Nitrate modelling of Newbald Becksies SSSI wetland catchment

Chief Scientist's Group report

August 2019

Version: SC160010/R2

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Professor Doug Wilson
Chief Scientist

Executive summary

This report presents the results of source apportionment modelling of nitrate to the Newbald Becksies Site of Special Scientific Interest (SSSI). The assessment was carried out as part of the Environment Agency project 'Nitrogen Source Apportionment Study at Two Groundwater Dependent Terrestrial Ecosystems (GWDTEs)'.

Newbald Becksies SSSI is a small spring-fed wetland, which is currently in unfavourable condition due to nutrient enrichment. A range of information from site observations, geophysics surveys and the Environment Agency's regional groundwater model was used to improve the delineation of the catchment. This determined that:

- the contributing catchment area is likely to be primarily to the south of the catchment
- the extent of the catchment area varies over time, depending on the hydrological conditions

Nitrate source apportionment calculations, based on an assumed (but realistic) crop rotation, suggested that the dominant source of nitrate in the catchment is from arable land, particularly from oilseed rape and vining peas. Leaching rates from grassland and rough grazing land are predicted to be much lower.

Reductions in nitrate inputs to Newbald Becksies are most likely to be achieved through targeted programmes of measures aimed at reducing nitrate leaching from arable land in the area immediately to the south and east of the site and, in the medium to longer term, from the area further to the south of the site.

However, the reductions in nitrate leaching likely to be achievable through commercially viable mitigation measures associated with arable land are unlikely to be compatible with the target water quality for the site; only extensive grazing land or forestry are compatible with the low desired concentrations.

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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- Tony Martin (Yorkshire Wildlife Trust)
- Chris MacGregor, Iain Diack, 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 Newbald Becksies wetland catchment in east Yorkshire. 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).

Newbald Becksies is a Site of Special Scientific Interest (SSSI) that consists of a small spring-fed valley-head wetland. 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 this assessment is to contribute to the understanding of the sources of nitrate in the catchment and potential mitigation options.

This report:

- provides an overview of various strands of evidence contributing to the site’s conceptual model and in particular the catchment area contributing to the site
- identifies potential sources of nitrate within the catchment
- describes the derivation 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 Groundwater catchment conceptual model

2.1 Introduction

The hydrology and hydrogeology of Newbald Becksies have been considered in a number of previous studies and so are not discussed in full here. This review sought to confirm the sources of water contributing to the wetland interest features at Newbald Becksies, and specifically to confirm the extent of the groundwater catchment area from which that water is derived.

Although the Environment Agency had previously delineated groundwater and surface water catchment areas for Newbald Becksies, following initial discussions with the Environment Agency it was felt sensible to review the information that had led them to be delineated as they are.

The currently assumed catchment areas are shown in Figure 2.1. The groundwater catchment area is 8.63km^2. The groundwater catchment extends more widely than might be expected from a review of Ordnance Survey mapping. It extends beyond the topographic catchment to both the south and north, and encompasses springs to the south-west that might ordinarily be expected to be in a separate catchment. For the purpose of this study, particular considerations include:

- the total size of the groundwater catchment
- the extent to which the catchment area to the north may contribute to the springs and wetlands within the site

Information for the study was drawn from:

- the draft 2011 report, 'Refining River Basin Planning Through Targeted Investigations at GWDTE: Newbald Becksies' (Environment Agency 2011), which presented the results of a range of hydrogeological, geophysical, ecological and hydrochemical surveys
- Asset Management Plan 4 (AMP4) investigations by Yorkshire Water Services into the impact of public water supply abstraction at North Newbald on the Newbald Becksies SSSI
- a 2009 MSc dissertation by Debbie Wilkinson from Leeds University which produced a MODFLOW model of Newbald Becksies (also in relation to Yorkshire Water's abstractions) (Wilkinson 2009)
- results of geophysics surveys (resistivity, conductivity and ground penetrating radar) carried out to support the GWDTE investigations (TerraDat 2009)
- outputs from the Yorkshire Chalk groundwater model
- site-specific data used to derive an approximate water balance for the wetland

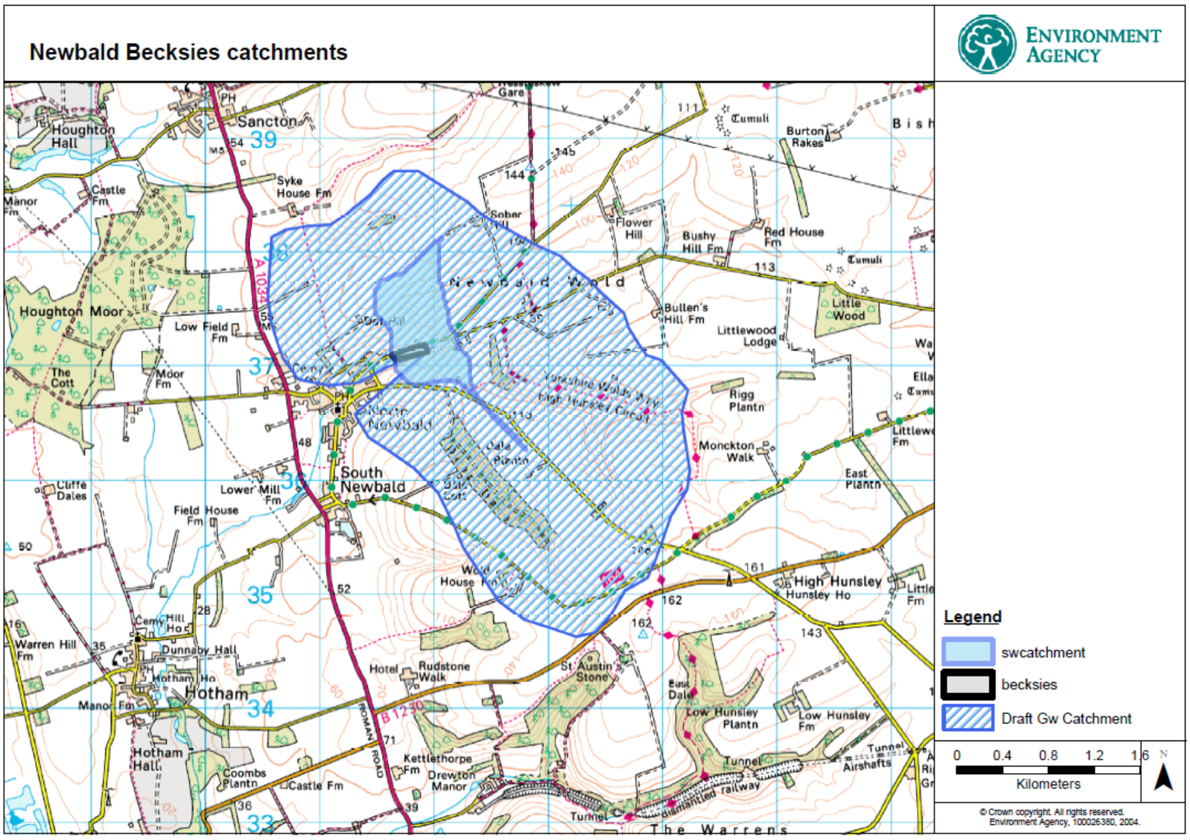

Figure 2.1 Surface water and groundwater catchments for Newbald Becksies SSSI as delineated by the Environment Agency

2.2 Overview of site conceptual model

- Flow into the site appears to be primarily from the hill to the south, with a line of springs emerging from the Chalk along the southern edge of the site. Flow is likely to be directly towards the site, with some deviation to the east due to the influence of the public water supplies (PWS). Once within the site, flow continues to be from south to north to the main channel running along the northern edge of the site.
- There is no observable flow from the north. This appears to be due to a French drain along the north side of the road, which intercepts flow from the north. The exception is during very high flows, when water can flow across the road into Newbald Becksies; scour marks from the edge of the road onto the site support this.
- Of 3 boreholes constructed for Yorkshire Water's AMP4 investigations, only the eastern-most one intersected Chalk, indicating that there is chalk present under the eastern end of the site. This contradicts the published 1:50,000 scale geology map, as does the apparent presence of a fault to the east of the site.

- Reverse particle tracking in MODFLOW suggests that the groundwater catchment area is 2km by 3km (Wilkinson 2009). Based on chemical analysis of water samples taken from the site, it appears that groundwater takes approximately a maximum of 20 years to travel to the wetland. (Wilkinson 2009, cited in Environment Agency 2011).

The various individual sources of information are discussed in more detail below.

2.3 MSc dissertation by Wilkinson (2009)

The dissertation was reviewed to examine its conclusions on catchment size. The initial modelling assumptions were based on the topographic catchment, the assumed edge of the Chalk to the west and the assumed fault to the east. However, Wilkinson (2009) stated that:

> 'It soon became apparent that the catchment area had to be larger than modelled. The model's water balance confirmed there was not enough recharge to supply the springs and abstraction wells; even when a value of 100% precipitation was used for recharge.' [Options were considered] 'To extend the model east, north and south; or to extend it north and south and use the impermeable fault as a groundwater divide,' [with the decision that] 'as the fault controls groundwater levels (according to groundwater levels at Newbald Becksies, Newbald Lodge, Dale Plantation and St Austin's Stone), it was opted to be used as a groundwater divide (no-flow boundary)'.

Wilkinson (2009) used reverse particle tracking to identify the refined catchment areas. The results were used to provide an approximate catchment area for the wetland (Figure 2.2).

Wilkinson (2009) also concluded that the fault lying to the east of Newbald Becksies is not completely impermeable, which might suggest that the catchment area could extend further to the east. The dissertation states that the fault was identified from local borehole logs but that it is not identified on any geological mapping.

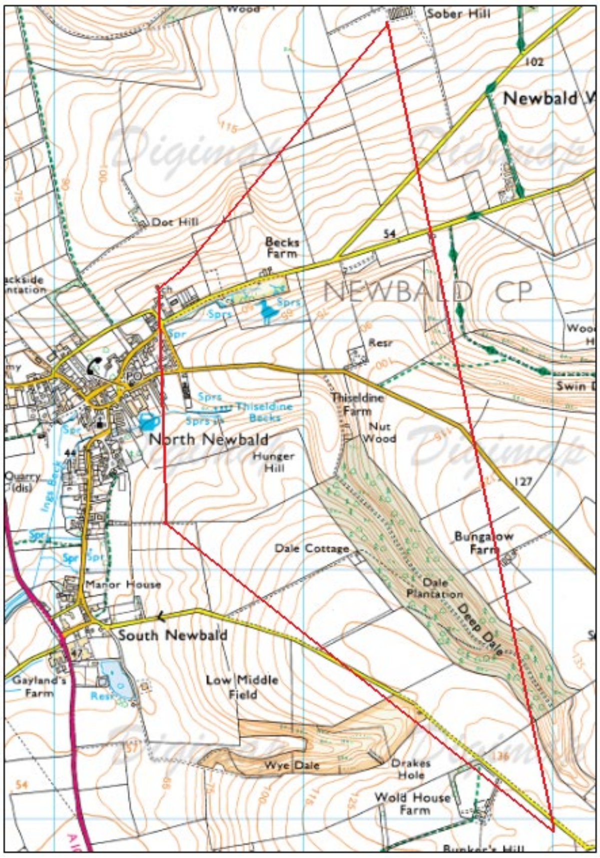

Figure 2.2 Drawn catchment area inferred from modelling findings

Source: Wilkinson (2009)

2.4 East Yorkshire Chalk regional groundwater model

Outputs from the East Yorkshire Chalk regional groundwater model were provided by the Environment Agency. The groundwater flow vectors are presented in Figure 2.3, which also shows the Environment Agency's groundwater catchment boundary.

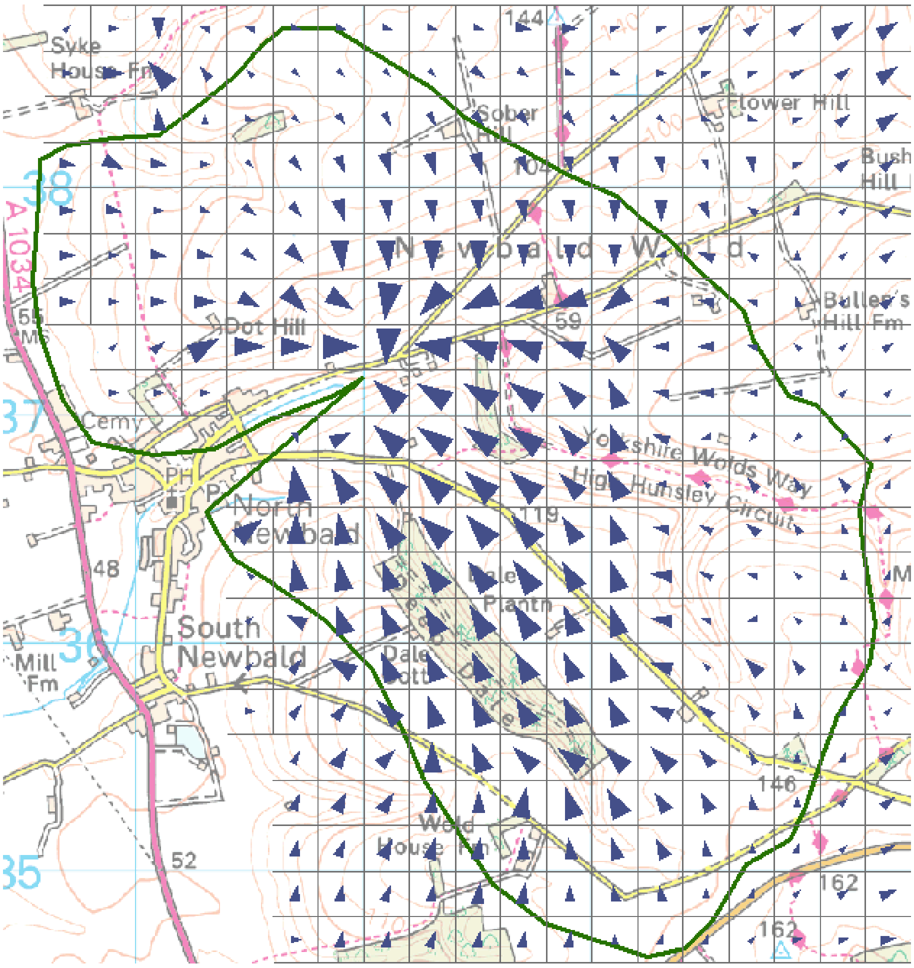

Figure 2.3 Recent Actual horizontal flow vectors (L2_11-04-2004, Yorkshire Chalk regional groundwater model)

Notes: For comparison, the green line denotes the boundary of the groundwater catchment as determined by the Environment Agency.

The directions of flow appear to be almost identical between the 'Recent Actual' (Figure 2.3) and 'Naturalized' (not shown) scenarios modelled,[1] although the volumes are slightly higher towards the Yorkshire Water abstraction in the Recent Actual scenario. The small difference between scenarios is likely to be due to the low recent actual use (stated as 0.4 million litres per day in ESI Consulting 2015) and suggests that the abstraction is not significantly influencing the catchment feeding Newbald Becksies. This conclusion differs from the findings of Wilkinson (2009), although the recent levels of abstraction represented in the regional model may be smaller than those considered by Wilkinson.

[1] Recent Actual and Naturalized are 'default' scenarios approved by the Environment Agency and used within its National Groundwater Modelling System (NGMS) project (https://publicwiki.deltares.nl/display/NGMS/National+Groundwater+Modelling+System+-++Home).

2.5 FlowSource analysis of the East Yorkshire Chalk regional model

The FlowSource tool was applied to the cell-by-cell flows calculated by the East Yorkshire Chalk regional groundwater model. FlowSource is a post-processing utility which analyses groundwater flow fields predicted by MODFLOW groundwater models. For a specific 'destination' model cell, FlowSource can be set up to calculate:

- the fraction of the flow through each model cell that will reach the destination cell (the 'Capture Fraction')
- the volume of water originating in each model cell (that is, added to the aquifer as recharge or stream leakage, or some other boundary condition) that will reach the destination cell (the 'Volume From')

Numerous other metrics can be calculated, but the two above are the main interest in this study.

Outputs from the East Yorkshire Chalk regional model were provided by the Environment Agency. Within this model, the Newbald Becksies site lies on the western edge of the model active area. The boundary of the active area (representing the edge of the Chalk) is cut in so that, to within the 200m resolution of the regional model, Newbald Becksies actually lies outside the model. This is, however, an artefact of the spatial resolution of the model, coupled with the model interpretation of the published geology map; as discussed in Section 2.2, the site actually lies on the feather edge of the Chalk.

Newbald Becksies is hosted in cells (220,69) and (220,70). Since the site lies outside the model boundary, for the purposes of this analysis FlowSource was used to determine the sources and pathways of flow to:

- the 2 model cells immediately to the north of Newbald Becksies – cells (219,69) and (219,70)
- the 2 model cells immediately to the south of the site – cells (221,69) and (221,70)
- the cell immediately to the east of the site – cell (220,71)

The 'destination' cells and the active model area (for Layer 2, the Chalk) are shown in Figure 2.4.

Separate calculations were carried out using the output from the Naturalized model (that is, with no abstractions or discharges represented) and the Recent Actual model (in which abstractions and discharges are represented at rates typical of the most recent few years). However, it was apparent that the differences in flow fields at Newbald Becksies – and hence in FlowSource outputs – were not minor.

The Capture Fraction and Volume From were calculated for each cell. Also calculated for each model cell was the long-term average value, which is the average value over all stress periods in the model (the model covers the period from 1 January 1970 to 31 March 2014, a total of 1,593 stress periods). In addition, Capture Fraction and Volume From metrics were calculated for the

Recent Actual model for a period of low water levels (September 1992, stress period 818) and a period of high water levels (November 2000, stress period 1,111).

The catchment for Newbald Becksies can be considered to be the boundary of the model cells that have a non-zero Capture Fraction. The Volume From metric provides an indication of those parts of the aquifer in which most flow to the site enters the aquifer as recharge.

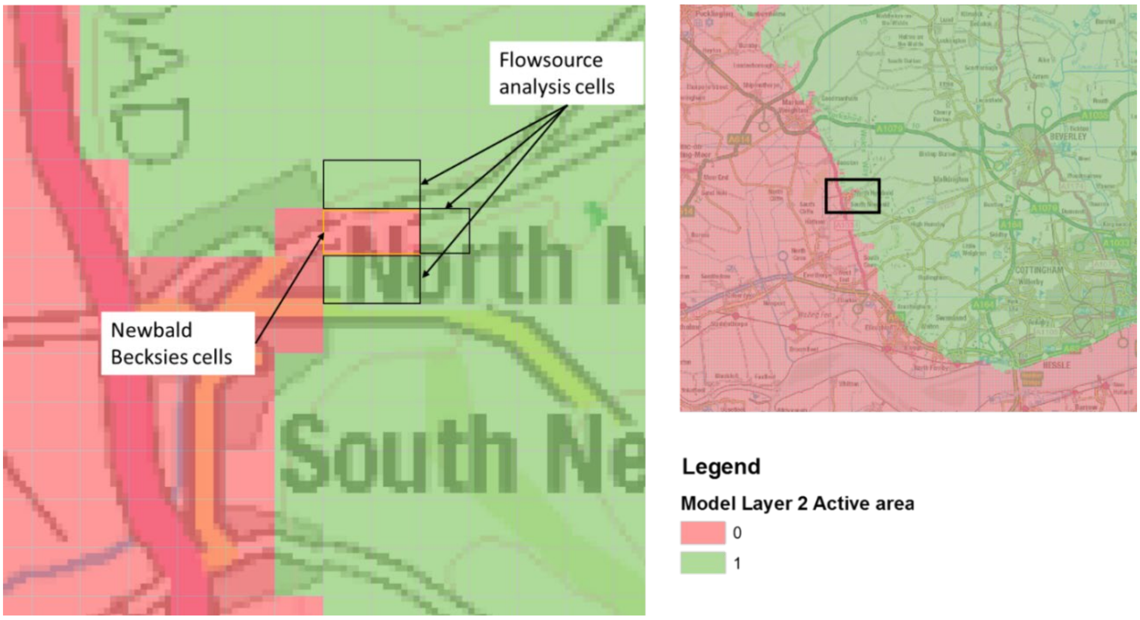

Figure 2.4 Model setting: cells representing Newbald Becksies and cells used for FlowSource analysis

The calculated long-term average Capture Fraction and the calculated long-term average Volume From are shown in Figure 2.5 and Figure 2.6 respectivel. Also shown is the draft groundwater catchment boundary derived by the Environment Agency (from Figure 2.1).

The Volume From of the model cells to the north, south and east of Newbald Becksies under the Recent Actual scenario for high and low water level conditions is shown in Figure 2.7 and 2.8 respectively.

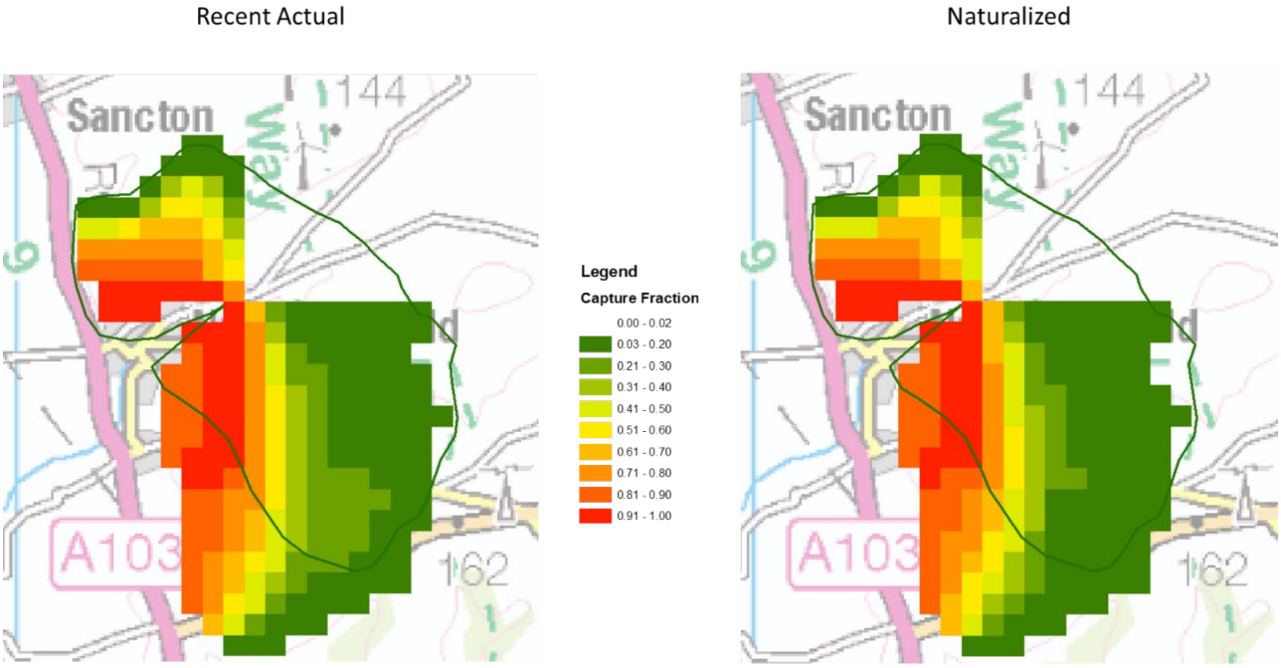

Figure 2.5 Long-term average Capture Fraction of the model cells to the north, south and east of Newbald Becksies under the Recent Actual (left) and Naturalized (right) scenarios

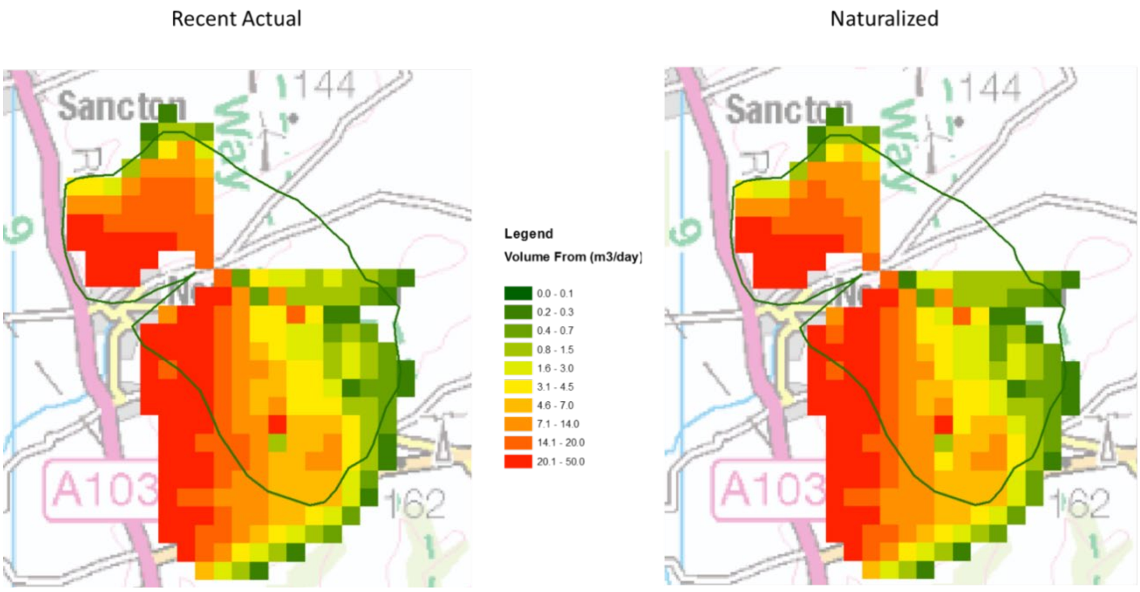

Figure 2.6 Long-term average Volume From of the model cells to the north, south and east of Newbald Becksies under the Recent Actual (left) and Naturalized (right) scenarios

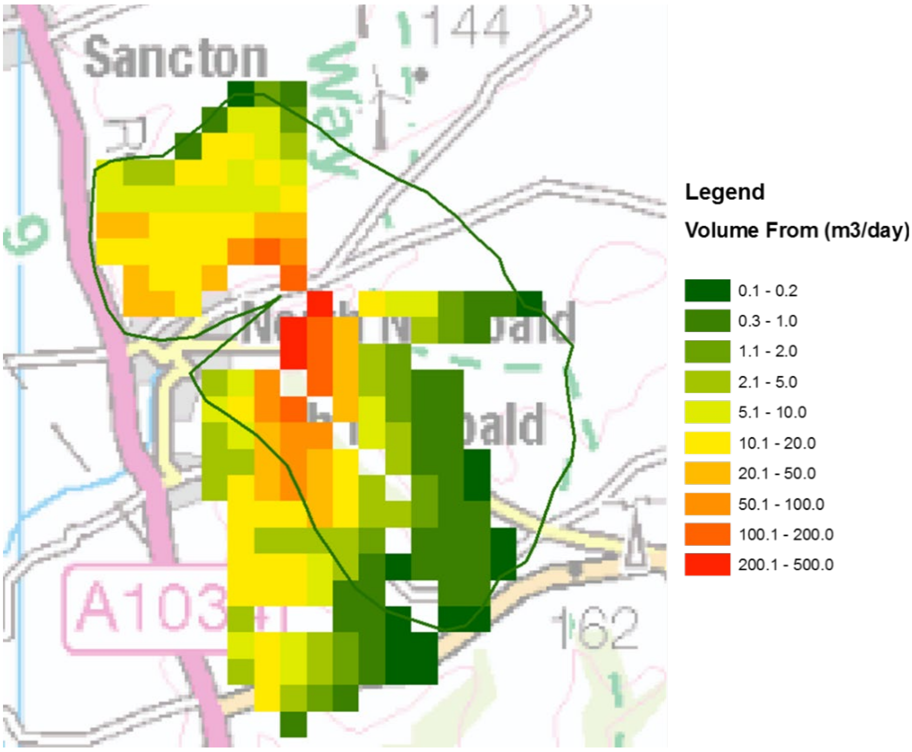

Figure 2.7 Volume From of the model cells to the north, south and east of Newbald Becksies under the Recent Actual scenario and high water level conditions

Notes: The scale in this figure is different from that used in Figure 2.5.

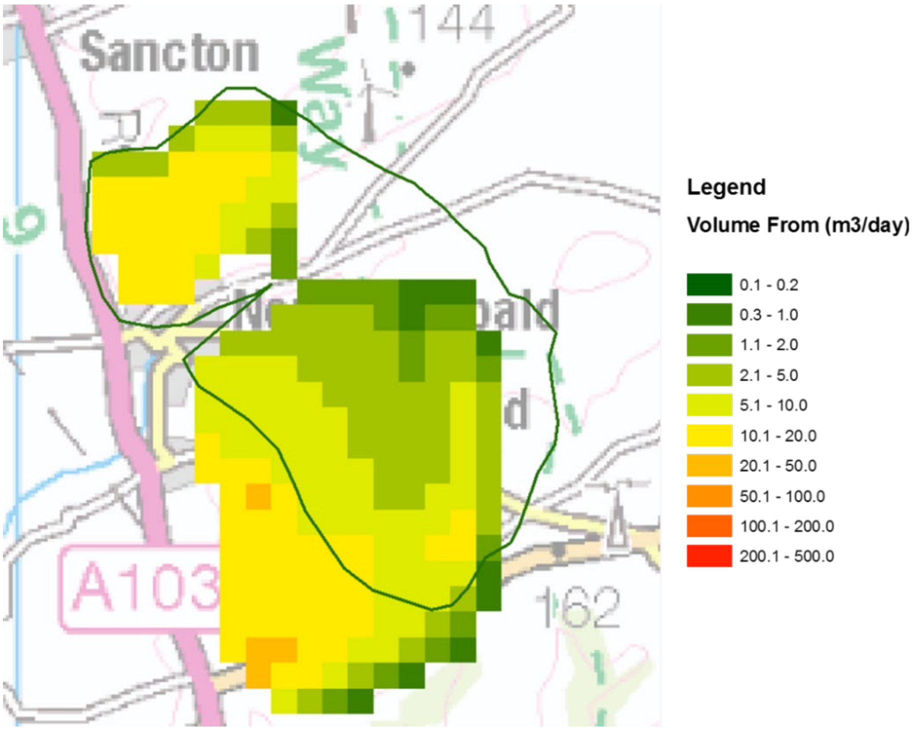

Figure 2.8 Volume From of the model cells to the north, south and east of Newbald Becksies under the Recent Actual scenario and low water level conditions

Notes: The scale in this figure is different from that used in Figure 2.6.

The area to the north, which contributes flow in a southerly direction to the site, is a good match with the draft groundwater catchment as provided by the Environment Agency. This is because previous modelling work to derive the catchment took the FlowSource results for this part of the aquifer into account.

The catchment area to the south of the site – from which groundwater flows in a northerly direction onto the site – agrees less well with the draft groundwater catchment. FlowSource suggests that flow to the site is in a more northerly direction, as opposed to north-westerly, and hence that the southern catchment area lies to the west of the draft catchment. The reasons for this difference are not known, since it is understood that the groundwater model was used to delineate the draft catchment.

However, this part of the aquifer is adjacent to the edge of the active model area and the western edge of the FlowSource catchment (defined as those cells with non-zero capture fraction) exactly abuts the boundary of the model. It is therefore very likely that regional groundwater fields as predicted by the East Yorkshire Chalk model are influenced by the proximity of the model boundary, and some caution is required in interpreting the model output.

The east–west extent of the FlowSource catchment is smaller than that of the draft groundwater catchment. FlowSource suggests that:

- there is little flow to the site from the aquifer beyond about 1km to the east of Newbald Becksies
- there is no significant flow to the site from the north-east
- the dominant flow pattern is north–south with much less east–west flow

However, it does suggest that the southern part of the catchment extends further to the south than the draft catchment boundary.

The FlowSource results predict no flow to the site from the north-east. This was investigated by further FlowSource analysis on the model cell to the north-east of the eastern end of the site (that is, the cell with model co-ordinates (219,72). This cell receives some flow from the north and east, but there appears to be a barrier to flow in cells to the east of this target cell (that is, north-east of Newbald Becksies). The reasons for this are not currently clear, but could relate to a model boundary condition present in those cells, or to the cells drying out and hence becoming a barrier to flow. This remains a source of uncertainty and requires further investigation.

The Volume From output suggests that the majority of the flow towards the site originates in the areas closest to the site – to the north and south. In the southern part of the catchment, more flow originates in the western part of the catchment than in the eastern part. Under high water levels, the area adjacent to the site and immediately to the south-east contributes very large volumes of flow to the site. Under low flow conditions, the wider area of the catchment due south of the site becomes more significant.

2.6 Water balance calculations

Using available monitoring data, a simple water balance calculation was made to estimate the catchment area contributing to Newbald Becksies. The following data were available:

- outflow data from Newbald Becksies for October 2003 to March 2013, and March 2016 to January 2017
- rainfall data from 2004 to 2016
- potential evapotranspiration (PET) data for 2012 to 2016
- estimates of annual rainfall-recharge up to 2007, taken from the Yorkshire Chalk conceptual report (ESI Consulting 2010, Figure 8.3), for use in years without PET data

A recent actual average abstraction rate of 0.4 million litres per day was assumed up to 2013, using the value stated in ESI Consulting (2015). For 2014 onwards, no abstraction has been assumed.[2]

Annual average outflow and total hydrologically effective rainfall (HER) were calculated using the best available information for each year from 2005 to 2016. These were used to calculate a catchment area year-by-year as annual outflow divided by annual HER. The values for 2014 and 2015 were not calculated because no outflow data were available for those years.

The results are shown in Figure 2.9. They should be treated with some caution due to the level of uncertainty in the data in some years (particularly where an average % recharge has been assumed rather than using actual data, in 2008-11). Nevertheless, the data suggest that the catchment area varies over time, from perhaps 2 km^2 up to 8 km^2. This corresponds with the FlowSource findings. Including the Yorkshire Water abstraction in the calculation makes a relatively small ($<1km^2$) difference to the catchment area (again corresponding to FlowSource).

[2] Personal communication from Mark Whiteman of the Environment Agency

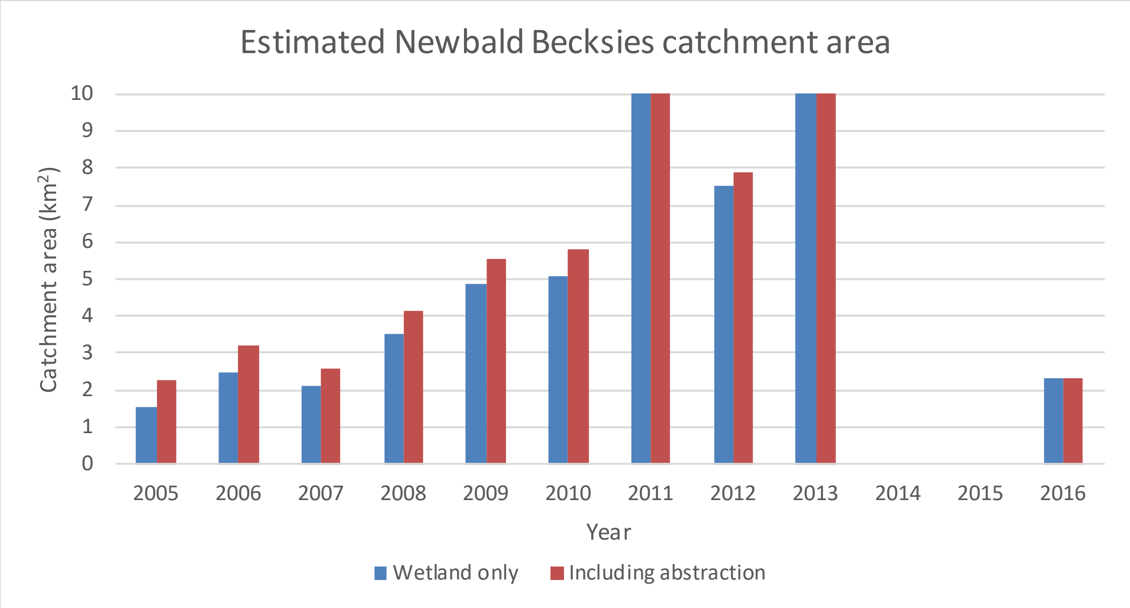

Figure 2.9 Catchment area contributing to Newbald Becksies wetland as calculated from annual water balance data

Notes: The values for 2011 and 2013 were very high. Rainfall data in 2013 were erroneously low due to problems with the rain gauge; this is likely to be contributing to the high calculated area. The reason for the high value in 2011 is unknown. It is assumed to be data-related rather than a 'real' catchment area, and as a result the y-axis of the graph has been truncated at $10km^2$.

2.7 Geophysics surveys

In 2009, TerraDat undertook geophysics surveys of Newbald Becksies wetland including resistivity, conductivity and ground penetrating radar. The objectives were to:

> 'identify the outcrops, distribution and thicknesses of the various lithological formations and, where possible, to assess the nature of the deposits' (TerraDat 2009).

More broadly, this was to feed into the investigations of the details of the groundwater connectivity and potential risks and sources of nitrate pollution. The subsequent report presents the results of the surveys and potential interpretations about the geology underlying the site (TerraDat 2009). In particular, it discusses the possible presence of faulting directly beneath the site and the extent of gravels lying in the valley bottom. The potential scenarios put forward by TerraDat are illustrated in Figure 2.10. Although a firm conclusion was not reached about which of the scenarios is 'correct', both options indicate a low permeability zone at the surface in the centre of the site, suggesting that the Chalk to the north and south of the site are isolated from each other.

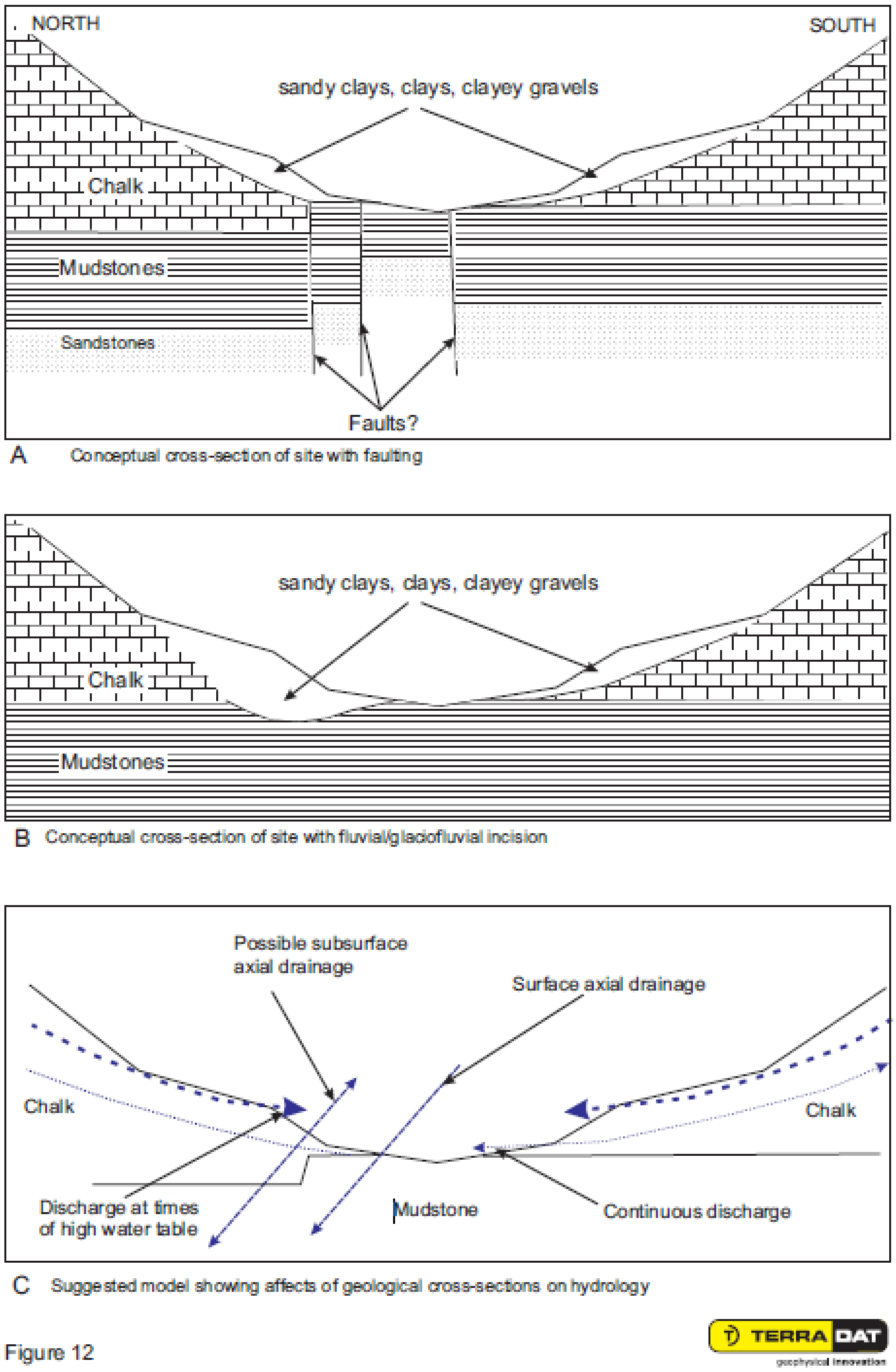

Figure 2.10 Potential structure beneath Newbald Becksies wetland as inferred from geophysical surveys

Source: TerraDat (2009)

2.8 Catchment area conclusions

The following conclusions about the catchment area can be drawn from the various sources of information presented above.

- The extent of the groundwater catchment area includes areas beyond the immediate topographical divides.
- FlowSource analysis of the flows calculated by the Recent Actual and Naturalized regional model scenarios suggests that much of the flow to the southern boundary of the site originates from the area due south of Newbald Becksies, rather than from the south-east.
- Back-calculation of catchment area from site water balance data (outflow, rainfall and PET) suggests that the catchment area varies over time. Over the years for which data were available, the catchment area appears to have varied between $2km^2$ and $8km^2$. This variation over time is also shown in the FlowSource results, with flow contributions being concentrated from a local area during high water levels, but extending from a much larger area to the south during dry conditions.
- These findings are supported by earlier modelling of Newbald Becksies by Wilkinson (2009), who found that using the local topographical catchment alone (bounded to the east by a fault) provided insufficient recharge. The catchment area derived through that study was somewhat smaller overall than the draft catchment area derived by the Environment Agency. It did not extend as far east and included a smaller area to the north.
- Yorkshire Water Services' AMP4 investigations, including Wilkinson's (2009) dissertation, considered the influence of a north–south fault to the east of Newbald Becksies acting as an impermeable barrier. However, the extent of the fault appears to be relatively poorly documented and Wilkinson (2009) presented some evidence of pumping influences crossing the fault (from east to west). Thus a precautionary approach should not necessarily exclude the area to the east from the natural catchment area of the wetland, although other evidence suggests that contributions from the east are likely to be less those than north–south.
- The evidence discussed above shows the area to the north as contributing to Newbald Becksies, but evidence from the geophysics surveys (TerraDat 2009) suggests that there is no groundwater connectivity between the north and south sides of the valley (whether due to faulting or low permeability infill in the valley bottom). It is more likely that groundwater from the north will contribute only to the stream emanating from the site (with some being intercepted by the French drain alongside the road, then being channelled to the stream downstream of the site). Thus the catchment area to the north is unlikely to be influencing the springs emerging on the south side, and hence will not ordinarily influence the wetland habitats.
- The Yorkshire Water Services abstraction to the east of the wetland, when operating, may intersect groundwater flow that would otherwise reach the wetland. The extent of the Source Protection Zone shown in Figure 2.11 may provide a guide for this. However, the regional

groundwater model and water balance calculations suggest that the abstraction has relatively little influence on the catchment area.

Overall, there is some conflicting evidence about the extent and location of the groundwater catchment, along with the possibility that its extent may vary over time. It seems likely that the area to the south of the site contributes the most, but the evidence is not clear-cut enough to completely exclude the wider catchment area. As a result, the groundwater catchment provided by the Environment Agency has been retained, but has been split in to 4 sub-catchments (north-east, north-west, south-east and south-west), with the aim of allowing more or less focus to be placed on certain parts of the catchment. Separate models and scenarios have been derived for each of the sub-catchments (see Section 3).

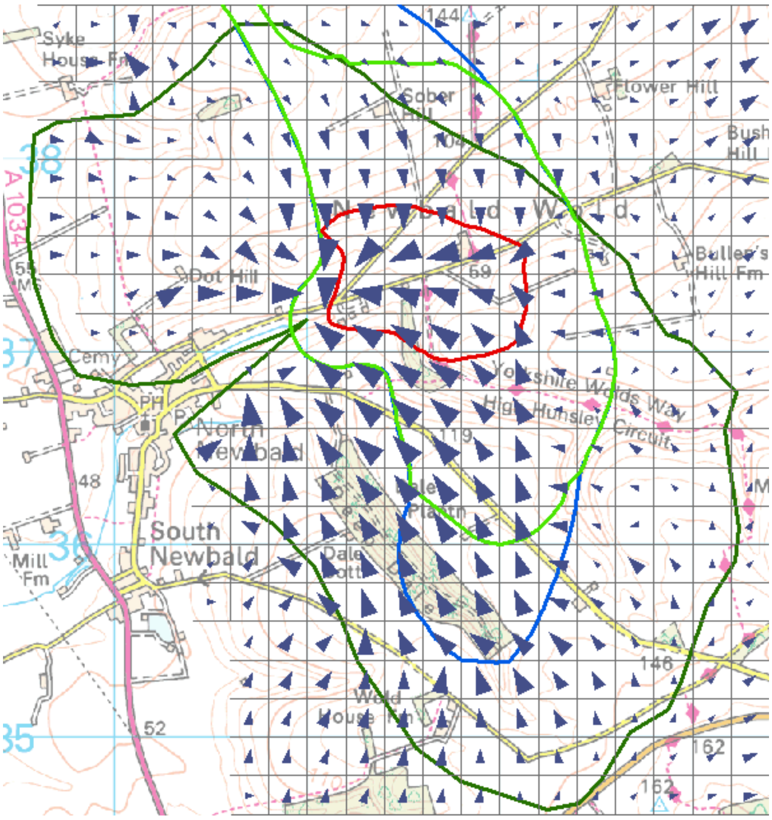

Figure 2.11 Source Protection Zone for North Newbald PWS

Notes: The red line shows the Source Protection Zone and the green line denotes the boundary of the groundwater catchment as determined by the Environment Agency

3 Land use and potential sources of nitrate

3.1 Land use in the sub-catchments

The 4 modelled sub-catchment areas (north-west, south-west, north-east and south-east) were modelled separately. Land use within each of the proposed model areas was estimated from satellite imagery (Figure 3.1). Fields where there is evidence from satellite imagery that oil seed rape (OSR) has been grown have been labelled with 'OSR' in Figure 3.1. In practice, this will be within an arable rotation; a plausible crop rotation was assumed (see Section 4).

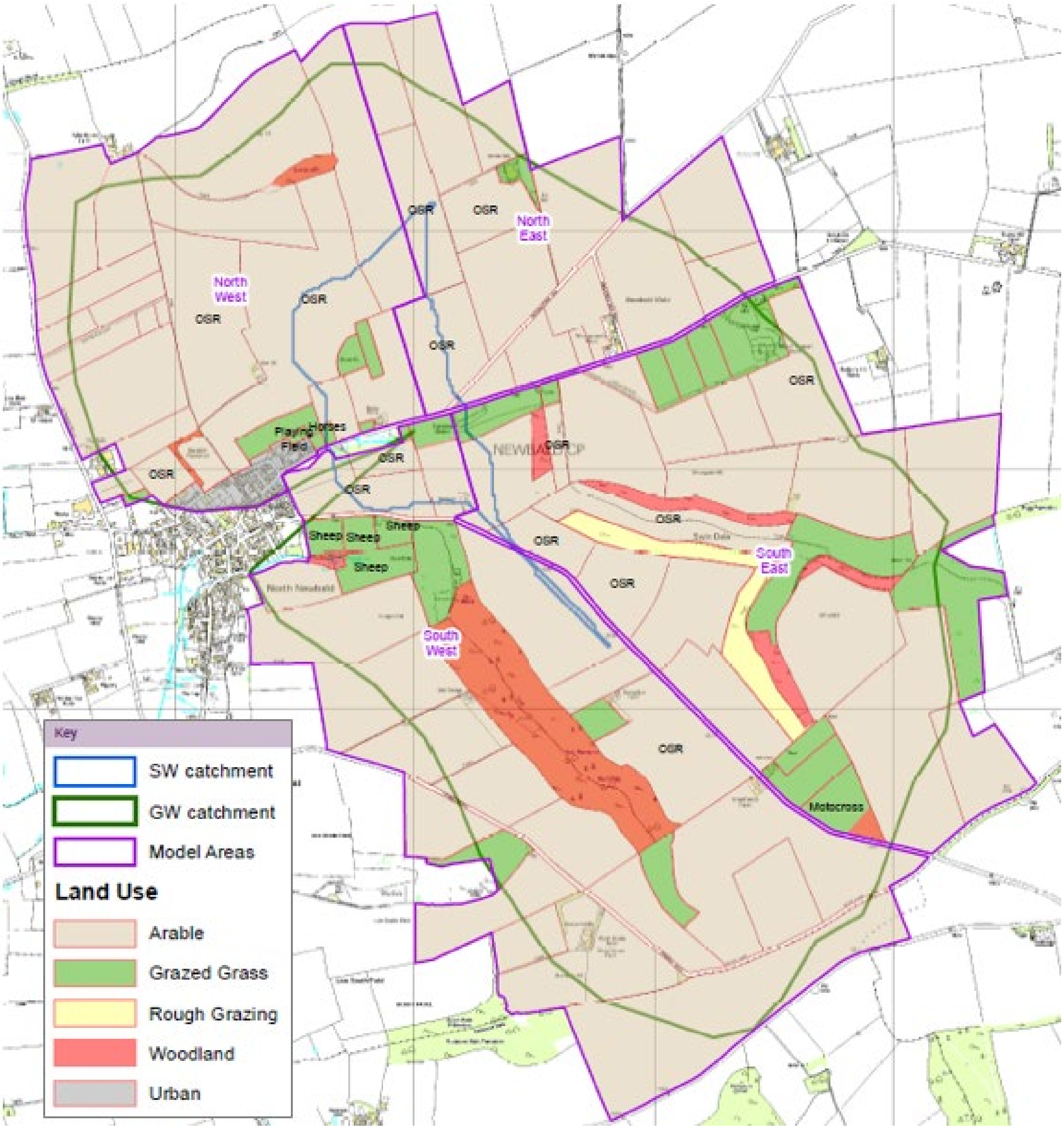

Figure 3.1 Land use in the groundwater catchment of Newbald Becksies

Notes: The purple lines indicate the boundaries of the 4 sub-catchments used for modelling.
GW = groundwater; SW = south-west

3.2 Potential sources of nitrate in the sub-catchments

The following potential sources of nitrate to groundwater were identified:

- leaching of nitrate from agricultural soils
- leaching of nitrate from soils on the site itself – atmospheric deposition and mineralisation
- leaching of nitrate from manure heaps in the catchment – while there are unlikely to be many given the low numbers of livestock within the catchment, there is a horse paddock on the opposite side of Beverley Road to Newbald Becksies where there may be a small manure heap
- leakage from septic tanks at dwellings within the catchment not connected to mains sewers
- sewer leakage from mains sewers serving the dwellings within the catchment
- mains water leakage from water mains serving the dwellings within the catchment

Although potentially sources of nitrate, the following were discounted as not being present within the catchment:

- graveyards or cemeteries – there are no cemeteries within the catchment as it is currently defined, but there is a cemetery close to the western boundary of the catchment in North Newbald
- landfills – there are no landfill sites within the catchment as it is currently defined, but there are 4 close to the western boundary of the catchment (Figure 3.2)
- animal burial sites
- farm slurry stores

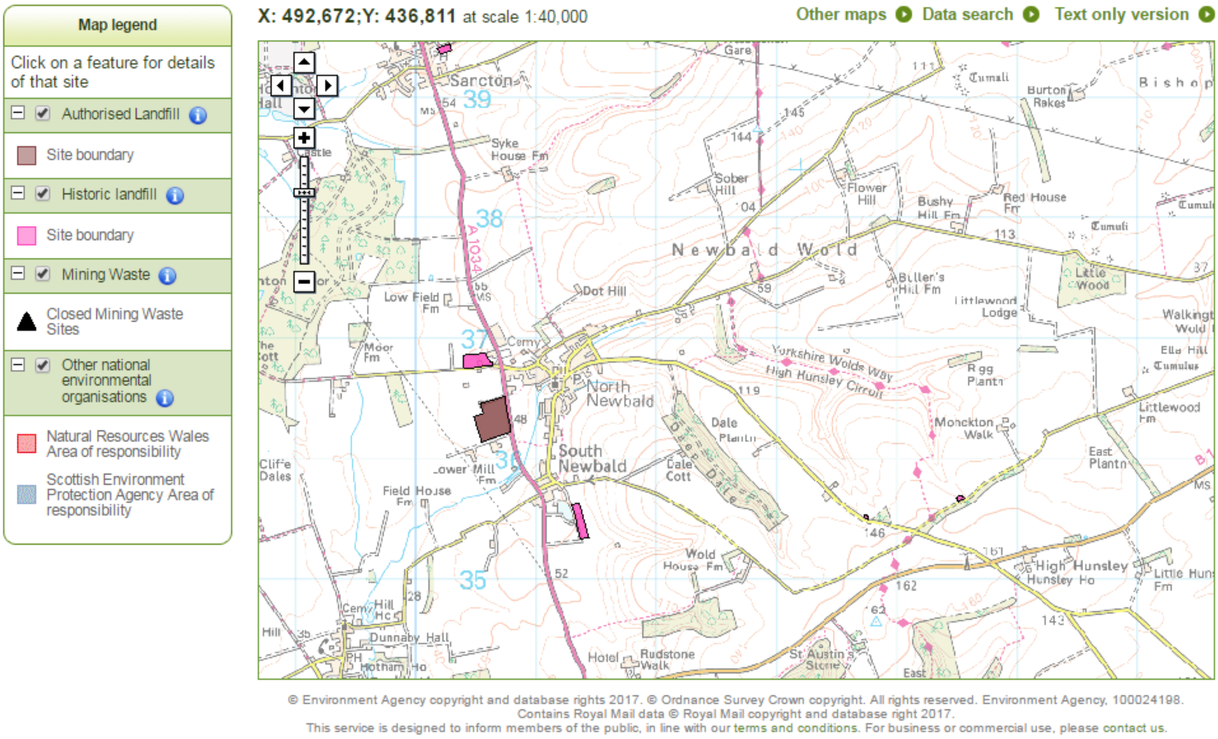

Figure 3.2 Authorised and historic landfill sites in the area

Source: Environment Agency's 'What's in your backyard?' online database

4 Nitrate modelling scenarios

4.1 Land management scenarios

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

The general assumptions for the nitrate modelling were as follows.

- Arable crop rotation is winter OSR, winter wheat, spring barley and vining peas. This is considered to be a plausible rotation given the observed area of OSR. Feedback from the project steering group suggests the assumptions are appropriate.
- Soil is free draining with low organic matter (www.landis.org.uk/soilscapes/).
- No manure is applied to arable land due to low livestock numbers – all fertiliser is inorganic.
- Soil Nitrogen Supply (SNS) is low (Index 1).

Average rainfall in the area is 660mm,[3] and so average summer rainfall will be around 330mm (half of the annual total). For shallow soils over Chalk, this gives a grass growth class of 'average' as defined as defined by the RB209 Nutrient Management Guide (AHDB 2018, Table 3.7).

Table 4.1 summarises the assumptions behind the definitions of the scenarios. The proposed model scenarios are described in Table 4.2. Once the detail of the land use and management are agreed, further scenarios can be defined using a feasible range of fertiliser and stocking rates.

Table 4.1 Summary of catchment data and assumptions for Newbald Becksies catchment

Variable	Total	Sub-catchments			
		North-east	North-west	South-east	South-west
Soil type	Loamy, shallow, free draining				
Annual rainfall	660mm per year				
Summer rainfall	330mm (half of the annual total rainfall)				

[3] The average rainfall for the period 2004 to 2016 at Newbald Becksies according to data provided by the Environment Agency.

Variable	Total	Sub-catchments			
		North-east	North-west	South-east	South-west
RB209 grass growth class	Average				
Area of arable fields (ha)	886.7	146.8	214.4	234.5	291.1
Area of grazed grass (ha)	101.5	1.7	8.2	60.8	30.8
Area of rough grazing (ha)	14.2	0	0	14.2	0
Area of woodland (ha)	48.4	0	2.5	12.4	33.5
Urban area (ha)	8.0	0	8.0	0	0
Farmscoper rainfall band	600–700mm rainfall				
Farmscoper soil type	Free draining				

Table 4.2 Land management scenarios for Newbald Becksies catchment

Land use/ scenario number	Nitrogen fertiliser rate	Stocking rate (LU per hectare)	Comments
Winter OSR	220kg per hectare inorganic	N/A	The RB209 fertiliser rate for a SNS index of 1.
Winter wheat	240kg per hectare inorganic	N/A	The RB209 fertiliser rate for a SNS index of 1.
Spring barley (malting)	120kg per hectare inorganic	N/A	The RB209 fertiliser rate for a SNS index of 1.
Vining peas	0kg per hectare	N/A	The RB209 fertiliser rate for a SNS index of 1.
Grazed grass	170kg per hectare	1.5 LU per hectare (9 ewes	Assumed no manure spread to grazed grass.

Land use/ scenario number	Nitrogen fertiliser rate	Stocking rate (LU per hectare)	Comments
		plus lambs per hectare)	
Rough grazing (as defined by Farmscoper)	Zero inorganic	0 LU per hectare	Assumed no manure spread to rough grazing.
Woodland (as defined by Farmscoper)	Zero inorganic	N/A	

Notes: Soils are shallow and free draining and rainfall is 'moderate' at 660 mm/yr. For fields previously in cereals, RB209 guidance suggests a low SNS index of 1 would be expected. For fields previously in OSR or peas an index of 2 might be expected.
LU = livestock unit

4.2 Non-agricultural sources and agricultural point sources of nitrate

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.

Input data relevant to the calculation of other potential sources of nitrate at Newbald Becksies are shown in Table 4.3. These values are estimates based on Ordnance Survey mapping data.

Table 4.3 Groundwater catchment input data for Newbald Becksies: non-agricultural sources and agricultural point sources

	Sub-catchments				
Parameter	**North-west**	**North-east**	**South-west**	**South-east**	**Comment**
Sewered population	115	0	0	0	~50 dwellings, average 2.3 people per household
Population served by septic tanks / package treatment plants	3	7	9	5	~10 dwellings, average 2.3 people per household

	Sub-catchments				
Parameter	**North-west**	**North-east**	**South-west**	**South-east**	**Comment**
Area of gardens	1ha	0	0	0	Assumed there are associated 50 houses in 8ha urban area
Area of manure heaps	0.1ha	0	0	0	Horse paddock
Area of paved and road surfaces	0.4ha	0.4ha	0.9ha	0.9ha	~6.4km of road estimated at 4m wide

5 Observed nitrate concentrations at Newbald Becksies

Observations of nitrate concentrations across the Newbald Becksies site were collated by the Environment Agency and made available to the project. The observation sites consist of 2 springs, 3 boreholes and a rain gauge. The discharge from the pipe that crosses the site (origin unknown) has also been monitored.

The monitoring data are made up of observations taken at irregular intervals over the periods 2009 to 2010 and 2015 to 2016. Readings of nitrate concentrations for 2009 to 2010 and 2015 to 2016 are summarised in Table 5.1 and Table 5.2 respectively. The observation sites are labelled in Figure 5.1 with the average concentration for the period from 2015 to 2016.

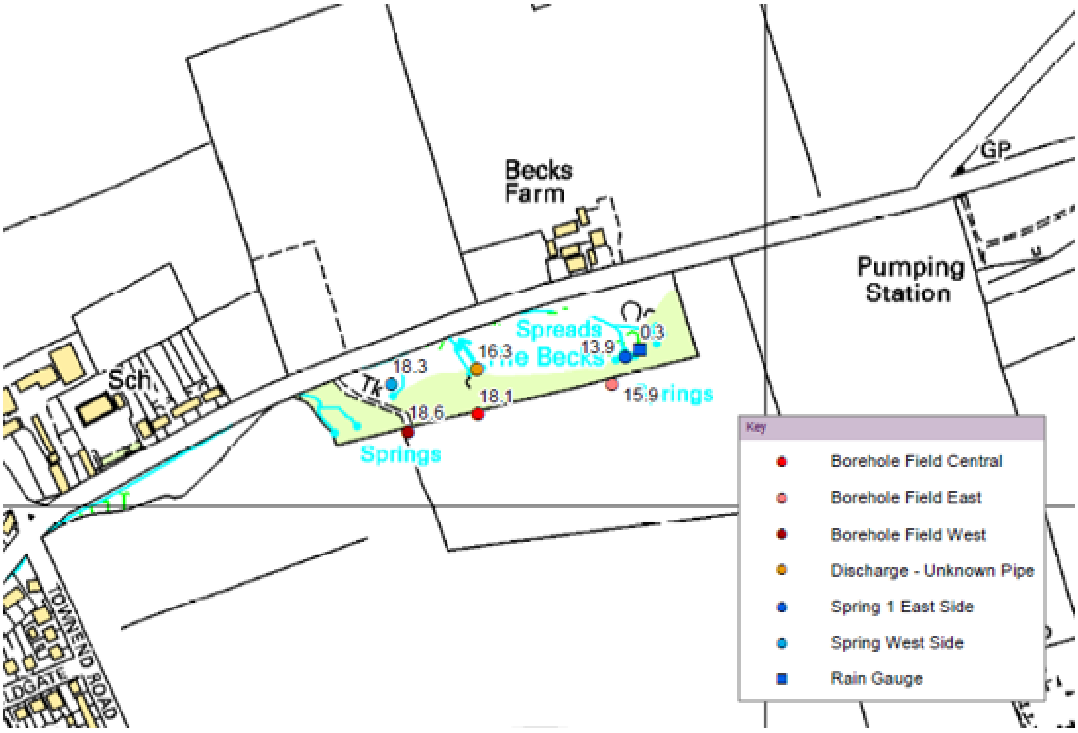

Figure 5.1 Newbald Becksies nitrate monitoring locations and average nitrate concentrations (mg-N per litre) in the 2015 to 2016 monitoring campaign

Table 5.1 Observations of nitrate concentration at Newbald Becksies, 2009 to 2010

Sample point	Date of first sample	Date of last sample	Nitrate concentration (nitrate-N, mg per litre)			Number of records
			Minimum	Maximum	Average	
Borehole field central	30 July 2009	19 October 2010	16.6	18.0	17.4	7
Borehole field east	30 July 2009	19 October 2010	14.8	16.8	15.8	7
Borehole field west	30 July 2009	19 October 2010	17.5	19.8	18.5	7
Spring 1 - east side of site	30 July 2009	19 October 2010	12.3	15.0	13.5	6
Discharge from unknown pipe	30 July 2009	19 October 2010	15.5	17.2	16.3	7

Table 5.2 Observations of nitrate concentration at Newbald Becksies, 2015 to 2016

Sample point	Date of first sample	Date of last sample	Nitrate concentration (nitrate-N, mg per litre)			Number of records
			Minimum	Maximum	Average	
Borehole field central	5 November 2015	18 August 2016	18.0	18.3	18.1	3
Borehole field east	5 November 2015	18 August 2016	14.9	16.5	15.9	3
Borehole field west	5 November 2015	18 August 2016	18.2	19.1	18.6	3
Spring 1 – east side of site	5 November 2015	18 August 2016	13.1	14.7	13.9	3
Spring – west	5 November 2015	18 August 2016	18.2	18.4	18.3	3

Sample point	Date of first sample	Date of last sample	Nitrate concentration (nitrate-N, mg per litre)			Number of records
			Minimum	Maximum	Average	
side of site						
Discharge from unknown pipe	5 November 2015	18 August 2016	15.5	16.7	16.3	3
Rain gauge	8 December 2015	24 November 2016	0.1	0.6	0.3	10

Comparison of the monitoring data for the 2 periods suggests nitrate concentrations at Newbald Becksies have remained relatively constant since 2009 (that is, no apparent rising or falling trend). There is, however, some variation across the site. Nitrate concentrations are typically higher at the western end of the site compared with the eastern end. Spring discharges at the western end of the site were observed to be smaller during the site visit made on 25 January 2017.

6 Farmscoper modelling results

6.1 Predicted nitrate leaching

The ADAS Farmscoper model (Gooday et al. 2015) was used to predict nitrate leaching from each of the land uses and management scenarios described in Tables 4.1 and 4.2.

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. The results of its application are shown in Table 6.1.

Table 6.1 Farmscoper predictions of nitrate leaching from each land use scenario

Land use	Nitrate loss (kg-N per hectare)	Soil drainage (mm)	Nitrate concentration (mg-N per litre)
Grazed grass	15.28	181.23	8.43
OSR	50.61	249.03	20.32
Winter wheat	31.75	249.03	12.75
Spring barley	27.94	223.68	12.49
Vining peas	52.53	223.68	23.49
Woodland	0.04	-	-
Rough grazing	4.01	247.76	1.62

Combined with the areas of each land use identified in each subcatchment (Table 4.1), these predictions of nitrate leaching result in the catchment total figures shown in Table 6.2.

Table 6.2 Farmscoper predictions of nitrate leaching in each sub-catchment

	Sub-catchments				Combined catchment
	North-east	North-west	South-east	South-west	
Area (ha)	148.5	233.1	321.9	355.4	1,058.8

	Sub-catchments				Combined catchment
	North-east	North-west	South-east	South-west	
Total nitrate-N loading (kg-N per year)	6,001.0	8,852.4	10,530.6	12,322.1	37,706.1
Total nitrate-N loading (kg-N per hectare per year)	40.4	39.3	32.7	34.7	35.9
Total drainage (mm per year)	235.7	231.7	217.3	209.3	220.3
Average concentration (mg-N per litre)	17.1	17.0	15.1	16.6	16.3

6.2 Nitrate loading from point sources

Based on the figures shown in Table 4.3, the total nitrate loading from point sources and other non-agricultural sources is as shown in Table 6.3. In all 4 sub-catchments, it is evident that non-agricultural sources are insignificant compared with the estimated leaching from agricultural land (Table 6.1).

Table 6.3 Estimated nitrate loading from non-agricultural sources and agricultural point sources at Newbald Becksies

Source	Sub-catchment nitrate loading (kg-N per year)			
	North-east	North-west	South-east	South-west
Sewer leakage	0	8.7	0	0
Septic tank discharges	11.5	4.9	8.2	14.8
Mains leakage	1.1	18.5	0.8	1.4
Leaching from gardens	0	5	0	0
Leaching from manure heaps	0	1	0	0
Run-off from paved and road surfaces	0.01	0.01	0.06	0.06
Total	**12.61**	**38.11**	**9.06**	**16.26**

6.3 Comparison with observed nitrate concentrations

Farmscoper predictions of nitrate concentrations in soil drainage are broadly similar in all of the 4 modelled sub-catchments, being in the range 15–17mg-N per litre. This is comparable with, or slightly lower than, observed nitrate concentrations in shallow groundwater at the site. The observed concentration in the eastern spring discharge is slightly lower than modelled values, while the concentration in the western spring discharge is slightly higher than modelled values. This is consistent with the modelling results, which suggest a lower concentration in drainage from the south-east catchment than from the south-west, although there is significant uncertainty in the modelled scenarios of land management, as well as in the understanding of the detail of how different parts of the catchment might influence the site.

Broadly speaking, however, the model predictions agree well with observed nitrate concentrations at the site.

6.4 Nitrate source apportionment

Based on the results of the Farmscoper modelling, sub-catchment scale source apportionment of nitrate leaching from agricultural land is as shown in Figure 6.1. Source apportionment calculations for the entire catchment area are shown in Figure 6.2.

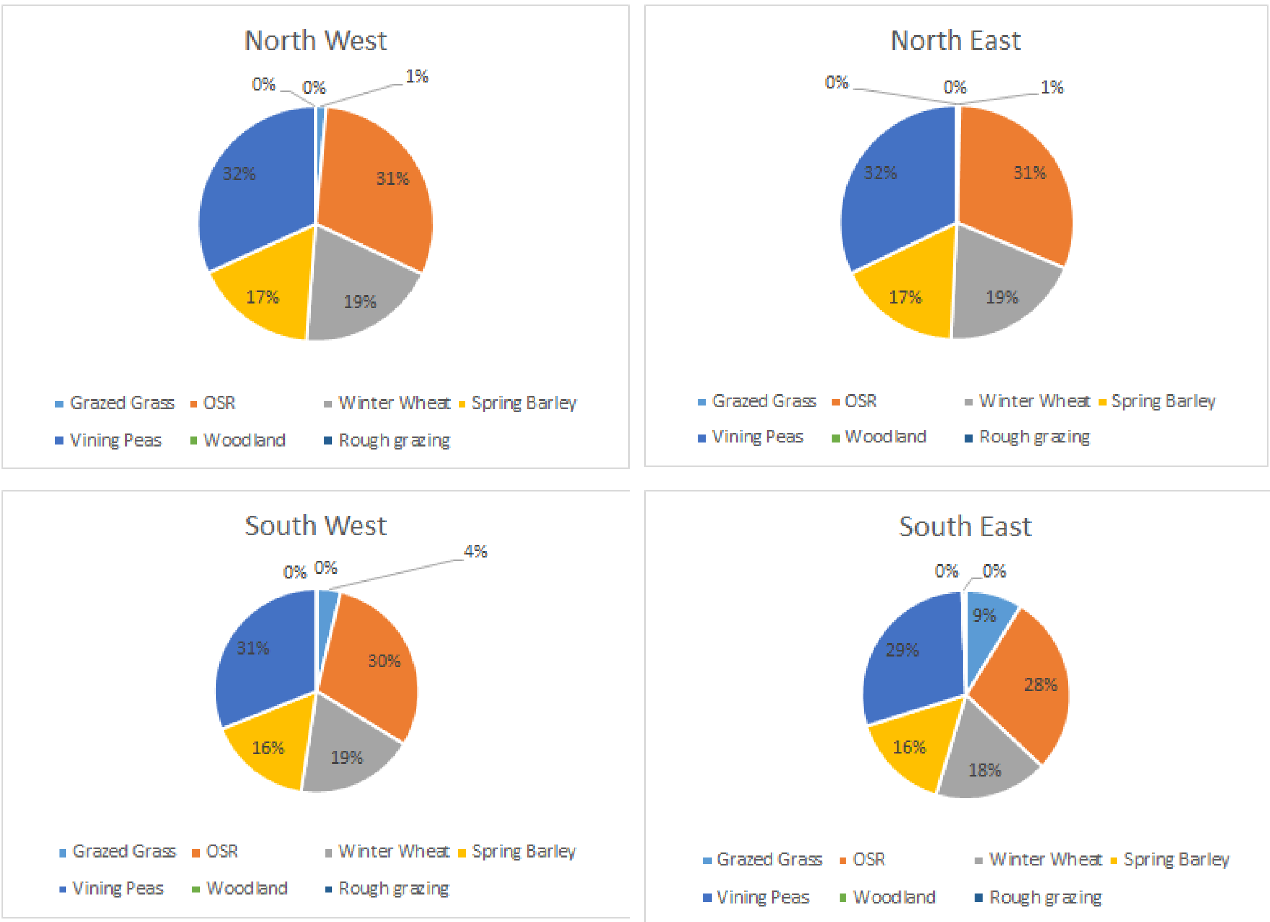

Figure 6.1 Sub-catchment nitrate source apportionment

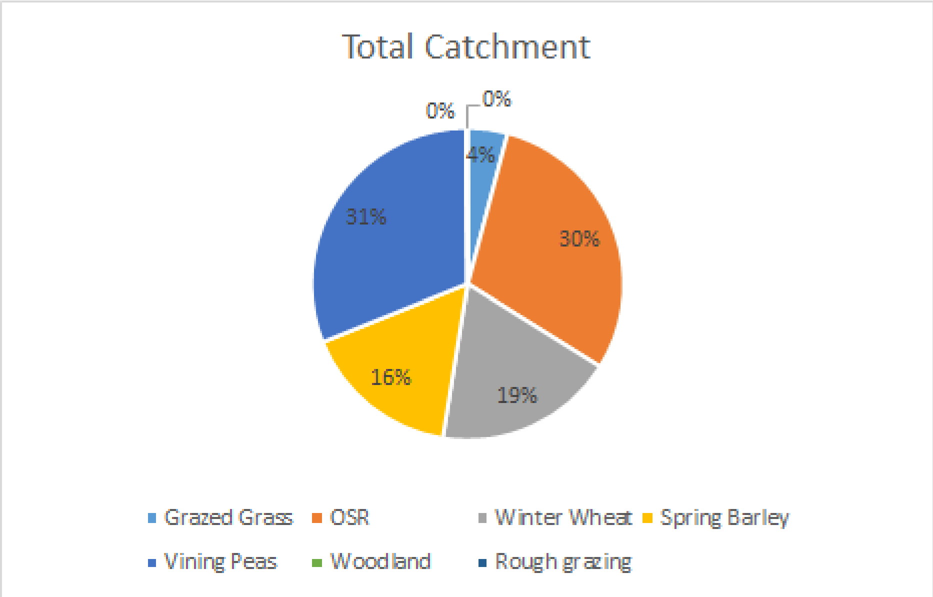

Figure 6.2 Nitrate source apportionment for the catchment for Newbald Becksies

7 Mitigation against nitrate loss

The source apportionment calculations suggest that the majority of leaching occurs from arable land, and in particular from OSR and vining peas crops (the presence of this crop rotation in the catchment is not confirmed, although feedback from the project steering group agreed this to be a reasonable assumption).

Predicted leaching rates are slightly lower from cereal crops and substantially lower from grassland. Point sources may be relevant locally, but are not predicted to contribute a significant nitrate loading at catchment scale.

This suggests that the most effective mitigation against nitrate leaching will be that targeted at arable land in the catchment, and in particular the management of OSR and peas. The Farmscoper model was used to evaluate an optimal set of mitigation methods to reduce nitrate leaching from the four-course arable rotation described in Table 4.2.

Farmscoper identifies the combination of measures shown in Table 7.1 as the most optimal to reduce nitrate leaching. However, this assessment is based on national-scale data, which may differ significantly from local management practices. As such, the identified measures may not be appropriate on all farms, or may already be in place. Similarly, the estimated costs of implementation are indicative only.

Table 7.1 Optimal combination of nitrate mitigation methods (as predicted by Farmscoper)

Measure number	Description	Assumed prior implementation (%)
117	Use correctly inflated low ground pressure tyres on machinery.	50
113	Plant undersown spring cereals.	2
27	Use manufactured fertiliser placement technologies.	10
23	Integrate fertiliser and manure nutrient supply.	80
21	Ensure correct calibration of fertiliser spreader.	80
20	Use plants with improved nitrogen use efficiency.	0

- The baseline nitrate loss from all arable land in the catchment, assuming no implementation of any mitigation measures, is predicted to be 35,985kg-N.
- The assumed Farmscoper default levels of prior implementation of these measures (as shown in Table 7.1) would reduce the baseline leaching loss to 32,935kg-N, a reduction of about 8%. This leaching

loss corresponds to a concentration in soil drainage of 14.2mg-N per litre.

- Implementing the identified combination of measures in full on all arable land in the catchment (that is, implementation for all measures in Table 7.1, increased to 100%) is predicted to result in a reduction in nitrate leaching to 31,747 kg-N, or a further 4%.
- These measures are predicted to have a capital cost of £4,578 (relative to the 'prior implementation' scenario), but to provide an operational cost saving overall of £30,905. The net saving of these measures at catchment scale is therefore £26,327.
- In the extreme scenario that all 19 measures identified by Farmscoper as having some beneficial effect on nitrate leaching were implemented in full in the catchment, nitrate leaching is predicted to reduce to 28,245kg-N, equivalent to 12.2mg-N per litre.
- Relative to the 'prior implementation' scenario, this scenario would carry a capital cost of £11,788 and an operational cost of £133,467, or a total of £145,255.

Total nitrate leaching of 31,747kg-N across the catchment corresponds to a concentration of 13.7mg-N per litre reaching the Newbald Becksies SSSI. This is still considerably higher than the UKTAG threshold for 'wetlands directly irrigated by spring or seepage' of 2mg-N per litre (UKTAG 2012).

Changes to crop types – particularly relating to OSR and vining peas, with their higher nitrate leaching – will be more effective in reducing concentrations. But as shown in Table 6.1, concentrations from areas of winter wheat and spring barley are still predicted to be around 12mg-N per litre. Only the non-arable land uses in Table 6.1 attain concentrations less than 2mg-N per litre.

Reversion of arable land to unfertilised, ungrazed grass would achieve much more substantial reductions in nitrate leaching. The Defra Diffuse Pollution Inventory User Manual (Newell Price et al. 2011) estimates the cost of such land use change to be £7,500 per farm per year for farms previously growing combinable crops, and notes that uptake is likely to be very low without the provision of suitable incentives.

In this context it is worth looking again at which are the key contributing areas in the wider catchment. The FlowSource analysis described in Section 2.5 suggests that much of the flow to the southern side of the site originates from the area adjacent to the site to the south and south-east, and from further afield due south of the site. As a result, these should be priority areas for programmes of measures.

8 Conclusions and recommendations

Although much work has been done to develop a robust conceptual understanding of the hydrology and hydrogeology of Newbald Becksies, some uncertainty remains as to the extent and location of the catchment to the site. However, the evidence does indicate the following.

- FlowSource analysis of flows calculated by the East Yorkshire Chalk regional groundwater model suggests that much of the flow to the southern side of the site originates from the area adjacent to Newbald Becksies to the south and south-east, and further afield from due south of the site.
- FlowSource and water balance calculations using stream flow data suggest that the catchment area varies over time with hydrological conditions.
- Site observations and the results of geophysics surveys suggest that the area to the north of Newbald Becksies is unlikely to contribute groundwater to the wetland habitats, with groundwater flow from that direction being intercepted by the stream.

However, it is recommended that the East Yorkshire Chalk regional groundwater model should be revisited to consider whether any local refinements are necessary. This is because the site lies on the far western edge of the model and the representation of the site within the model has not previously been given detailed consideration. This may allow increased confidence in refining the most important catchment area.

Nitrate source apportionment calculations, based on an assumed (but realistic) crop rotation, suggest that the dominant source of nitrate leaching in the catchment is arable land, and in particular OSR and vining peas. Leaching rates from grassland and rough grazing land are predicted to be much lower.

Reductions in nitrate inputs to Newbald Becksies are therefore most likely to be achieved through targeted programmes of measures aimed at reducing nitrate leaching from arable land in the area immediately to the south and east of the site and, in the medium to longer term, from the area further to the south of the site.

However, the reductions in nitrate leaching that are likely to be achievable through commercially viable mitigation measures are unlikely to be compatible with the current water quality target of 2mg-N per litre. Of the land uses simulated, only extensive grazing land or forestry are compatible with this target.

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List of abbreviations

AMP4	Asset Management Plan 4
GWDTE	groundwater-dependent terrestrial ecosystem
HER	hydrologically effective rainfall
OSR	oil seed rape
PET	potential evapotranspiration
PWS	public water supply
SNS	Soil Nitrogen Supply
SSSI	Site of Special Scientific Interest

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