Environment Agency

Nitrate modelling of Wybunbury Moss SSSI wetland catchment

Chief Scientist's Group report

August 2019

Version: SC160010/R3

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Professor Doug Wilson
Chief Scientist

Executive summary

This report presents the results of source apportionment modelling of nitrate to Wybunbury Moss, an assessment carried out as part of the Environment Agency project 'Nitrogen Source Apportionment Study at Two Groundwater Dependent Terrestrial Ecosystems (GWDTEs)'.

Wybunbury Moss is a Site of Special Scientific Interest and a National Nature Reserve, and part of the West Midlands Mosses Special Area of Conservation. It has a 'quaking bog' on a floating peat raft, surrounded by fen and mixed woodland. The site is currently in unfavourable condition due to concerns about nutrient enrichment. It has a small catchment area, which is predominantly to the north and west of the site. Land use in the catchment is predominantly extensively grazed grass, with only 2 arable fields identified, and some point sources.

The results of the modelling work suggest that:

- agricultural land to the north of the site is contributing to elevated nitrate concentrations in shallow groundwater along the northern boundary of the site
- the point sources and non-agricultural sources are not significant contributors of nitrogen

Particularly high concentrations are predicted in soil drainage from maize crops. This prediction is supported by elevated observed nitrate concentrations to the south of a field known to be used for maize.

Simulation of potential mitigation methods against nitrate leaching in the catchment suggests that it is not possible to achieve target water quality at the site through changes to nutrient management of the maize crop alone. Changes in the use of all arable land (maize and wheat) would be required, along with low stocking rates on grazed grassland.

Information of a private, confidential or sensitive nature has been removed from this report prior to external publication. This applies mainly to sources of high nitrogen input within the catchment where information relating to their precise location has been removed while further investigations are carried out. A copy of the report containing the full details has been published for internal circulation only.

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- Natalie Phillips, Mark Whiteman, Angela Haslam, Laura Ward, Steven Lee (Environment Agency)
- Tony Martin (Yorkshire Wildlife Trust)
- Rupert Randall, Iain Diack, Helen Wake, Anna Wetherell (Natural England)
- Gareth Farr (British Geological Survey)

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1 Introduction

This report presents the results of the source apportionment modelling of nitrate to the Wybunbury Moss wetland catchment in Cheshire. This assessment was carried out as part of project SC160010 ‘Nitrogen Source Apportionment Study at Two Groundwater Dependent Terrestrial Ecosystems (GWDTEs)’. It forms one of two case study examples used to trial the approach to nitrate source apportionment at wetland sites developed as part of the project (Environment Agency 2018).

Wybunbury Moss is a Site of Special Scientific Interest (SSSI) and a National Nature Reserve, and part of the West Midlands Mosses Special Area of Conservation. It consists of a ‘quaking bog’ on a floating peat raft, surrounded by fen and mixed woodland.

There are concerns about nutrient enrichment to the site, which has resulted in the SSSI currently being in unfavourable condition. Observed water quality data show nitrate concentrations to exceed the threshold value of 2mg nitrogen (N) per litre set for the site (based on UKTAG 2012). The purpose of the assessment was to contribute to the understanding of the sources of nitrate in the catchment and potential mitigation options.

This report:

- provides a brief overview of the site’s conceptual model and how this has influenced the assessment
- identifies potential sources of nitrate to Wybunbury Moss
- describes the derivation of a range of feasible land management scenarios for modelling
- presents the results of the modelling of those scenarios and discusses them in comparison with observed data
- discusses the likely effectiveness of a range of potential mitigation options in reducing nitrate leaching within the catchment

2 Conceptual model

This section presents a summary of the relevant aspects of the conceptual model of the hydrology and hydrogeology of the site. Note that prior knowledge of the general setting and character of the site is assumed.

The conceptual model of the site, as envisaged by Wheeler et al. (2016), is presented in Figure 2.1. The cross-section shows Wybunbury Moss being adjacent to the sands and gravel to the north, but with boulder clay to the south. The boulder clay is underlain by halite, which could potentially be connected to the water underlying the peat raft, although the evidence for or against this is limited.

Various studies have considered the nature and extent of connectivity between Wybunbury Moss itself and the sands and gravels to the north. There have been some suggestions of a low permeability 'curtain' at the edge of the Moss restricting the connectivity, although the most recent study rejected this (Wheeler et al. 2016). It is certainly accepted that groundwater would reach that part of the lagg fen which occupies the northern and western part of the site, and it is probable that there is at least some connectivity to the water beneath the peat raft.

The presence of boulder clay to the south will limit any groundwater contributions. Wheeler et al. (2016) concluded that from the south:

> 'telluric water supply is probably fairly limited … rain-generated run-off from the adjoining basin slope together with along-lagg flow'.

There are no major surface inflows to Wybunbury Moss, although there are some old drains that may provide a route for surface run-off or groundwater discharging to the lagg fen to reach the habitats on the peat raft.

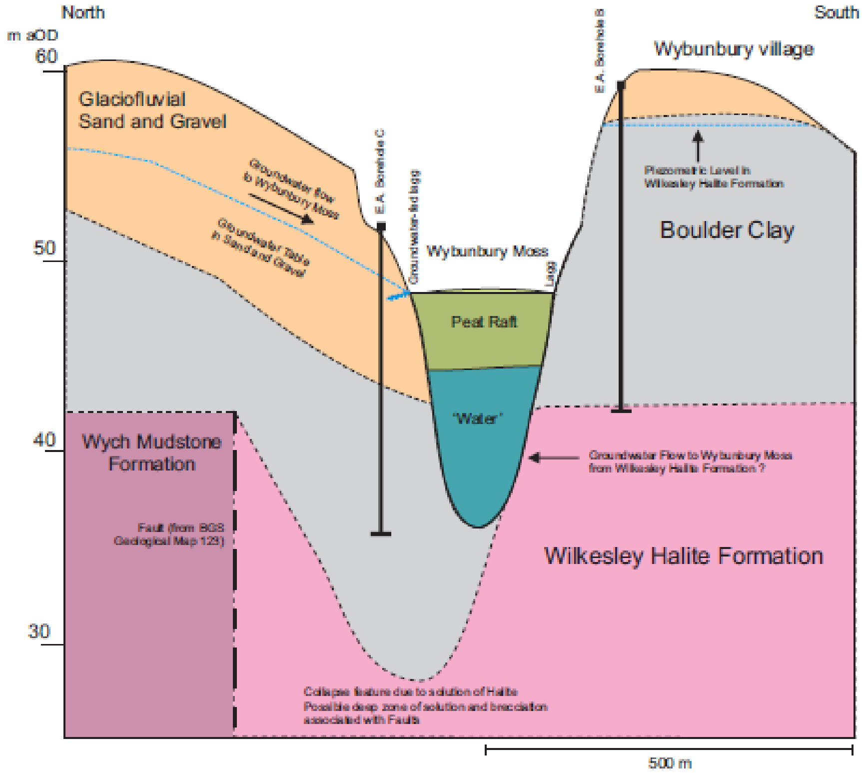

Figure 2.1 Conceptual model of Wybunbury Moss as envisaged by Wheeler et al. (2016)

2.1 Modelling assumptions

For the purpose of modelling, the following assumptions were made about the site's hydrogeology.

- The modelling represents nitrate contributions reaching the northern edge of the site. This can be assumed to contribute to the lagg fen along the north side of Wybunbury Moss. It is also effectively assumed that there is connectivity onwards to Wybunbury Moss, although no distinction is drawn between different parts of the site in the modelling.
- Surface water inputs from the north of the site are not significant, since the soils are free draining. Any surface water flow will be considered jointly with subsurface interflow, since both will respond similarly and with short lag times.
- Connectivity to the halite is not significant. The basis for this assumption is that:
  - even if there is connectivity, it is likely that nitrate concentrations in the halite will be low
  - recharge to the halite will likely be a considerable distance from the site due to the confining boulder clay

- Groundwater inputs from sands and gravels to the south of the site are not significant due to the presence of boulder clay. The surface water catchment to the south was considered separately and applied as shown in Figure 2.2.
- Atmospheric deposition is currently the subject of a separate investigation and is not explicitly considered here.

In summary, the modelling sought to estimate quantitatively the nitrate loading to the northern edge of the site in leachate from the land to the north. Separately, the nitrate loading onto Wybunbury Moss in surface run-off or shallow subsurface flow is considered from the small surface water catchment to the south.

2.2 Sources of nitrate included in model

The catchment to the north of the site is predominantly agricultural with only a few dwellings. For ease of reference, the land units within the catchment were numbered, as shown in Figure 2.3.

Potential sources of nitrate to shallow groundwater within the catchment were identified from the following sources of information:

- previous surveys and conceptual modelling conducted by the Environment Agency and Natural England
- discussions with the Natural England site manager
- a catchment walkover made by members of the project steering group in November 2016
- Google Earth imagery

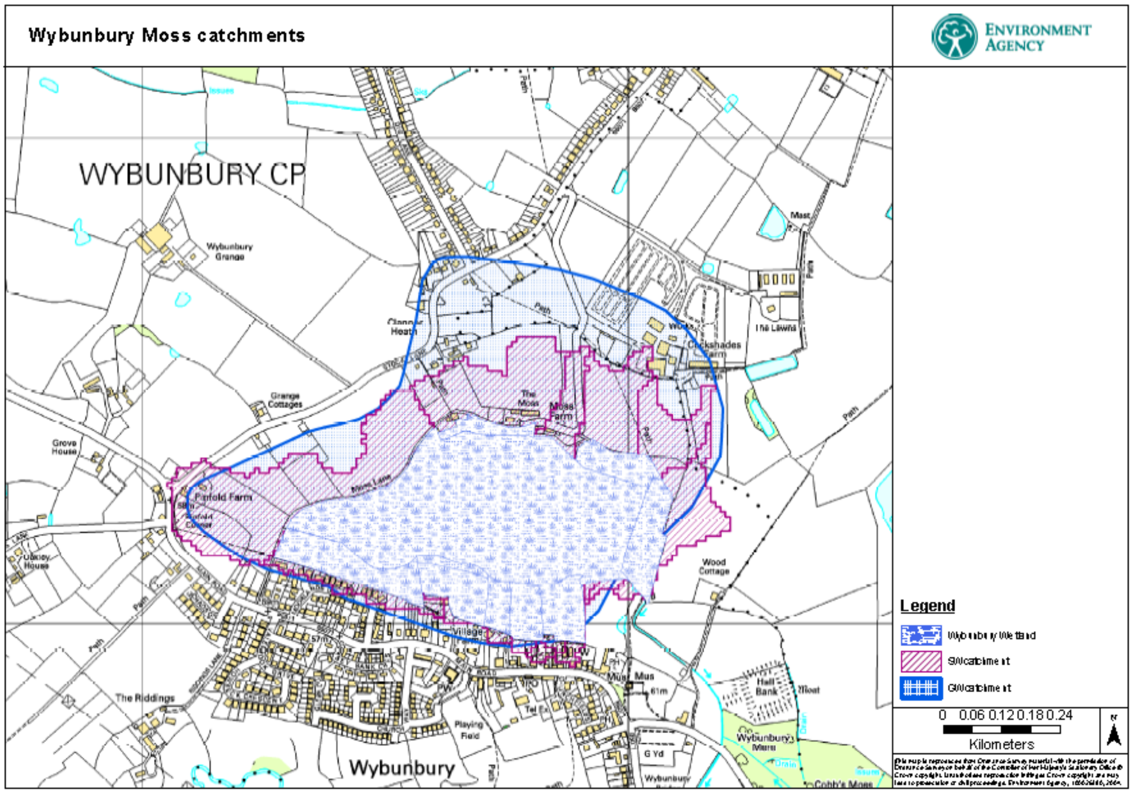

Figure 2.2 Catchment to Wybunbury Moss

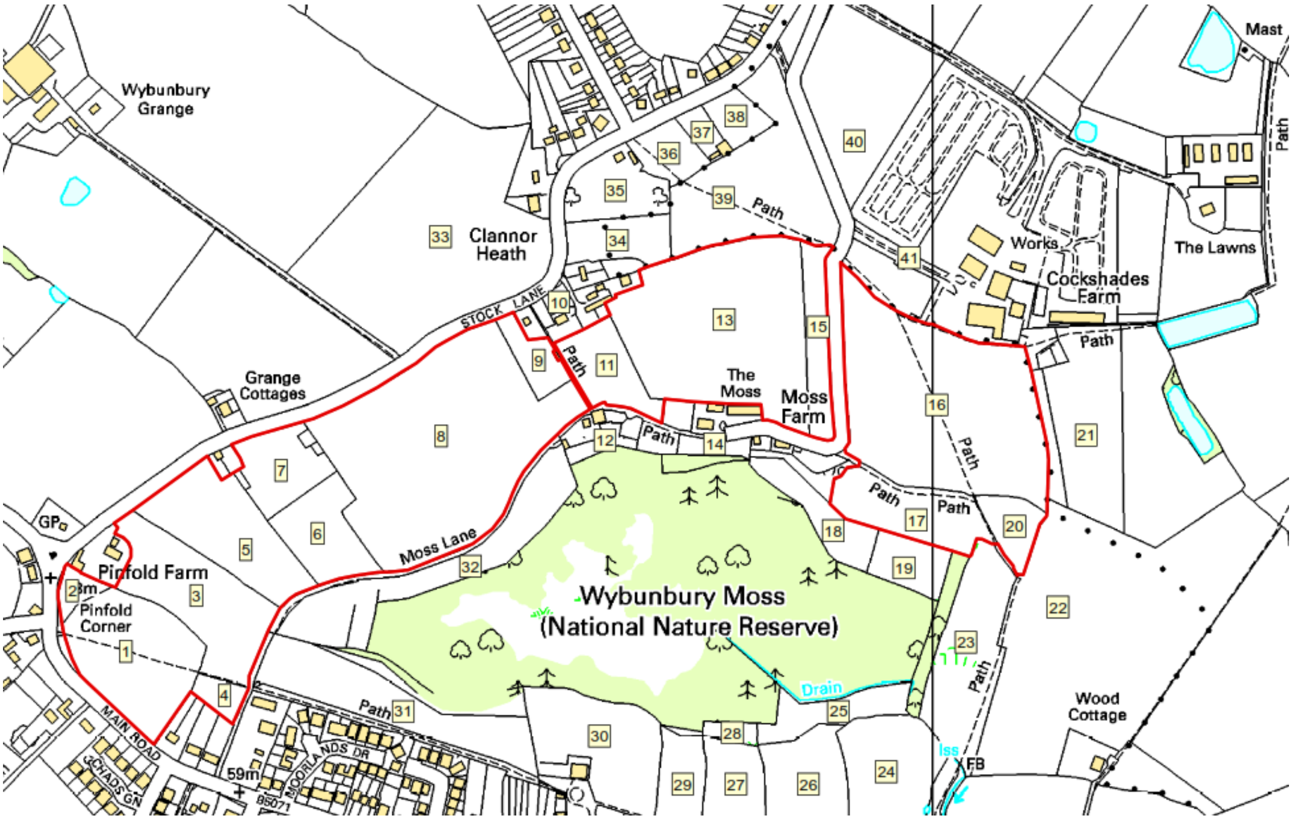

Figure 2.3 Field numbering within the catchment

Notes: The red boundary line indicates the fields for which nitrate modelling was carried out.

Although fields 34–39 are just within the boundary of the groundwater catchment as defined here, they were not included in the modelling. This is because they appear to be mainly amenity grass and woodland rather than agricultural land and, as such, will contribute negligible nitrate loading.

The following potential sources of nitrate to shallow groundwater were identified (though not all necessarily present):

- leaching of nitrate from agricultural soils on land to the north of the site – includes both arable land and improved grassland, with or without grazing livestock
- leaching of nitrate from soils on the fen itself
- run-off from a light industrial unit
- leaching of nitrate from manure heaps in the catchment[1]
- sewer leakage from mains sewers serving the dwellings within the catchment
- mains water leakage from water mains serving the dwellings within the catchment

The following potential sources of nitrate were discounted as not being present within the catchment based on discussions with the Natural England site manager and other sources of information:

- leakage from septic tanks within the catchment (septic tanks were present historically, all dwellings are believed to now be connected to mains sewers)
- landfill sites
- graveyards
- animal burials
- farm slurry stores

Wheeler et al. (2016) also identified the following potential sources of nitrate to Wybunbury Moss:

- culvert under Moss Lane (the western edge of the site), which was 'enriched by drainage from agricultural land'
- Farm yard drainage water
- a stream that flows into the site from the south

The surface water catchment to the south of the site is assumed to consist of fields 23–31 (Figure 2.3). These fields are assumed not to contribute to groundwater as they are on boulder clay, though they could generate surface run-off that could reach Wybunbury Moss. This land is entirely under grass.

[1] There appears to be, or to have been historically, a manure heap. The connectivity of this location to the fen is uncertain.

3 Numerical models and calculation methods

3.1 Predictions of nitrate leaching

Nitrate leaching from the agricultural land in the catchment towards the northern edge of Wybunbury Moss was estimated using the ADAS Farmscoper tool (Gooday et al. 2015). Farmscoper is a decision support tool that can be used to:

- assess diffuse agricultural pollutant loads on a farm
- quantify the impacts of farm mitigation methods on these pollutants

It requires data on the management of the farm's land and livestock, and generates predictions of nutrient loadings by sector and pathway.

Non-agricultural sources of nitrate and agricultural point sources were estimated using the results of research described in Entec (2010). This work included a comprehensive literature survey of nitrate (and phosphorus) loadings to groundwater from a variety of potential catchment sources including sewage discharges, landfill, graveyards, mains water and sewer leakage, urban diffuse sources, and agricultural diffuse and point sources.

3.2 Methods

Farmscoper and the information obtained from Entec (2010) were used to provide predictions of the concentration of nitrate in soil drainage from each of the identified potential sources of nitrate in the catchment, and hence derive an average figure for drainage to the northern edge of the site. This process involved the following.

- The areas of each of the agricultural fields and other land units were estimated in a geographical information system (GIS) from Ordnance Survey mapping data (see Figure 2.2).
- Two fields were identified as being in arable production under maize and another under winter wheat (as per communication from Natural England).
- The remaining agricultural fields along the northern side of the site were assumed to be permanent pasture grazed by beef. These agricultural fields were assumed to receive fertiliser (either inorganic or manure, or both). The details of land management are not known and a number of scenarios were therefore considered (see Section 3.3).
- Leaching from the manure heap was also estimated, though it lies to the east of Wybunbury Moss (Figure 2.2) and is unlikely to have a direct impact on the site.
- Hydrologically effective rainfall (that is, the quantity of soil drainage) was estimated using Farmscoper.

- The average nitrate concentration in soil drainage was calculated based on the area of each field and the predicted nitrate concentration.

3.3 Land management scenarios

The degree of nitrate leaching from managed agricultural land in a catchment is a function of land management (fertiliser applications and livestock stocking rates). The details of this management within the catchment of Wybunbury Moss were not known and so assumptions were made in order to construct a number of feasible scenarios.

These scenarios are intended to bracket the likely nitrate leaching from the land around Wybunbury Moss: each pair of scenarios represents a ‘high’ scenario, with estimated nitrogen inputs towards the upper end of the range that might be expected, and a ‘low’ scenario with estimated nitrogen inputs towards the lower end of the range. A pair of scenarios was derived for 3 cover types: maize, wheat and pasture land.

The total area of pasture within the groundwater catchment to the north of Wybunbury Moss was calculated to be around 14ha (fields 2–7, 9, 11, 13, 15–17, 20). The area of assumed to be under winter wheat is 1.6ha. The area under maize is 4.3ha. Field 22 was excluded because it lies largely outside the defined catchment area, with the exception of its north-west corner. The potential nitrate loading from the manure heap thought to have been present historically was estimated to allow comparison with the estimated diffuse loading from the catchment; this manure heap, however, may not be in hydraulic connectivity with the site (see Section 2).

The number of beef cattle present on the pasture around Wybunbury Moss is not known, but it is thought that they are not intensively grazed. The average stocking rate on lowland grass in England is 0.58 livestock units (LU) per hectare (Chesterton 2009). Assuming that one beef cow is equivalent to 0.6 LU,[2] this stocking rate would equate to a herd of 14 beef cattle grazing the pasture north of the site. An alternative scenario is also considered of half this stocking rate, equating to 7 cattle or 0.3 LU per hectare.

Average rainfall in the area is 695mm (Ingram and Seymour 2003) and so average summer rainfall will be around 350mm (half of the annual total). For light, sandy soils this gives a grass growth class of ‘poor’ as defined by the RB209 Nutrient Management Guide (AHDB 2018, Table 3.7).

For a growth class of ‘poor’, the total nitrogen requirement is extremely low, at around 8kg per hectare. A slightly lower stocking rate of 0.5 LU per hectare would reduce this figure to zero. At a stocking rate of 0.3 LU per hectare, RB209 suggests a fertiliser rate of zero for all growth classes. For the purposes of this work, this fertiliser rate is assumed negligible and is set to zero for all pasture scenarios.

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[2] Figure given in the RB209 Fertiliser Manual (Defra 2010, p. 189) for an average beef animal.

If cattle are kept in the catchment all year round, they would normally be housed for part of the year, generating a need for manure storage and spreading (as noted in Section 2 there is historical evidence of a manure heap). Manure is likely to be spread to permanent pasture and it is likely that any fields under maize would also receive applications of organic manure. Again, the actual management of manure from the cattle is not known. Given that the arable land is managed by a dairy farmer, it is possible that manure is imported to the catchment (personal communication from Natural England). The modelling scenarios therefore include applications of manure to the maize field, but it is recognised that the application rate is highly uncertain.

The assumptions behind the definitions of the scenarios are summarised in Table 3.1. The modelled scenarios are described in Table 3.2.

Table 3.1 Summary of catchment data and assumptions for Wybunbury Moss catchment

Variable	Description
Soil type	Sandy, free draining
Annual rainfall	695mm per year (after Ingram and Seymour 2003)
Summer rainfall	350mm (half of the annual total rainfall)
RB209 grass growth class	Poor
Area of pasture fields (ha)	14
Area of wheat field (ha)	1.6
Area of maize field (ha)	4.3
Farmscoper rainfall band	700–900mm rainfall[1]
Farmscoper soil type	Free draining

Notes: [1] An annual rainfall figure of 695mm lies on the boundary between 2 climate bands. Choosing the lower band results in lower predicted soil drainage and nitrate loadings and similar nitrate concentrations to those obtained using the upper band.

Table 3.2 Land management scenarios for Wybunbury Moss catchment

Land use/ scenario number	Nitrogen fertiliser rate	Stocking rate	Comments
Maize 1	150 kg per hectare inorganic + managed manure from 14 cattle	N/A	Inorganic fertiliser rate is the RB209 rate for a SNS index of 0. No allowance is made for the nutrient content of the applied manure, which is calculated as 93 kg per hectare (total N).
Maize 2	100 kg per hectare inorganic No manure	N/A	Fertiliser rate is the RB209 rate for a SNS index of 1.
Wheat 1	160 kg per hectare inorganic	N/A	Fertiliser rate is the RB209 rate for a SNS index of 0 on light sandy soil.
Wheat 2	130 kg per hectare inorganic	N/A	The RB209 fertiliser rate for a SNS index of 1.
Pasture 1	Zero inorganic + managed manure	0.6 LU per hectare (14 cattle in total)	Manure assumed to be spread to permanent pasture.

Land use/ scenario number	Nitrogen fertiliser rate	Stocking rate	Comments
Pasture 2	Zero inorganic	0.3 LU per hectare (7 cattle in total)	Manure assumed to be spread elsewhere.

Notes: Soils are sandy and free draining and rainfall is 'moderate' at 695mm per year. For fields previously in wheat or maize, RB209 guidance suggests that a low SNS index of 0 or 1 would be expected.
N/A = not applicable; SNS = Soil Nitrogen Supply

3.4 Non-agricultural sources and agricultural point sources of nitrate (to the north)

Input data relevant to the calculation of other potential sources of nitrate are shown in Table 3.3. These values are estimates based on Ordnance Survey mapping data, including only the catchment area to the north of Wybunbury Moss.

Table 3.3 Groundwater catchment input data to north of Wybunbury Moss: non-agricultural sources and agricultural point sources

Parameter	Value	Comment
Sewered population	46	~20 dwellings, average 2.3 people per household
Population served by septic tanks/ package treatment plants	0	
Area of gardens	1ha	Assumed associated with farms and dwellings on Stock Lane
Area of manure heaps	0.1ha	
Area generating farmyard run-off	0.5ha	Paddocks and yards
Area of paved and road surfaces	0.5ha	

3.5 Catchment to the south of Wybunbury Moss

The area of agricultural land and urban land in the surface water catchment to the south of Wybunbury Moss was estimated using a GIS. The area of grassland is estimated as being equal to 10.3ha and the urban area as being equal to 0.5ha. The management of this area of agricultural grassland is assumed to be similar to that of the grassland in the groundwater catchment to the north of the site. Nitrate from urban sources was estimated using the approach described in Section 3.4 and based on the input data shown in Table 3.4.

Potential sources of nitrate leaching from this area include mains leakage, sewer leakage and nitrate leaching from soils in the gardens. Although it is not certain to what extent nitrate from subsurface sources (sewer leakage and mains leakage) may reach Wybunbury Moss, given the presence of boulder clay in the catchment, they were included to allow for comparison with other sources.

Table 3.4 Surface water catchment input data to the south of Wybunbury Moss: non-agricultural sources

Parameter	Value	Comment
Sewered population	30	~13 dwellings, average 2.3 people per household
Population served by septic tanks / package treatment plants	0	
Area of gardens	0.5ha	Associated with the 13 dwellings

4 Observed nitrate concentrations at Wybunbury Moss

Observations of nitrate concentrations from a number of locations across the Wybunbury Moss site were collated by the British Geological Survey (BGS) and made available to the project.[3] The data are made up of a number of observations taken irregularly over the period between 2001 and 2016. Readings of nitrate concentrations are summarised in Table 4.1. The observation sites are labelled in Figure 4.1.

Table 4.1 Observations of nitrate concentration in the sands and gravels to the north of Wybunbury Moss

Sample point	Date of first sample	Date of last sample	Nitrate concentration (nitrate-N, mg per litre)			Number of records
			Minimum	Maximum	Average	
Wybunbury Moss – SGA2	3 June 2009	20 January 2010	23.70	28.30	24.86	5
Wybunbury Moss – SGA3	3 June 2009	10 March 2016	15.50	21.40	18.66	14
Wybunbury Moss – SGB2	3 June 2009	20 January 2010	37.10	46.00	41.44	5
Wybunbury Moss – SGB3	3 June 2009	20 January 2010	30.10	36.70	32.34	5
Wybunbury Moss – SGC2	4 June 2009	20 January 2010	35.20	39.30	37.96	5
Wybunbury Moss – SGC3	4 June 2009	20 January 2010	0.22	3.88	1.14	5
Wybunbury Moss – SGD2	4 June 2009	20 January 2010	3.09	9.75	6.71	5
Wybunbury Moss C SJ65/24	7 July 2003	15 November 2007	13.50	29.30	20.90	4

[3] Email from Gareth Farr, 31 October 2016

Sample point	Date of first sample	Date of last sample	Nitrate concentration (nitrate-N, mg per litre)			Number of records
			Minimum	Maximu m	Averag e	
Wybunbury Moss borehole D SJ65/25	19 March 2008	16 August 2016	10.90	39.30	21.10	22
Wybunbury Moss lag fen	6 Novembe r 2015	10 March 2016	0.10	0.10	0.10	4

It is apparent that there is considerable variation in nitrate concentrations around the northern side of Wybunbury Moss, with very high concentrations at sites SGB2, SGB3 and SGC2, and to a lesser extent SGA2, SGA3 and boreholes C and D. On the lagg fen, concentrations are much lower. There is also a marked contrast in concentrations between sites SGC2 and SGC3, which is thought to be due to differences in the depths to which the 2 boreholes are screened.

In general it is observed that sites close to or down gradient of the high N input land uses (SGB and SGC, and boreholes C and D) show high concentrations of nitrate, with the notable exception of SGC3, while site SGD2 and the site on the lagg fen show much lower concentrations.

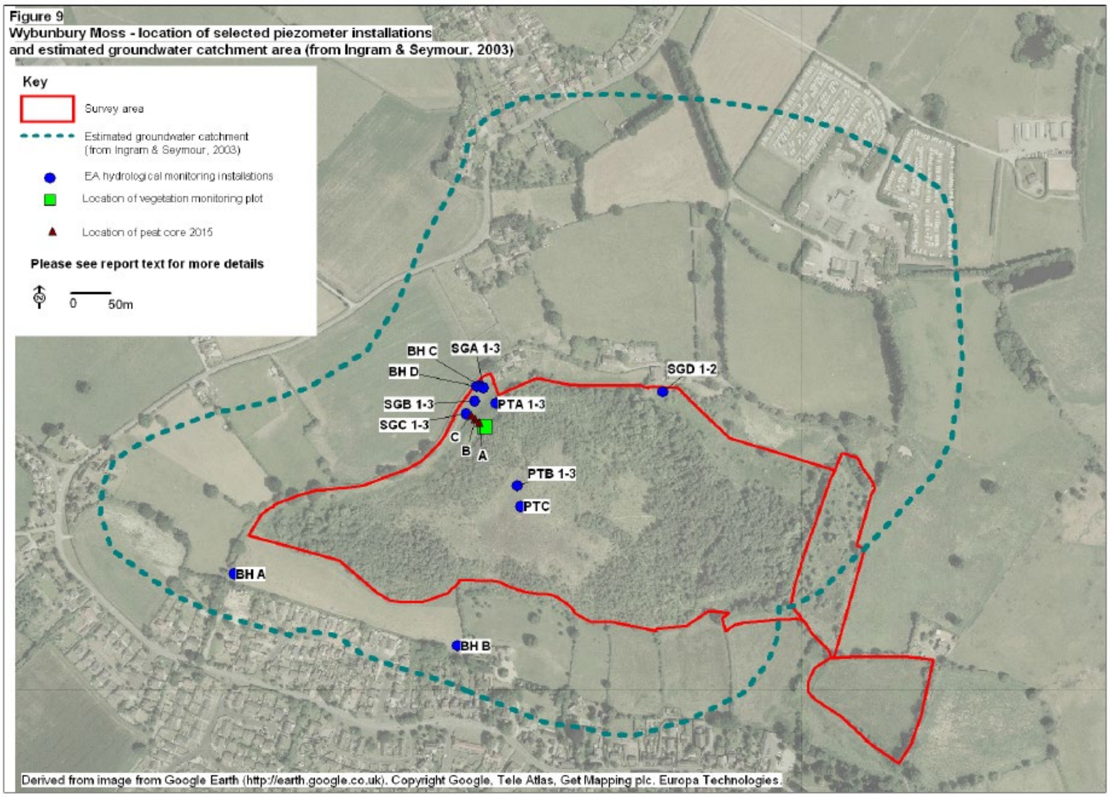


Figure 4.1 Locations of water quality monitoring sites at Wybunbury Moss

Source: Wheeler et al. (2016)

Further monitoring was undertaken by APEM on behalf of Natural England between August 2015 and February 2016. Samples were taken monthly and the limit of detection was 0.2mg-N per litre. The monitoring locations are as shown in Figure 4.2 and a summary of the measured nitrate concentrations is presented in Table 4.2.

Figure 4.2 Locations of water quality monitoring sites (APEM monitoring, 2015)

Table 4.2 Observations of nitrate concentrations at Wybunbury Moss from APEM monitoring in 2015)

Site	Number of observations	Nitrate concentration (mg-N per litre)	
		Average	Maximum
1	6	3.5	4.0
2	7	0.8	2.7
3	7	0.2	0.2
4	7	0.2	0.2
5	7	0.2	0.2
6	5	0.2	0.2
7	7	0.2	0.3
8	7	0.2	0.2
9	7	0.2	0.2

It is evident from these data that nitrate concentrations on Wybunbury Moss during the APEM monitoring period were generally very low. Average concentrations above the limit of detection were found only at sites 1 and 2, which lie at the western end of the site, down gradient of field 1 (under wheat).

5 Farmscoper modelling results

5.1 Nitrate loading from the northern catchment

Table 5.1 shows the results of the Farmscoper modelling for each land use scenario.

Table 5.1 Results of Farmscoper modelling for the northern catchment for different land use scenarios

Land use /scenario number	Area (ha)	Drainage (mm per year)[1]	Nitrate-N load (kg-N per hectare year)	Nitrate-N concentration (mg-N per litre)	Nitrate-N load (kg-N per year)
Maize 1	4.3	341	93.4	27.4	401.6
Maize 2	4.3	341	42.9	12.6	184.4
Wheat 1	1.6	374	35.9	9.6	57.5
Wheat 2	1.6	374	33.6	9.0	53.7
Pasture 1	14.0	329	15.2	4.6	212.7
Pasture 2	14.0	329	5.7	1.7	79.1

Notes: [1] Drainage values are as calculated by the Farmscoper model.

Table 5.2 shows the estimated loadings from non-agricultural sources and agricultural point sources.

Table 5.2 Point sources and non-agricultural sources for the northern catchment

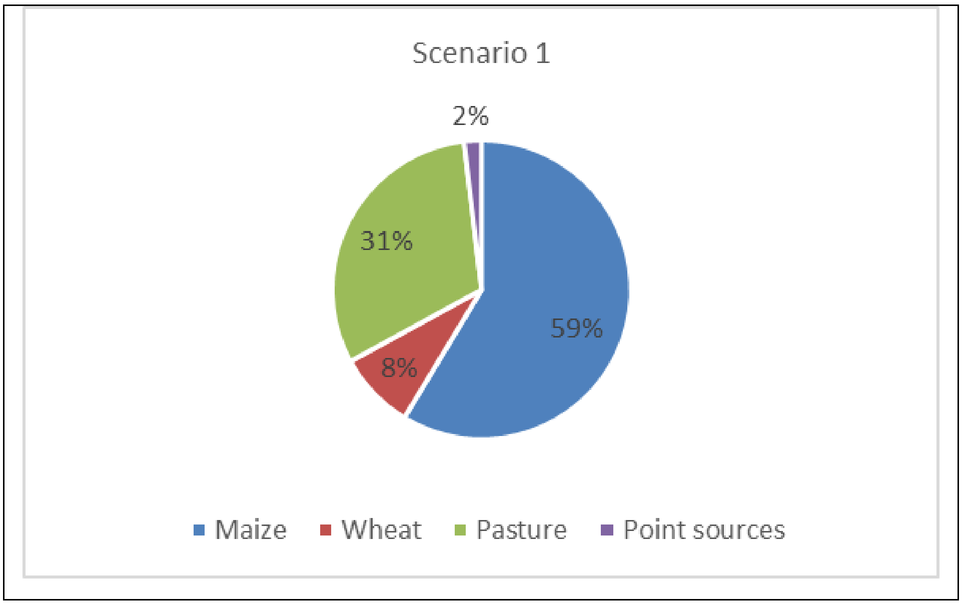
Point source	Nitrogen load (kg-N per year)	Comments
Sewer leakage	3.5	
Mains leakage	7.2	
Manure heaps	1.9	Assumed leachate quality of 10mg-N per litre and 100mm of drainage per year.
Roads	0.2	
Urban area	0.1	
Total	**12.9**	

The catchment total loadings are shown in Table 5.3 and Figure 5.1. These were produced by aggregating the 3 'high' scenarios and the 3 'low' scenarios, taking account of the area and loading per land use. The same point source and non-agricultural loadings (as shown in Table 5.2) were included in both aggregate scenarios.

These results show the loading to the whole northern catchment area. However, this does not necessarily infer complete mixing of all groundwater reaching Wybunbury Moss (that is, the concentrations and relative contributions may vary in different parts of the site).

Table 5.3 Total nitrate loading in the northern catchment

Scenario number	Nitrate-N load (kg-N per year)	Nitrate-N load (kg-N per ha per year)	Nitrate-N concentration (mg-N per litre)
1 'High' leaching: Maize 1, Wheat 1, Pasture 1	684.7	34.4	10.3
2 'Low' leaching: Maize 2, Wheat 2, Pasture 2	330.1	16.7	5.0



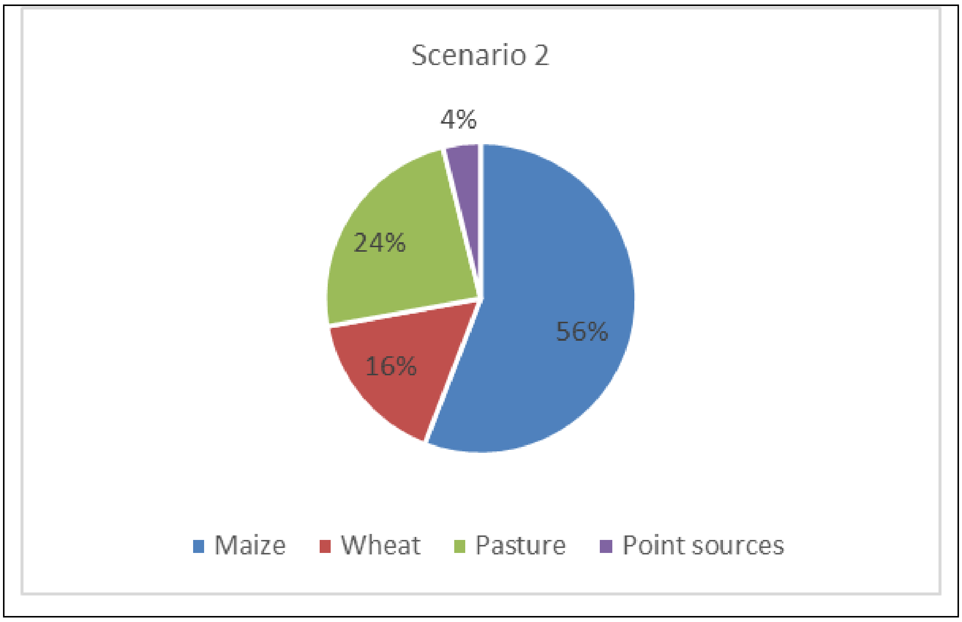


Figure 5.1 Northern catchment nitrate load apportionment under Scenario 1 (Maize 1, Wheat 1, Pasture 1) and Scenario 2 (Maize 2, Wheat 2, Pasture 2)

5.2 Nitrate loading from the southern catchment

The nitrate loading from the agricultural grassland in the southern part of the catchment was assumed to be equal to that calculated in the 'Pasture 1' and 'Pasture 2' scenarios described in Section 5.1 (that is, the nitrate concentration in surface run-off from the southern catchment was assumed to be equal to that in soil drainage from the northern catchment). The total loading is thus as shown in Table 5.4. The estimated loading from non-agricultural sources is shown in Table 5.5 and the total loading from the southern catchment in Table 5.6.

Table 5.4 Estimated loading from agricultural grassland in the southern catchment

Land use /scenario	Area (ha)	Drainage (mm per year)	Nitrate-N load (kg-N per ha per year)	Nitrate-N concentration (mg-N per litre)	Nitrate-N load (kg-N per year)
Pasture 1	10.3	329	15.2	4.6	156.6
Pasture 2	10.3	329	5.7	1.7	58.7

Table 5.5 Point sources and non-agricultural sources in the southern catchment

	Drainage (mm)	Nitrate loss (kg-N per ha per year)	Nitrate concentration (mg-N/l)	Nitrate-N load (kg-N per year)
Sewer leakage	10	4.53	1.43	2.27
Mains leakage	110	9.42	8.5	4.71
Leaching from gardens	350	5.0	1.43	2.50
Total		**18.95**	**3.08**	**9.48**

Table 5.6 Total nitrate loading in the southern catchment

Land use/ scenario number	Agricultural nitrate load (kg-N per year)	Non-agricultural nitrate load (kg-N per year)	Total nitrate load (kg-N per year)	Total nitrate load (kg-N per ha per year)	Nitrate concentration (mg-N/l)
'High leaching': Pasture 1	156.6	9.5	166.0	14.7	4.5
'Low leaching': Pasture 2	58.7	9.5	68.2	6.0	1.8

Notes Calculations are based on a southern catchment area of 11.3ha and drainage of 329mm per year.

5.3 Relative nitrate loading between northern and southern catchments

The total estimated loading from the southern surface water catchment (as kg-N per year) is therefore 21–24% of that from the groundwater catchment to the north of the site (Tables 5.3 and 5.5).[4] However, this assumes that nitrate from subsurface sources in the surface water catchment (sewer leakage, mains leakage) is able to reach Wybunbury Moss. If this is not the case, the loading from the surface water catchment will be slightly reduced. In addition, the majority of surface run-off will be intercepted by the drains on the southern side of the site, such that it has little potential to interact with Wybunbury Moss.

[4] For the 'low' scenario, the comparable figures for total load are 68.2 and 330.1kg-N per year (21%). For the 'high' scenario, they are 166 and 684.7kg-N per year (24%).

6 Discussion of current land use scenarios and implications

6.1 Interpretation of model results

The calculated nitrate loadings to shallow groundwater are dominated by leaching from agricultural land. Two scenarios have been considered – notionally a 'high leaching' scenario and a 'low leaching' scenario:

- Based on the Farmscoper results, the average concentration of nitrate in drainage from the catchment to the north of the site is 10.3mg-N per litre (high scenario) and 5.0mg-N per litre (low scenario) (Table 5.3).
- Point sources are not predicted to be significant compared with nitrate leaching from arable and grassland.
- There is a great deal of variability in predicted leachate concentrations between the crops and land uses in the catchment, with predicted leachate concentrations from maize being highest, followed by those from wheat crops, and predicted concentrations from grassland being the lowest.

The calculated average nitrate concentration in surface water run-off from the southern catchment is between 1.8 and 4.5mg per litre (Table 5.6). However, it is likely that the majority of the surface run-off from the south will be intercepted by the drains on the southern side of the site and will not penetrate into Wybunbury Moss. In contrast, there is no doubt that shallow groundwater from the northern catchment can reach the site and has the potential to influence sensitive habitats.

6.2 Comparison with observed data

This section compares the modelling results with the observed data. However, it is important to recognise that the observations were collected over an extended period, with different sites being sampled at different times:

- The variability in measured nitrate concentrations in shallow groundwater broadly mirrors the variability in predicted leachate concentration from the agricultural land to the north, with the highest nitrate concentrations being observed immediately down gradient of the maize field and lower concentrations further east, down gradient of pasture. This suggests that there is incomplete mixing of shallow groundwater from the different parts of the catchment in the east and west.
- The predicted concentrations of nitrate under the 'Maize 1' scenario are high, but not as high as has been observed at sampling points SGB2 and SGB3. However, these observations cover a single period from June 2009 to January 2010 which may not be representative of

long-term average conditions, whereas the model predictions are of annual average values.

- The most recent observed concentrations at sampling points SGA2 (24.7mg-N per litre in January 2010) and SGA3 (17.6mg-N per litre in March 2016) are higher than the predicted concentrations from the wheat scenarios.
- Observed concentrations from the 2015 to 2016 monitoring campaign at sites 1 and 2 down gradient of the wheat field are lower than the predicted concentrations from the wheat scenarios. Again, these observations cover a single winter period whereas the model predictions are of annual average values).

There are a number of possible reasons for the apparent under prediction of the models compared with observed data, including:

- the assumptions around crop husbandry and nutrient management underestimate the rates of fertiliser application
- soil nitrogen supply has been underestimated
- observed concentrations, which cover a number of sampling times, seasons and years from 2003 to 2016, are not representative of current leaching (that is, of current land use and management)
- model predictions of annual average nitrate concentrations in leachate are not directly comparable with spot measurements from a limited period within one year

6.3 Comparison with water quality targets

The target nitrate concentration for Wybunbury Moss is 2mg-N per litre. This corresponds to the threshold value in UKTAG (2012) for peatbog and has been applied to the whole site. Looking at the results from the Farmscoper modelling (see Section 5), of all the scenarios for the management of agricultural land in the catchment, only ‘Pasture 2’ achieves a predicted nitrate concentration in soil drainage that is consistent with this target water quality.

However, the monitoring data obtained by APEM in 2015 (Table 4.2) show some very low nitrate concentrations. This suggests that higher nitrate concentrations either have not yet reached some parts of the site, or those areas are predominantly rain-fed. As such, some parts of the site may be less susceptible to nitrate in groundwater than others and currently meet the 2mg-N per litre target. Nevertheless, both monitoring data and modelled results show that some parts of the site, where there is more potential for groundwater contribution, are experiencing concentrations considerably above the target. This requires further consideration.

To achieve the target water quality would require the average water quality in all drainage to the site from across the catchment to be better than 2mg-N per litre. On the basis of the modelling results presented here, this would require large reductions in nitrate leaching from all agricultural land in the catchment, including the extensive grassland, to a leaching scenario similar to ‘Pasture 2’.

Measures to reduce nitrate leaching from agricultural land are discussed in Section 7.

6.4 Times of travel

The BGS estimated the times of travel of water from the point of recharge at the water table to sampling points SGA3, PTC and B2 (see Figure 4.1 for the locations of these sampling points).[5] There is substantial variability in these estimates depending on the calculation methodology, but the estimated year of recharge lies between 1970 and 'present day' for sampling point SGA3, between 1959 and 'present day' for sampling point PTC, and between 1963 and 1979 for sampling point B2.

In general, this indicates relatively rapid movement of water from the point of recharge to Wybunbury Moss, and suggests that measures to reduce input nitrate loads in shallow groundwater could reduce the nitrate loading to Wybunbury Moss within a relatively short time frame. The timescale for such measures to be reflected in changes in the ecology at the site could, however, be much longer.

6.5 Uncertainty

There is considerable uncertainty in the model predictions of nitrate leaching presented here. The principal sources of uncertainty are around the pathways of water to the site and the management of nutrients in the catchment.

The area of agricultural land modelled represents the estimated area draining to the north side of Wybunbury Moss. The southern surface water catchment area was included separately. However, uncertainties remain around:

- the potential for groundwater contributions from the south (from sands and gravels or halite)
- the extent to which groundwater contributes to some parts of the site

Much greater uncertainty is attached to the management of the agricultural land. The details of nutrient management are not known and assumptions have been made as to how the land is managed. The use of multiple scenarios for each of the major agricultural land uses, representing deliberately high and low estimated concentrations of nutrient inputs, is an attempt to capture this uncertainty. That predicted nitrate concentrations under the high input scenarios are lower than measured concentrations at some monitoring sites suggests that actual nutrient inputs may be higher still.

[5] Personal communication from Gareth Farr

7 Mitigation of nitrate leaching

The modelling results presented in Section 5 suggest that the dominant source of nitrate draining to the site is agricultural land. Non-agricultural sources are not thought to be significant.[6]

The lack of information on nutrient management in the catchment makes it difficult to confirm the effectiveness of potential programmes of mitigation measures that could be implemented to reduce nitrate leaching from agricultural land. Nonetheless, this section considers some hypothetical changes to nutrient management and land use that could act to reduce nitrate leaching at the catchment scale and improve water quality at the site, focusing on the northern catchment. The measures are those included in the Farmscoper model and are described in Defra's Diffuse Pollution Inventory User Manual (Newell Price et al. 2011).

On the basis of the modelling of scenarios of current land use (see Table 5.1), the majority of the nitrate loading to the site is thought to originate from the maize field. The simplest way to reduce the impact of nitrate leaching from this field at minimal cost is to rotate land use within the farm holding so that the maize is grown elsewhere, in a lower risk field, and is replaced with a lower risk crop. However, this may not be possible.

Several alternative scenarios were simulated for mitigation of nitrate leaching from the maize field. Each assumes that land use across the rest of the catchment stays the same and is as described by the low nitrate input scenarios 'Wheat 2' and 'Pasture 2' (that is, the nitrate concentration in leachate from land under wheat is 9.0mg-N per litre and that from grassland is 1.7mg-N per litre). Point sources are not included in the mitigation scenarios, but these are not predicted to be significant (point sources are predicted to be responsible for 0.2mg-N per litre of nitrate in drainage across the catchment).

The scenarios are presented in Table 7.1. Table 7.2 presents the results in terms of the nitrate concentration in leachate from the maize field and from the catchment overall. The baseline is the 'Maize 1' scenario described in Section 5.

Table 7.1 Mitigation scenarios for the maize field

Mitigation scenario	Description
Establish cover crop in autumn	37% reduction in nitrate leaching (figure from Farmscoper modelling)
Change from maize to winter wheat	Change from maize crop to winter wheat, managed as per the 'Wheat 2' scenario (see Tables 3.2 and 5.1), which is predicted to leach at 9.0mg-N per litre.

[6] Atmospheric deposition directly to the surface of Wybunbury Moss has not been considered as part of this work and is the subject of a separate study.

Mitigation scenario	Description
Change from maize to cut grass (silage)	Change from maize crop to grass cut for silage. Grass is assumed to receive dairy slurry at 46.5 tonnes per hectare (total N 140kg per hectare). Farmscoper predicts a resulting nitrate loss of 40.8kg-N per hectare.
Change from maize to extensive grass	Change from maize crop to extensive grass, managed as per the 'Pasture 2' scenario (see Tables 3.2 and 5.1), which is predicted to leach at 1.7mg-N per litre.
Change from maize to woodland (reversion)	90% reduction in nitrate leaching (Newell Price et al. 2011)

Table 7.2 Results from mitigation or alternative land use scenarios

Mitigation scenario (maize field)	Nitrate-N concentration (mg-N per litre)	
	Maize field	Whole northern catchment
Establish cover crop in autumn	17.3	5.8
Change from maize to winter wheat	9.0	4.1
Change from maize to cut grass (silage)	12.0	4.6
Change from maize to extensive grass	1.7	2.4
Change from maize to woodland (reversion)	2.7	2.6

These mitigation scenarios will have associated costs. Farmscoper estimates the cost of establishing cover crops at £63 per hectare, giving an estimated cost of £271 per year to establish cover crops in a field of 4.3ha.

On the assumption that the maize is used for cattle feed, growing winter wheat rather than maize would require the farm business to purchase in maize silage from elsewhere (assuming that there was no option to relocate the maize crop outside the Wybunbury catchment area). Based on data from Nix (2016), the gross margin on feed wheat (average yield) is £657 per hectare, while the cost of buying in maize (standing crop) is £750 to £920 per hectare. Taking the average figure of £835 per hectare for a maize standing crop, this change would therefore incur a cost of £178 per hectare, or £765 per year for an area of 4.3ha. This figure is an underestimate as it does not include the costs of maize harvesting and transport operations.

None of these scenarios is predicted to achieve the target catchment average water quality of 2mg-N per litre (Table 7.2). Even if the maize field were managed as per the ‘Pasture 2’ scenario (meaning that all modelled land in the catchment except for the 1.6ha wheat field is predicted to leach at a concentration below 2mg-N per litre), the catchment average concentration of nitrate in soil drainage remains above this threshold.

This implies that, to meet water quality targets at the site, it would be necessary to revert all arable land in the catchment (both maize and wheat) to very extensively grazed or zero-input grassland, or a similar very low leaching land use.

8 Conclusions

This case study used the ADAS Farmscoper to model land management scenarios in order to consider the source apportionment of nitrate to Wybunbury Moss. Potential mitigation options have been considered to reduce nitrate loading, based on a target nitrate concentration of 2mg per litre.

- The groundwater catchment to the north of the site was estimated based on previous conceptual modelling of the site, with a small surface water catchment area to the south.
- Based on land use in this catchment area, a number of potential point and diffuse sources of nitrate were identified that could contribute to nitrate loadings in shallow groundwater draining towards the site from the north.
- Land use in the catchment is predominantly extensively grazed grass. Two arable fields were identified; one of these, due north of the site, has recently been under maize.
- Farmscoper was used to simulate nitrate leaching from agricultural land in the catchment. Nitrate leaching from point sources was estimated based on the findings of a literature review prepared for the Environment Agency, SEPA, the Northern Ireland Environment Agency and the Environmental Protection Agency in Ireland (Entec 2010).
- The results of the modelling work suggest that agricultural land to the north of the site is contributing to elevated nitrate concentrations in shallow groundwater along the northern boundary of the site.
- The maize field in particular is predicted to leach relatively high concentrations of nitrate in soil drainage. This prediction is supported by elevated observed nitrate concentrations just to the south of the field.
- Concentrations of nitrate in soil drainage from the other agricultural land in the catchment are lower, but still in excess of target water quality standards for the site.
- There may also be nitrate reaching Wybunbury Moss from agricultural grassland in the surface water catchment to the south of the site, although this is likely to be restricted to surface water pathways along the southern edge of the site.
- The nitrate loading from the southern surface water catchment is estimated at 21–24% of the loading from the northern groundwater catchment.
- Point sources and other non-agricultural sources of nitrate are not thought to be significant at the catchment scale.
- Simulation of potential mitigation methods against nitrate leaching in the catchment suggests that it would not be possible to achieve

target water quality at the site through changes to nutrient management of the maize crop alone. Changes to use of all arable land (maize and wheat) would be required, along with low stocking rates on grazed grassland.

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List of abbreviations

BGS	British Geological Survey
GIS	geographical information system
GWDTE	groundwater-dependent terrestrial ecosystem
LU	livestock units
SNS	Soil Nitrogen Supply
SSSI	Site of Special Scientific Interest

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