Environment Agency

An approach to terrestrial nitrate source apportionment for wetlands

Chief Scientist's Group report

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Professor Doug Wilson
Chief Scientist

Executive summary

This report presents a suggested approach to carrying out nitrate source apportionment calculations at groundwater-dependent terrestrial ecosystem (GWDTE) sites, and identifying suitable mitigation measures. The approach is also applicable to safeguard zones and water protection zones where the receptor is failing due to elevated nitrate in water. It is based on the work carried out as part of project SC160010 ‘Nitrogen source apportionment study at Two Groundwater Dependent Terrestrial Ecosystems (GWDTEs)’.

The purpose of the project was to identify and trial a ‘transferable approach’ to nitrate source apportionment at wetland sites. Approaches were trialled at 2 wetland sites: Newbald Becksies SSSI in east Yorkshire and Wybunbury Moss SSSI in Cheshire. The guidance covers not just the tools used in the 2 example studies, but also other approaches drawn from wider experience.

Nitrate source apportionment at a wetland site broadly comprises the following steps:

1. Review of the catchment conceptual model and catchment definition
2. Identification of potential sources and pathways of nitrate in the catchment
3. Collation of catchment data
4. Deployment of an appropriate methodology to predict nitrate leaching from sources in the catchment
5. Validation and interpretation of results

Having a robust conceptual model is crucial to developing a reliable estimate of source apportionment. In particular, it is necessary to understand the sources of water contributing to the site, and the size and location of the catchment area. These factors will define the sources and pathways of nitrate that could affect the site, and so without this information, it is not possible to identify or apportion nitrate sources reliably. The report discusses the most important aspects of a wetland conceptual model relevant to a source apportionment study and outlines some tools and techniques that may be of use in catchment definition.

A number of tools are available to assist with estimating nitrate leaching from a variety of sources that may be present. For many point sources such as septic tanks or sewage discharges to ground, literature estimates of typical nitrate loadings are available. For diffuse sources such as leaching from agricultural land, however, it is often necessary to use models. This project considered 2 tools that estimate nitrate leaching from agricultural land: the ADAS Farmscoper model and the Environment Agency’s Nitrate Leaching Tool. Both can be used to estimate nitrate leaching from various crops and land uses, and both can be used to assess the effectiveness of mitigation measures. There are some differences between them which may make one or the other more suitable for use in a particular context. Ultimately, however, the choice of approach is likely to be governed by the availability of data, particularly for larger catchments. Whenever possible, model results should be compared with observed site-specific data.

To maximise cost-effectiveness, programmes of measures should be targeted at those areas within the catchment that contribute the highest nitrate load to the wetland site. However, there may also be benefit in targeting areas that have rapid pathways to the site, since these may provide a ‘quick hit’ reduction in nitrate concentrations. Reductions in nitrate inputs in parts of the catchment with longer travel times may take years to be realised in improved water quality at the site.

The results from the 2 case studies are presented in separate reports.

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- Gareth Farr (British Geological Survey)

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1 Introduction

This report describes a suggested approach to carrying out nitrate source apportionment calculations at groundwater-dependent terrestrial ecosystem (GWDTE) sites and the identification of suitable mitigation measures. It is based on the work carried out for Environment Agency project SC160010 'Nitrogen Source Apportionment Study at Two Groundwater Dependent Terrestrial Ecosystems (GWDTEs)'.

1.1 Overview of the project

The purpose of the project was to identify and trial a 'transferable approach' to nitrate source apportionment at wetland sites, that is:

- to explore the tools and techniques available
- to establish some guiding principles towards establishing the most appropriate approach for a particular site

The outputs from the project are based on example nitrate source apportionment studies for 2 wetland sites that are currently failing target nitrate concentrations (UKTAG 2012a). The sites investigated were:

- Newbald Becksies Site of Special Scientific Interest (SSSI) in east Yorkshire (Environment Agency 2018a)
- Wybunbury Moss SSSI in Cheshire (Environment Agency 2018b)

The work included consideration of the tools available to contribute towards a wetland source apportionment study not only for specific application to these sites but also with a view to how they might be applied elsewhere.

The guidance covers not just the tools used in the 2 example studies but also other approaches drawn from wider experience. Although the approach taken for each site was similar, it was necessary to take their different hydrogeological conditions into account. Having a robust conceptual model, particularly in terms of understanding the catchment area contributing to the wetland, was found to be crucial to producing relevant outputs.

1.2 Why do a nitrate source apportionment?

The source apportionments carried out in this project for Wybunbury Moss SSSI and Newbald Becksies SSSI were produced to provide supporting evidence towards identifying appropriate programmes of measures to address high nitrate concentrations in the wetlands – that is, a failure to meet the target concentrations set by the UK Technical Advisory Group for the Water Framework Directive (UKTAG).

Both wetlands are identified as groundwater-dependent terrestrial ecosystems (GWDTEs) and are therefore linked to the condition of the underlying groundwater body for Water Framework Directive classification purposes. It is anticipated that similar exercises may be carried out at other sites where high nitrate concentrations are resulting in the failure of the underlying groundwater body and/or causing a designated wetland site to be in unfavourable condition.

A source apportionment exercise aims to:

- identify potential sources of nitrate that could be contributing to nitrate concentrations at the wetland
- quantify the contributions from each of those sources

These objectives recognise that nitrate may originate from a potentially wide range of diffuse or point sources across a catchment, which may make it difficult to identify or justify measures to reduce nitrate concentration. A source apportionment may help to target measures by identifying the predominant sources and quantifying the extent to which various measures could reduce nitrate loading from those sources.

Carrying out a source apportionment requires a team with the appropriate skills and experience necessary to gain an understanding of:

- the site's hydrological and hydrogeological conceptual model (that is, understanding the hydrological pathways by which nitrate could reach the wetland)
- the current and historic land use and management practices within the wetland's catchment area

This report discusses these technical requirements in more detail and sets out how they can be achieved in practice.

1.3 Report structure

The most important stages in carrying out a source apportionment assessment are addressed in turn in the following sections.

- Section 2 explains how to develop a conceptual understanding of the site (including catchment definition).
- Section 3 considers how to select an appropriate numerical approach.
- Section 4 describes how to collate the input data.
- Section 5 sets out how to interpret the results and develop a programme of measures.

This suggested approach is not prescriptive.

The degree of effort that should be expended on each stage will depend on:

- the level to which the site has previously been studied
- the confidence attached to any existing conceptual model
- the size of the site's catchment

- the data available

Professional judgement should be used in deciding the most appropriate approach at any given site.

2 Review of conceptual model and catchment definition

2.1 Overview

Having a robust conceptual model is crucial to developing a reliable source apportionment. In particular, it is necessary to understand:

- the sources of water contributing to the site
- the size and location of the catchment area

These factors will define the sources and pathways of nitrate that could affect the site. So without this information, it is not possible to reliably identify or apportion nitrate sources.

This section discusses the most important aspects of a wetland conceptual model that are relevant to a source apportionment study. It does not provide a comprehensive guide to 'producing a hydrogeological conceptual model of a wetland', which is addressed elsewhere (see, for example, Environment Agency 2004, Environment Agency 2009, Whiteman et al. 2009).

It is expected that at least a basic conceptual understanding will already exist of any GWDTE at which a source apportionment is being considered; some sites may have had received more detailed investigations. The 2 sites studied for this project (Wybunbury Moss and Newbald Becksies SSSIs) have both been subject to a range of previous investigations with the aim of understanding their hydrogeological conceptual model and nitrate concentrations. Even in those cases, however, it was found that the conceptual model needed to be revisited in order to provide the right kind of information to inform the source apportionment.

2.2 Key features of the conceptual model

The hydrological and hydrogeological information required for a reliable source apportionment will contribute to answering the question: 'What are the sources and pathways of water (and hence potentially of nitrate) contributing to the wetland?'.

The key questions are:

- Are there surface water sources to the site? This may include diffuse surface run-off.
  - If there is surface water within or adjacent to the site, does it actually interact with the ecological features of interest? For example, a boundary drain that carries water around the edge of a site may prevent surface water from actually contributing to the wetland itself.
  - For any surface water sources that do contribute, what is their catchment area?

- Which aquifers contribute groundwater to the site? What is their catchment area?

A source apportionment may differ in focus from a more common wetland conceptual modelling exercise, which would generally focus at, and within, the boundary of the wetland. For the purpose of the source apportionment, understanding how the surrounding area contributes to the site is of the greatest importance. At more complex sites, however, it is possible that different parts of the site may be affected by different sources and pathways of water supply (and hence of nitrate). In such cases, developing a more detailed conceptual model for within the site (for example, using the references identified in Section 2.1) may be important to understanding the spatial variability of source apportionment.

A basic approach to source apportionment will assume that the whole catchment area contributes equally to the wetland. But particularly for larger catchments, any evidence as to which parts of the catchment contribute the most flow, and the relative significance of groundwater and surface water pathways, can be valuable in targeting measures.

2.3 Catchment delineation

The catchment to a GWDTE may consist of 2 catchments of potentially differing extent:

- a surface water catchment
- a groundwater catchment

The surface water catchment can usually be defined simply on the basis of topography as the boundary of the area from which water will flow by gravity onto the site. It is possible to use ArcView 'HydroTools' to process a topographical watershed for each GWDTE provided the site boundary is known and a DTM (Digital Terrain Model) is available. However, it is possible for catchments to have been artificially modified by transferring water from outside the natural catchment area. As noted above, it also needs to be established to what extent any surface water flow actually interacts with the interest features at the site: in some cases drains or other watercourses may divert surface run-off away from the wetland habitats.

In contrast, the groundwater catchment may not necessarily be topographically defined. The groundwater catchment to the site defines the part of the aquifer(s) or shallow subsurface from which subsurface flow to the site originates. Water flows into the catchment either as recharge to groundwater or via some other boundary condition such as leakage from a stream. It then flows along subsurface pathways to the site. If more than one aquifer contributes flow to the site, there may be more than one groundwater catchment.

In some cases, only groundwater pathways will be relevant. But if there is significant generation of surface run-off, and that run-off has the potential to reach the GWDTE wetland habitats, then both catchments will need to be defined. Figure 2.1 illustrates conceptual flow pathways to a groundwater-dependent wetland site.

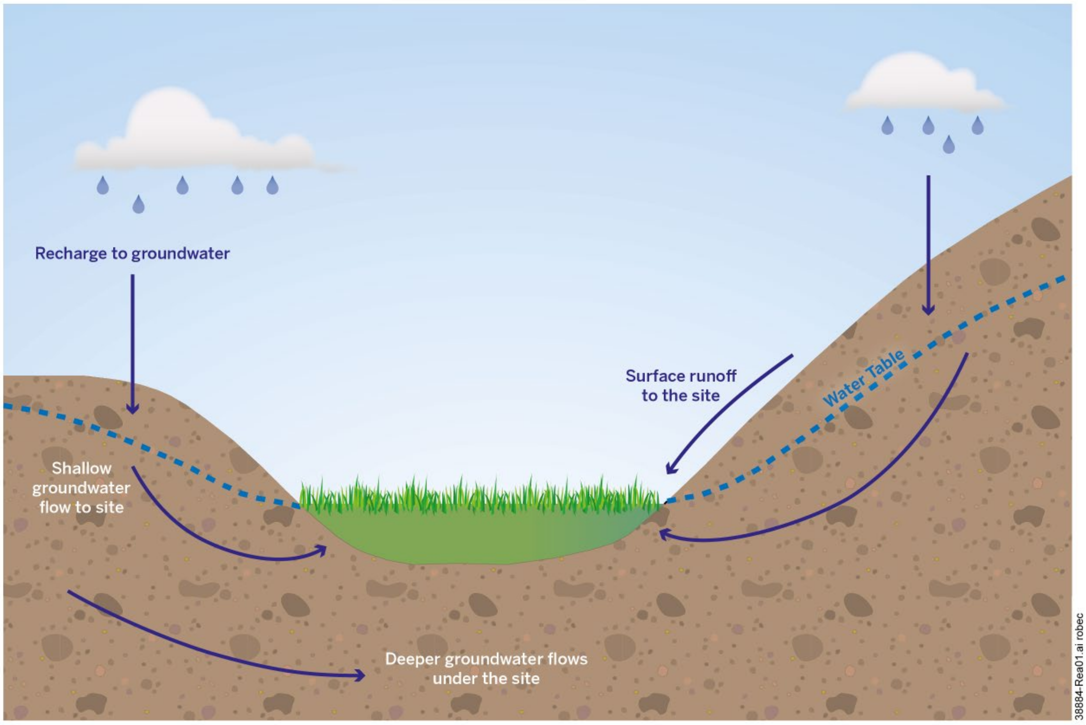

Figure 2.1 Conceptual flow pathways to a groundwater-fed wetland site

2.4 Possibly useful tools

A number of techniques can be used to assist in the definition of a groundwater catchment to a site. These are outlined below.

2.4.1 Water balance calculations

If the volume of water discharging from the site is known (for example, because it flows into a discharging stream which is gauged), then a water balance calculation can give an indication of the approximate area of the groundwater catchment:

$$Q = \frac{R.A}{1{,}000} \qquad (2.1)$$

where:

Q = stream discharge (m^3 per year)

R = rate of recharge to groundwater (mm per year)

A = area of groundwater catchment (m^2)

Recharge may be estimated as 'rainfall minus evapotranspiration'. Ideally this will be carried out with data from a number of years so as to compare the results over time: it is possible for the catchment area to vary over time as hydrological conditions change.

Once the area is known, the catchment boundary may be estimated, extending up the groundwater gradient to the appropriate extent (that is, in the opposite direction to regional groundwater flow). Unless other hydrogeological information is available, topography is likely to be used as a guide to the shape of the catchment.

If there are any public water supply abstractions nearby, the orientation and shape of their source protection zones can provide a guide to regional groundwater flow and the catchment to the GWDTE.

2.4.2 Regional groundwater models

Many of the major aquifers in England have regional groundwater models and these can be used to indicate groundwater flow in the vicinity of wetland sites. The use of tools such as FlowSource (Black and Foley 2013) may be particularly useful for directly predicting groundwater catchments. Given output from a regional model, FlowSource calculates the fraction of the flow in each model cell that will ultimately reach a specified destination (for example, the model cell hosting a GWDTE). All model cells for which this quantity is non-zero are therefore in the catchment to the wetland.

The calculations can be carried out for every stress period in the model representing a range of hydrogeological conditions. They therefore also provide an indication of how groundwater catchments vary with fluctuations in groundwater levels, both in extent and potentially also in orientation.

While some caution should be exercised when interpreting the results of such calculations, particularly if the wetland and its catchment area have not been specifically considered during model refinements, this provides a tool for identifying both the total catchment area and the most important key contributing areas (that is, some parts of the catchment will contribute more flow, and more consistently, than others).

2.4.3 Historical incidents

Any recorded historical pollution incidents will provide evidence of subsurface pathways, where they have been shown to have had an impact on a GWDTE and the source is known.

2.4.4 Site-specific investigations

A range of other site investigation approaches will contribute to a GWDTE conceptual model and may provide information relevant specifically to a source apportionment exercise. These might include:

- flow and water level monitoring
- water quality monitoring
- ecological surveys
- coring and geophysical surveys

These approaches are discussed in more detail in other reports such as Farr et al (2018, 2014) and Brooks et al (2009).

2.5 Conceptual model

The complete conceptual model of the catchment to a GWDTE will include:

- an indication of the relative significance of all flow pathways of surface and subsurface flow to the site
- the area from which those flows are sourced

However, it does not need to be a numerically quantified model of flow volumes in each pathway.

It is then necessary to identify all potential sources of nitrate in the catchment that could contribute to the GWDTE. Figure 2.2 shows some common pressures and monitoring options at GWDTEs. Again, it is not necessary at this stage to numerically quantify nitrate loadings from these sources but merely to confirm their presence.

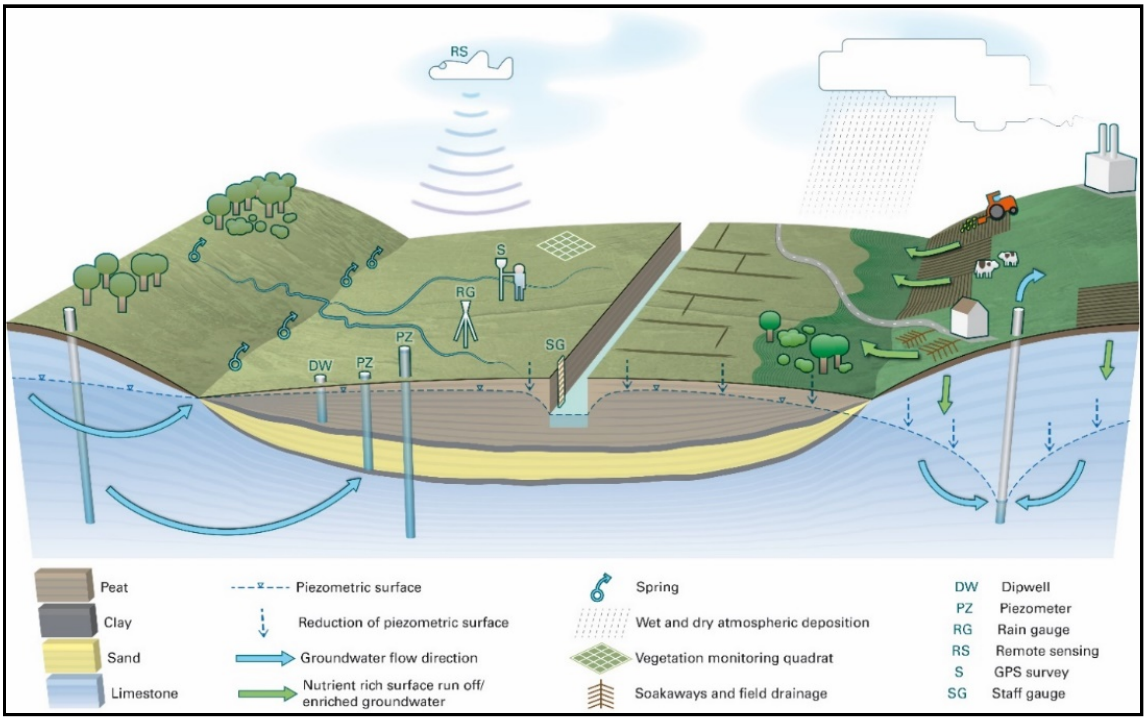

Figure 2.2 Common pressures and common monitoring options at GWDTEs in England and Wales © British Geological Survey

3 Overview of the Nitrate Leaching Tool and Farmscoper

3.1 Introduction

The definition of the groundwater and surface water catchments to a site will also define the potential sources of nitrate that may contribute to the site. The numerical quantification of each of these sources – and hence nitrate source apportionment – can then be carried out, typically using a simple model to quantify the nitrate loading from each identified source.

For many sources, the nitrate loading can be estimated from literature values and simple calculations. The nitrate loading from a sewage discharge to ground, for example, can be estimated on the basis of typical water use per household and literature values for the nitrate concentration in effluent from various different treatment types. Similarly, literature values are available for typical nitrate concentrations in landfill leachate, as functions of the type and age of waste. A literature review of nitrate loadings from various sources is included in Entec (2010).

For some sources, and in particular diffuse sources such as soil drainage from agricultural land, estimation is more difficult and models are typically used. This section provides a brief overview of the main points of 2 such tools:

- the ADAS Farmscoper model
- the Environment Agency's Nitrate Leaching Tool

3.2 Farmscoper

Farmscoper (www.adas.uk/Service/Farmscoper) is a decision support tool developed for the assessment of nitrate loads at farm scale and the impacts of mitigation methods on those nitrate loads. Although the tool can quantify loads of multiple pollutants, the focus here is on nitrate and so this discussion is confined to that aspect of the tool.

The baseline model is derived from the national scale ADAS NEAP-N model. The NEAP-N algorithms were applied to multiple combinations of soil series and climate characteristics applicable to the whole of England and Wales to predict nitrate losses from a number of sources via a number of pathways. From these, area-weighted average predicted nitrate losses were calculated for each of 3 soil types and 6 climate zones. Full details of the tool are provided in Gooday and Anthony (2010).

Farmscoper allows the user to define a modelled farm on the basis of livestock, cropping, and fertiliser and manure management. A suite of basic farm types are available, which may be customised as required. Pollutant losses are estimated at farm scale by:

- source area (arable, grassland, rough grazing)

- type (soil, fertiliser, manure)
- pathway (run-off, leaching)

The tool further allows the assessment of mitigation measures against nitrate pollution, based on information from the Diffuse Pollution Inventory (DPI) User Manual (Newell Price et al. 2011). Measures may be assessed individually or in combination. Finally, the costs and effectiveness of measures or combinations of measures can be estimated and optimal suites of measures derived, based on assumed levels of prior implementation.

Some caution is required when applying the tool at small scales, where local practices and environmental conditions may start to differ significantly from the national averages on which the tool is based. This is discussed in detail in ADAS (2017).

3.3 Nitrate Leaching Tool

The Nitrate Leaching Tool predicts average annual concentrations of nitrate leaching from agricultural land and selected potential point sources on farms based on farm-specific management practices. It is intended to be used to:

- estimate typical nitrate leaching from agricultural land at the field scale in order to identify high risk fields and practices
- assist in engagement by the Environment Agency with farmers and growers in order to reduce nitrate leaching to groundwater

The calculation methods in the tool are simple and do not simulate every detail of nutrient management. The tool therefore provides a rapid assessment of nitrate leaching risk under typical management conditions rather than a detailed, mechanistic calculation of soil nitrogen cycling.

For arable and horticultural crops, where a final yield is normally known, the Nitrate Leaching Tool calculates residual nitrogen using a simple soil balance approach.

For grassland, where crop yield is not normally known and the cycling of nitrogen through the system is potentially complicated by grazing animals, the tool uses an approach based on the N-Cycle model (Scholefield et al. 1991) to predict nitrate leaching directly.

The Nitrate Leaching Tool is accompanied by a geodatabase of field-scale data which can be interrogated by a geographical information system (GIS) to provide base data for a selection of fields to be simulated. These base data include information on field area, soil properties and hydrologically effective rainfall (HER). To complete the simulation, the user needs to add information on cropping and nutrient management – although default values of most parameters can be applied if detailed information is not available.

The tool provides predictions of nitrate loads and concentrations in soil drainage for each field individually, or averaged across a crop rotation where applicable. It can also be used to assess the effectiveness of mitigation measures against nitrate leaching, based on information from the DPI User Manual (Newell Price et al. 2011). Measures can be assessed individually or in combination.

The Nitrate Leaching Tool can also be used to provide estimates of nitrate leaching from agricultural point sources such as manure heaps or slurry stores.

3.4 Other Environment Agency tools

Another simple spreadsheet tool is available to the Environment Agency to estimate nitrate loadings to groundwater at catchment scale. The N&P Loading Spreadsheet has much in common with the Nitrate Leaching Tool in the methods used to estimate nitrate leaching from agricultural land. However, it can also estimate nitrate loadings from a variety of non-agricultural and urban sources such as sewer leakage and sewage discharges to ground. Intended for use at catchment scale, the spreadsheet does not include the field-scale geodatabase that accompanies the Nitrate Leaching Tool. Instead it requires information on bulk land use and crop areas, as well as urban population.

3.5 Summary

The simplest approach to estimating the nitrate loading from each source in a catchment is to use a decision support tool, of which a number are available. This section focuses on the ADAS Farmscoper tool and the Environment Agency's Nitrate Leaching Tool.

Both can be used to estimate nitrate leaching from various agricultural sources, but there are some differences between them which may make one or the other more suitable for use in a particular context. Ultimately, however, the choice of approach is likely to be governed by the availability of data, particularly for larger catchments.

- Both tools require the user to enter basic field or farm data such as the area of each crop, livestock numbers and nutrient management data (see Section 4).
- The Nitrate Leaching Tool uses an accompanying geodatabase of field data to enable leaching predictions at field scale. Farmscoper is based around a farm unit.
- The Nitrate Leaching Tool provides default values for most required input data (including default fertiliser rates for arable crops). Although the same had not previously been available for Farmscoper, the Environment Agency is working to produce pre-populated Farmscoper datasets to make scenario testing easier for Natura 2000 diffuse water pollution plan (N2K DWPP) sites.
- Farmscoper predicts nutrient losses by type and pathway. The Nitrate Leaching Tool only provides predictions of nitrate leaching in soil drainage.
- The Nitrate Leaching Tool can predict nitrate leaching from some agricultural point sources as well as diffuse leaching from agricultural soils.
- Both can be used to assess the effectiveness of mitigation measures, either individually or in combination.

- Farmscoper can also predict the costs and effectiveness associated with measures or suites of measures.

4 Input data requirements for nitrate leaching calculations

4.1 Overview

This section discusses the minimum data requirements of the Nitrate Leaching Tool and Farmscoper models to enable predictions of nitrate leaching (that is, the basic function of both models). Additional data will be required to use additional model functionality such as the assessment and optimisation of mitigation measures and farm economics. However, this functionality differs significantly between the models (and not all such functionality is available in the Nitrate Leaching Tool), hampering inter-tool comparison.

Both models aim to simplify the process of data entry by either providing multiple choice data entry options (for example, Farmscoper offers a choice of rainfall bands, rather than requiring the user to enter a value for annual rainfall), or default typical values for variables (for example, the Nitrate Leaching Tool crop templates offer a complete model description of each major crop).

The most important difference between the Nitrate Leaching Tool and Farmscoper is one of scale. The Nitrate Leaching Tool is a field-scale tool, and all data input apply to an individual field. Of course, many data will not vary between fields on a farm (for example, soil type, HER), but values can be varied individually as required. Farmscoper operates at farm scale, meaning that individual crops and land uses are modelled rather than individual fields. Results are provided for land use categories (arable, grassland and so on) rather than individual fields.

4.2 Farmscoper

Summaries of the farm-scale information required by the Farmscoper model and the additional information required for each livestock type or crop type are given in Table 4.1 and Table 4.2 respectively.

Table 4.1 Farm-scale input data

Input data	Comment
Rainfall	Multiple choice from 6 bands.
Soil type	Multiple choice from 2 options: ‘free draining’ or ‘other’.
Drainage status	If soil type is not ‘free draining’: multiple choice from drained or not drained, for arable and grassland.
Farm type	Select a model farm type from a dropdown list, or ‘blank farm’. This provides a template farm structure (areas of various crops and livestock numbers), which can then be customised.

Input data	Comment
Field operations (optional)	Each model farm type has a default set of field operations associated with it (for example, rolling, discing, ploughing). These can be changed if required.
Landscape data (optional)	Proportion of fields next to watercourses or with organic soils, and information on field boundary types (walls, hedges and so on). Default values are provided, which can be changed if required.
Manure management and animal husbandry data (optional)	Multiple choice options for the management of dirty water, extensive or intensive grazing, whether livestock have access to watercourses, or cross watercourses. Default values are provided, which can be changed if required.

Table 4.2 Field-scale input data

Input data	Comment
Crop data (data entered for each crop present)	
Area of crop grown (ha)	A fixed list of crop types is supported.
Inorganic fertiliser applied	
Organic fertiliser applied	The proportion of manure generated on the farm that is spread to the crop. Individual figures for each of 6 manure types are required.
Livestock data (data entered for each livestock type present)	
Number of livestock	Detailed subcategories are included. For example, for beef cattle the user must enter information for 7 subcategories.
Manure management	Proportion of livestock manure that is managed as slurry (for each subcategory of livestock type).
Details of grazing and manure management (optional)	Detailed information on manure nutrient content, livestock grazing period and so on. Default values are provided, which can be changed if required.

4.3 Nitrate Leaching Tool

Table 4.3 provides an overview of the Nitrate Leaching Tool base data. These data can be exported from the GIS geodatabase that accompanies the tool and do not need to be entered directly by the user. The database values can be overridden by the user if required. Data are required for each field.

Table 4.3 Nitrate Leaching Tool base data

Input data	Comment
Field area	Agreed area (ha)
Soil depth (mm)	Based on soil series data (NSRI)
Soil stored water (field capacity) (mm)	Based on soil series data (NSRI)
Hydrologically effective rainfall (mm)	Believed derived from NEAP-N
Standard percentage run-off (%)	Based on soil series data (NSRI)
Rural Payments Agency land use	A broad categorisation, not a crop type

Notes: NSRI = National Soil Resources Institute

In addition, the user is required to enter crop or livestock and management data for each field (Table 4.4).

Complete crop templates are provided which include default values for all input data, so the user only has to enter a crop type for each field. Alternatively, any or all of the default values may be overwritten as necessary. The minimum data requirement for each field is therefore simply a crop type or livestock type, with everything else only required if default values are not to be used.

Table 4.4 Nitrate Leaching Tool field data

Input data	Comment
Crop type	Selected from a list in a user form.
Uncultivated margin (m)	
Inorganic fertiliser applied (kg per ha)	
Soil Nitrogen Supply (SNS) Index	
Manure application type and rate	Selected from a list in a user form. Up to 2 applications may be specified. The Nitrate Leaching Tool also requires manure application timing information, although this is not actually used by the tool.
Crop data (for arable fields only)	
Crop yield (tonnes per ha)	Tables of literature values are provided.
Crop N content (%)	Tables of literature values are provided.
Livestock data (for grazed fields only)	
Livestock type	Selected from a list in a user form.
Stocking rate (low/medium/high)	Selected from a list in a user form.

Input data	Comment
Grazing period (months)	

5 Interpreting model output and developing programmes of measures

5.1 Interpretation of model output

Typically, source apportionment models aim to predict nitrate loads and concentrations in soil drainage from agricultural land. Combined with knowledge of the areas of land under each major crop and livestock numbers, a catchment-scale nitrate budget can then be constructed which quantifies the nitrate loading to a receptor from each major source in the catchment.

If measurements of nitrate concentrations in shallow groundwater at the receptor are available, it may be possible to compare measured and predicted nitrate concentrations so as to provide additional confidence in the model results. However, some caution is necessary, as there will be some sources of uncertainty in the model predictions. The following points should be considered.

- Predictions of nitrate concentrations in soil drainage are principally sensitive to assumptions around soil properties and nutrient management. The former in particular are often not well-known.
- Most models aim to predict nitrate leaching in a ‘typical’ year, with average rainfall and typical crop yields. There will always be some inter-annual variation not captured by the models.
- Given input data applicable to the present day, source apportionment models will predict leaching in present day conditions. Historically, land use and fertiliser rates could have been quite different. Depending on the travel times of water in the catchment, the nitrate concentrations observed today could be the result of soil leaching years or even decades ago.
- Any uncertainty in the conceptual model will result in uncertainty in nitrate sources, and potentially, the omission of sources resulting in inaccuracy in the resulting source apportionment calculations.
- The source apportionment approaches discussed in Sections 3 and 4 effectively treat a GWDTE as a point receptor, implicitly implying that all parts of the GWDTE interact with the catchment similarly, and that groundwater and surface water sources will be fully mixed to provide a consistent concentration across the site. In reality, this is unlikely to be the case. More detailed conceptual knowledge of the site itself and its hydro-ecological variability is likely to be necessary to compare observed and modelled concentrations, and subsequently to interpret the source apportionment results in terms of the impacts on the wetland habitats.

However, even if there is only moderate agreement between observed and predicted nitrate concentrations at a site, source apportionment models can in general still provide valuable information. In particular, comparison of predicted leachate quality between the various crops and land uses in a catchment can give an indication of which present the highest risk and hence where programmes of measures should be targeted.

5.2 Nitrate thresholds and standards

It is important to carefully consider which nitrate standard or threshold to use when assessing whether waters and/or protected areas such as a wetlands are being adversely affected by nitrates or when determining an acceptable target for nitrate reduction measures.

Nitrate standards, thresholds and other criteria are complex and vary across the various receiving environments and depending on the receptor being protected such as a drinking water abstraction, river or wetland. However, they can be broken down into three main groupings as follows.

- Standards or thresholds for protecting human health as regards tap water and raw drinking water sources (ground and surface water). The current UK and EU drinking water standard for nitrate is 50 mg/l as NO3 based on the World Health Organisation's guidelines. This standard is also used in the Nitrate Pollution Prevention Regulations 2015 to identify if groundwater is polluted or at risk of pollution. However more stringent management thresholds of 37.5 mg/l as NO3 are used for general groundwater quality and drinking water classification tests under the Water Framework Directive (WFD) (UKTAG, 2012c).

- Standards or thresholds associated with eutrophication and thus ecological health of different categories of waters such as lakes, estuaries and coastal waters. These are typically defined in terms of milligrams of nitrate per litre of water and are often used alongside biological thresholds for eutrophication. For GWDTEs nitrate thresholds range between 4 and 26 mg/l as NO3 (UKTAG, 2012b). This is significantly more stringent than the 50 mg/l nitrate drinking water figure.

- Critical loads for acidity, ammonia and eutrophication (nutrient nitrogen) from atmospheric deposition provide an estimate of exposure below which ecological impact is not thought to occur. Critical loads for atmospheric nitrogen deposition have been defined in Europe for a wide range of habitat types (see Bobbink & Hettelingh, 2011) and are presented as a range (e.g. wet heath 10-20 kg N ha-1 year-1). In the UK a single value within each range has been applied to nitrogen-sensitive habitats (Hall et al., 2015) however, site-based assessments may use the lower end of the critical load range, or take account of the whole range.

The choice of nitrate threshold may significantly alter the range of mitigation options available, particularly for more stringent targets, and could have cost implications for those implementing the measures depending on the delivery mechanism. It is recommended that ecologist advice is sought on the most suitable threshold to use as this may vary depending on the receptor of interest and scale (site, habitat or species).

5.3 Programmes of measures

To maximise cost-effectiveness, programmes of measures should be targeted at those areas within the catchment that contribute the highest nitrate load to the wetland site. However, there may also be benefit in targeting areas that have rapid pathways to the site, since these may provide a ‘quick hit’ reduction in nitrate concentrations. Reductions in nitrate inputs in parts of the catchment with longer travel times may take years to be realised in the form of improved water quality at the site.

The following points should be taken into consideration when designing a programme of measures for nitrate mitigation at a wetland site.

- Applicability of measures – for example, there is little point proposing measures to improve manure management in a catchment in which little or no manure is used.
- Levels of prior implementation – there will be little benefit in proposing measures that have already been widely adopted.
- Measures will be most effective in those parts of the catchment that provide the most recharge to groundwater. The catchment conceptual model can help in informing this.
- Measures should be targeted at those crops or land management practices that are predicted to result in the greatest concentrations of nitrate leaching. However, it is important to ground truth model results by comparing them with farm data.

The Defra DPI User Manual (Newell Price et al. 2011) provides a description of over 80 mitigation methods against diffuse pollution from agriculture, including information on applicability, effectiveness and costs. In addition, there may be other local expertise such as Catchment Sensitive Farming officers who should be consulted when considering appropriate measures to reduce diffuse nitrate pollution.

6 Conclusions

Nitrate source apportionment at a wetland site broadly consists of the following steps:

1. Review of the catchment conceptual model and catchment definition
2. Identification of potential sources and pathways of nitrate in the catchment
3. Collation of catchment data
4. Deployment of an appropriate methodology to predict nitrate leaching from sources in the catchment
5. Validation and interpretation of results

Thorough review of the current conceptual understanding of the site is crucial to ensure that the catchment definition is based on the best available information. If the site's catchment is not identified correctly, then source apportionment calculations are unlikely to be correct.

The collation and review of catchment data (likely sources of nitrate, land management data, soil and climate data) can inform the most appropriate approach to source apportionment calculations. Many methods are available, but this report focuses on the ADAS Farmscoper model and the Environment Agency's Nitrate Leaching Tool, both of these predict nitrate leaching from agricultural soils.

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List of abbreviations

DPI	Diffuse Pollution Inventory
GWDTE	groundwater-dependent terrestrial ecosystem
HER	hydrologically effective rainfall
SSSI	Site of Special Scientific Interest
UKTAG	UK Technical Advisory Group

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