaluate where the frequency of manure application was accounted for (see Annex 1).

Table 3-1. Annual average nitrate-N concentrations (mg l^{-1}), by soil type and annual average rainfall (AAR), assuming full compliance with required actions under the FRfW, and NVZ regulations within the NVZ area, and typical uptake of the other mitigation measures in Farmscoper. Cells highlighted in grey are greater than 2.0 mg l^{-1}, those in orange are less than 2.0 mg l^{-1} but above 1.0 mg l^{-1} and those in green are below 1.0 mg l^{-1}.

No.	Name	Non-NVZ Area						NVZ Area					
		900-1200 mm AAR			1200-1500 mm AAR			900-1200 mm AAR			1200-1500 mm AAR		
		FD	DA	DAG	FD	DA	DAG	FD	DA	DAG	FD	DA	DAG
1	Winter Wheat	5.6	5.7	4.9	3.8	4.5	4.0	5.6	5.6	4.9	3.8	4.5	4.0
2	Spring Barley	5.3	4.9	3.8	3.6	3.8	3.0	5.3	4.9	3.8	3.6	3.8	3.0
3	Brassica	12.2	10.2	7.1	8.3	7.8	5.2	12.2	10.2	7.1	8.2	7.8	5.2
4	Extensive sheep grazing	1.5	1.5	1.3	0.9	1.1	1.2	1.5	1.5	1.3	0.9	1.1	1.2
5	Intensive sheep grazing	2.1	2.2	2.3	1.4	1.6	2.0	2.1	2.2	2.3	1.4	1.6	2.0
6	Low input silage	0.8	0.8	0.6	0.5	0.6	0.6	0.8	0.8	0.6	0.5	0.6	0.6
7	Low input silage with FYM	1.4	1.5	1.2	0.9	1.0	1.0	1.4	1.4	1.2	0.9	1.0	1.0
8	Low input silage with slurry	1.4	1.3	0.9	0.9	1.0	0.8	1.3	1.3	0.9	0.9	1.0	0.8
9	High input silage	0.9	1.0	1.7	0.6	0.8	1.7	0.9	1.0	1.7	0.6	0.8	1.7
10	High input silage with FYM	2.2	2.2	2.8	1.5	1.7	2.5	2.2	2.2	2.8	1.5	1.7	2.5
11	High input silage with slurry	2.0	2.0	2.3	1.4	1.5	2.1	2.0	2.0	2.2	1.4	1.5	2.1
12	Extensive beef grazing	1.4	1.4	1.1	0.9	1.0	1.1	1.4	1.4	1.1	0.9	1.0	1.1
13	Extensive beef grazing with FYM	2.0	2.0	1.7	1.4	1.5	1.5	2.0	2.0	1.7	1.3	1.5	1.5
14	Extensive beef grazing with slurry	2.0	2.0	1.5	1.3	1.4	1.3	2.0	2.0	1.5	1.3	1.4	1.3
15	Intensive beef grazing	1.9	1.9	1.7	1.3	1.4	1.7	1.9	1.9	1.7	1.3	1.4	1.7

16	Intensive beef grazing with FYM	3.1	3.2	2.7	2.1	2.3	2.4	3.1	3.1	2.7	2.1	2.3	2.4
17	Intensive beef grazing with slurry	3.0	3.0	2.4	2.1	2.2	2.1	3.0	3.0	2.4	2.1	2.2	2.1
18	Dairy grazing	2.2	2.2	1.5	1.4	1.5	1.4	2.2	2.2	1.5	1.4	1.5	1.4
19	Dairy grazing with FYM	3.8	3.8	2.9	2.5	2.7	2.5	3.8	3.8	2.9	2.5	2.7	2.5
20	Dairy grazing with slurry	4.1	4.0	2.8	2.8	2.9	2.4	4.0	4.0	2.8	2.7	2.9	2.4

FD = Free draining soil.

DA = Slowly permeable soil requiring under drainage for arable use.

DAG = Slowly permeable soil requiring under drainage for arable or grassland use.

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Table 3-2. Annual average nitrate-N concentrations (mg l^{-1}), by soil type and annual average rainfall (AAR), assuming full compliance with required actions under the FRfW and those that could be considered reasonable precautions to prevent pollution as per FR4W, the NVZ regulations within the NVZ area, and typical uptake of the other mitigation measures in Farmscoper. Cells highlighted in grey are greater than 2.0 mg l^{-1}, those in orange are less than 2.0 mg l^{-1} but above 1.0 mg l^{-1} and those in green are below 1.0 mg l^{-1}.

No.	Name	Non-NVZ Area						NVZ Area					
		900-1200 mm AAR			1200-1500 mm AAR			900-1200 mm AAR			1200-1500 mm AAR		
		FD	DA	DAG	FD	DA	DAG	FD	DA	DAG	FD	DA	DAG
1	Winter Wheat	5.4	5.4	4.7	3.6	4.3	3.9	5.4	5.4	4.7	3.6	4.3	3.9
2	Spring Barley	5.0	4.4	3.5	3.4	3.4	2.7	5.0	4.4	3.5	3.4	3.4	2.7
3	Brassica	11.6	9.1	6.4	7.9	6.9	4.7	11.6	9.1	6.4	7.9	6.9	4.7
4	Extensive sheep grazing	1.4	1.5	1.3	0.9	1.0	1.2	1.4	1.4	1.3	0.9	1.0	1.2
5	Intensive sheep grazing	2.1	2.1	2.2	1.4	1.5	2.0	2.1	2.1	2.2	1.4	1.5	2.0
6	Low input silage	0.8	0.8	0.6	0.5	0.6	0.6	0.8	0.8	0.6	0.5	0.6	0.6
7	Low input silage with FYM	1.4	1.4	1.2	0.9	1.0	1.0	1.4	1.4	1.2	0.9	1.0	1.0

8	Low input silage with slurry	1.3	1.3	0.9	0.9	1.0	0.8	1.3	1.3	0.9	0.9	0.9	0.8
9	High input silage	0.9	0.9	1.7	0.6	0.7	1.7	0.9	0.9	1.7	0.6	0.7	1.7
10	High input silage with FYM	2.1	2.2	2.8	1.4	1.6	2.5	2.1	2.2	2.8	1.4	1.6	2.5
11	High input silage with slurry	2.0	2.0	2.2	1.4	1.5	2.1	1.9	1.9	2.2	1.4	1.5	2.1
12	Extensive beef grazing	1.4	1.4	1.1	0.9	1.0	1.1	1.4	1.4	1.1	0.9	1.0	1.1
13	Extensive beef grazing with FYM	2.0	2.0	1.6	1.3	1.4	1.4	2.0	2.0	1.6	1.3	1.4	1.4
14	Extensive beef grazing with slurry	1.9	1.9	1.4	1.3	1.4	1.3	1.9	1.9	1.4	1.3	1.4	1.3
15	Intensive beef grazing	1.9	1.9	1.7	1.2	1.4	1.6	1.9	1.9	1.7	1.2	1.4	1.6
16	Intensive beef grazing with FYM	3.1	3.1	2.6	2.0	2.2	2.3	3.0	3.0	2.6	2.0	2.2	2.3
17	Intensive beef grazing with slurry	3.0	2.9	2.3	2.0	2.2	2.1	2.9	2.9	2.3	2.0	2.1	2.1
18	Dairy grazing	2.1	2.1	1.5	1.3	1.5	1.4	2.1	2.1	1.5	1.3	1.5	1.4
19	Dairy grazing with FYM	3.8	3.7	2.8	2.4	2.6	2.4	3.7	3.7	2.8	2.4	2.6	2.4
20	Dairy grazing with slurry	4.0	3.9	2.7	2.7	2.9	2.4	4.0	3.9	2.7	2.7	2.8	2.4

FD = Free draining soil.

DA = Slowly permeable soil requiring under drainage for arable use.

DAG = Slowly permeable soil requiring under drainage for arable or grassland use.

4 SUMMARY

Penwith Moors in Cornwall is being considered by Natural England for designation as a Site of Special Scientific Interest. The Farmscoper model has been used to determine annual average nitrate concentrations in drainage water for a suite of typical farm management systems, and these have been compared to threshold nitrate concentrations that would help to achieve or maintain favourable condition of the wetlands within the Penwith Moors.

The annual average nitrate concentrations from arable land always exceed the higher threshold concentration of 2 mg l^{-1} NO_3-N. Grassland fields receiving around 150 kg N ha^{-1} yr^{-1} or more from fertiliser, manure and excreta deposited at grazing are also likely to exceed 2 mg l^{-1} unless the N is only as fertiliser. For concentrations to be below the lower threshold of 1 mg l^{-1}, it is necessary to have a low input grassland system, with total N inputs some way below 100 kg N unless the N input is fertiliser only. There is some variation with the physical environment, with concentrations lower where rainfall is higher and differing by soil type due to denitrification and other factors within the model.

The modelling has assumed full compliance with the ‘required’ actions with the Farming Rules for Water as a baseline. The effects of assuming compliance with the Nitrate Vulnerable Zone regulations (NVZs extend across some of the Penwith Moors) and full compliance with the ‘reasonable precautions’ within the FRfW are small (10% at most) and do not change the general conclusions about the suitability of different farm management for achieving the target thresholds.

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GLOSSARY

BSFP	British Survey of Fertiliser Practice
Concentration	In this project, the annual average flow-weighted mean concentration – the annual pollutant loss divided by the annual drainage. Reducing the loss will reduce the concentration and vice versa.
Favourable condition	a quality measure of SSSIs, achieved when the designated features of a SSSI are in a healthy state and are being conserved by appropriate management. See: Sites of special scientific interest: managing your land - GOV.UK (www.gov.uk) This is assessed by Natural England based upon attributes and targets defined by the Joint Nature Conservation Committee (JNCC). See: Common Standards Monitoring | JNCC - Adviser to Government on Nature Conservation There are 6 possible SSSI condition statuses: favourable condition, unfavourable recovering condition, unfavourable no change condition, unfavourable declining condition, part destroyed or destroyed. Government has set a target to restore 75% of protected sites in England (including SSSIs) to favourable condition as part of its 25-year Environment Plan. See: At a glance: summary of targets in our 25 year environment plan - GOV.UK (www.gov.uk)
FRfW	Farming Rules for Water
FYM	Farmyard Manure
Loss	The amount of nitrate, phosphorus etc leaving the agricultural system as a pollutant. Comparable to the term 'emissions', although that is more commonly used to refer to losses to air. Water-borne losses are those to the watercourse or to groundwater, and do not account for retention or any other in-stream processes.
Manure	All types of managed manure – slurry, FYM, broiler litter, poultry manure etc.
NVZ	Nitrate Vulnerable Zone
SSSI	Site of Special Scientific Interest

ANNEX 1 – NOTES ON THE FARMSCOPER METHODOLOGY

This section is intended to describe some of the procedures and approaches applied in the use of Farmscoper for this modelling work, in order to allow someone already familiar with Farmscoper to repeat the tasks undertaken. The modelling approach has used the default version of Farmscoper v5 with two modifications described in this section.

The scenarios to be modelled were agreed as part of project. Inputs were taken from published sources (e.g. fertiliser rates from the British Survey of Fertiliser Practice) or based upon typical practice (e.g. 2 cows per hectare). There was some iteration of the fertiliser, excreta and manure inputs assumed for the scenarios so that the predicted results were close to the desired nitrate concentration thresholds. This iteration was a manual process, as the variation in results for a scenario by soil, climate and implementation of mitigation measures meant a single exact answer for each scenario was not trying to be found.

For each scenario, a 10 ha area of the relevant crop was used to limit any issues due to rounding. Where livestock were present but the manure from those livestock was not applied to that land, the application percentage in Farmscoper for that crop-manure type combination was set to 0%. Where there were no livestock present, but manure was applied, the manure import feature was used in Farmscoper. The amount of manure imported was set to achieve the desired amount of manure N applied (for this work, it was decided to have, for example, the same manure N from FYM applied on the extensive grazing and the silage system).

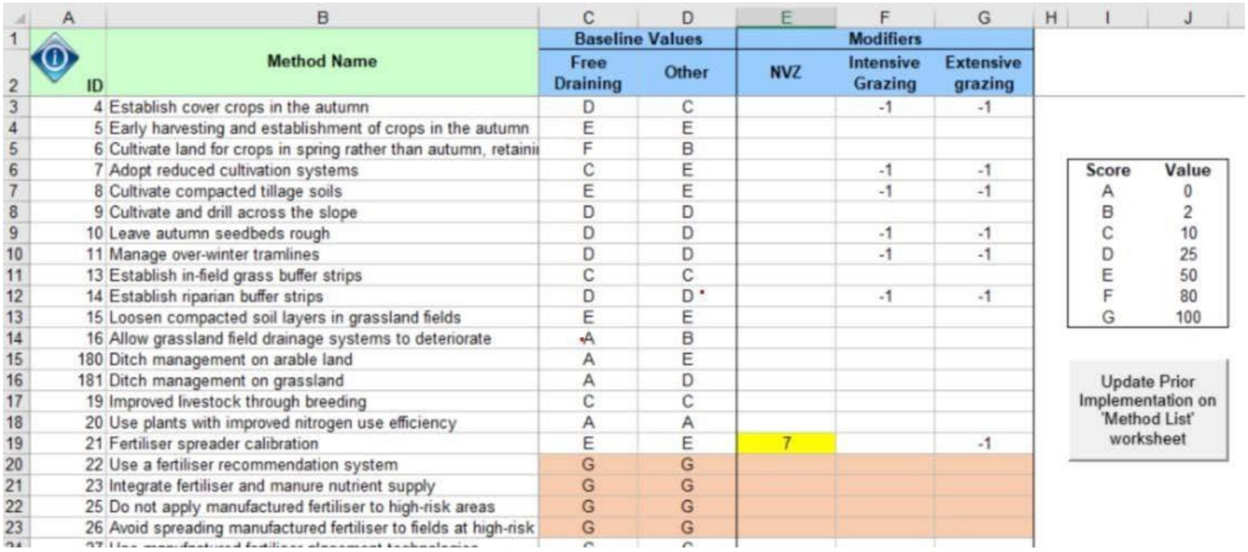
Data entry for the scenarios could be undertaken in the Farmscoper_Create workbook, and then the results generated for each soil and climate zone of interest. However, the 'Farm Results' tab and the option to run for 'Custom Data' within Farmscoper_Upscale allows the population and creation of multiple Farmscoper Create workbooks, which reduces the user input required. Because it was pollutant concentrations that were of interest in this project, it was necessary to make a modification to the code within Farmscoper_Upscale, as by default the drainage volume is not retained and so concentrations cannot be calculated.

For nitrate (and indirect nitrous oxide), Farmscoper predicts both the short- and medium-term losses in the weeks and months following manure application, and also the long-term loss resulting from the buildup of soil organic matter. It is necessary to reflect the frequency of manure application so as not to overestimate the organic matter contribution where fields do not receive manure every year. A simple way to do this is to reduce the manure inputs in proportion to the frequency of application (i.e. reduce them by two thirds if manure is applied once every three years). This provides the average loss over the period, but does not, however, reflect the higher losses that occur in the year of application as the short- and medium term losses are also averaged out. Therefore, in this project it was decided to leave the short- and medium-term losses unaltered, and reduce the long-term losses to account for the frequency of application. This was achieved by adding a new mitigation measure in Farmscoper_Evalute, with 100% prior implementation (and zero costs), that reduce theses long-term losses. The required data for the 'Method Impact' tab are shown in Table A1. The results of this measure are obviously not included until the Farmscoper_Evalute file has been applied, and so any baseline losses would not reflect the frequency of application.

Table A1. Method Impact values for the 'Manure History' mitigation measure, designed to reflect the frequency of manure application

Output	Source	Area	Pathway	Type	Timescale	Form	Typical Impact	Max. Impact	Min. Impact
Nitrate	AllAnimal	Arable|Grass	All	Slurry|FYM|Litter	Long	Dissolved	66	1.0	0.0
Nitrous Oxide	AllAnimal	Arable|Grass	All	Slurry|FYM|Litter	Long	All	66	-10	-50

The scenarios assumed full compliance with regulations, and also the default rates for the other mitigation measures. This was achieved by selecting 'Use prior implementation tables' within Farmscoper_Evalute, and then setting the values on the 'Settings-Priors' tab to 'G' for the Farming rules for Water measures (so that the implementation rate would be 1005) and to '7' for the NVZ measures (so that uptake would be increased by 7 bands, i.e. to 'G' value, if the farm was set to be within an NVZ). A screenshot of part of the 'Settings-Priors' tab is shown in Figure A1 to help show this. Note that this approach was designed to allow for both compliance and background uptake, and the automatic creation of NVZ farms through Farmscoper_Upscale. To simply specify a fixed rate for each measure, prior uptake could have been set to the desired value on the 'Method List' tab and the 'Use prior implementation tables' option disabled.



ID	Method Name	Baseline Values: Free Draining	Baseline Values: Other	Modifiers: NVZ	Modifiers: Intensive Grazing	Modifiers: Extensive grazing
4	Establish cover crops in the autumn	D	C		-1	-1
5	Early harvesting and establishment of crops in the autumn	E	E			
6	Cultivate land for crops in spring rather than autumn, retaini	F	B			
7	Adopt reduced cultivation systems	C	E		-1	-1
8	Cultivate compacted tillage soils	E	E		-1	-1
9	Cultivate and drill across the slope	D	D			
10	Leave autumn seedbeds rough	D	D		-1	-1
11	Manage over-winter tramlines	D	D		-1	-1
13	Establish in-field grass buffer strips	C	C			
14	Establish riparian buffer strips	D	D		-1	-1
15	Loosen compacted soil layers in grassland fields	E	E			
16	Allow grassland field drainage systems to deteriorate	A	B			
180	Ditch management on arable land	A	E			
181	Ditch management on grassland	A	D			
19	Improved livestock through breeding	C	C			
20	Use plants with improved nitrogen use efficiency	A	A			
21	Fertiliser spreader calibration	E	E	7		-1
22	Use a fertiliser recommendation system	G	G			
23	Integrate fertiliser and manure nutrient supply	G	G			
25	Do not apply manufactured fertiliser to high-risk areas	G	G			
26	Avoid spreading manufactured fertiliser to fields at high-risk	G	G			

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

Figure A1. How to represent full compliance with some mitigation measures, whilst leaving implementation rates for other measures to vary by soil, farm type and in/out NVZ.

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