South Downs National Park Authority

South Downs Collaborative Nitrate Modelling

Nitrate Modelling Report

7 May 2014

AMEC Environment & Infrastructure UK Limited

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Report for

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Executive Summary

Purpose of this Report

This report has been produced for the purpose of building a compelling evidence base in support of existing or new initiatives which will deliver groundwater quality improvements through sustainable land management in the South Downs Way Ahead Nature Improvement Area (NIA). The initiatives include catchment management schemes (e.g. through CSF partnerships or water company funded actions), environmental stewardship schemes, voluntary changes to land-management and enforcement by the Environment Agency. The investigation used nitrate source apportionment, risk mapping and trend modelling at different scales of catchment to build up a set of potential actions which could be implemented to improve groundwater quality. The potential actions or measures identified for individual PWS abstractions have also been assessed economically to produce nitrate cost-curves which identify the most cost-effective measure per abstraction.

The outcomes of source apportionment of 17 groundwater bodies (GWBs) in the study area identified that the main sources of nitrate were agricultural, from wheat and oil seed rape crops, or from grassland receiving fertiliser inputs. Landfill contribution could also be high, but there is large uncertainty in this term and further work to refine this, where relevant, should be carried out. Mains leakage and sewer leakage may also provide high contributions of nitrate to groundwater in densely populated areas, although most large conurbations are at the coast and this groundwater will discharge to the sea.

Predicted nitrate concentrations leaching from soils at the current day are above the WFD threshold value of 37.5 mg/l NO_3 for this parameter at several GWBs, especially where denitrification within the aquifer is identified through very low observed nitrate concentrations or thought to occur due to the presence of impermeable strata and retarded flow (e.g. the Cuckmere and Pevensey Levels Secondary, Adur and Ouse Secondary, Arun and Western Streams Secondary and Isle of Wight Lower Greensand). In implementing measures to address future nitrate, priority should be given to catchments where this attenuation of nitrate is variable or just doesn’t occur, where the contribution of baseflow to rivers discharging to eutrophic transitional waters and where the predicted leaching concentrations exceed the WFD threshold. Nitrate risk mapping was also carried out to support the source apportionment, using N loading, drift cover type and depth to water table to identify groundwater vulnerability. This mapping allows focusing of measures in specific parts of GWBs.

Source apportionment and nitrate trend assessment has also been carried out at ten groundwater Safeguard Zones and for the groundwater contribution to the River Lavant (Sussex). The catchments are typically rural, and the source apportionment identified the main sources of nitrate as wheat, oil seed rape, improved grassland (cut and grazed receiving fertiliser) and woodland. The woodland source is only significant in the Eastergate and Westergate catchments at 10% contribution and is source from 44% of the catchment area indicating that woodland is actually a good sink of nitrate compared to arable land. The trend modelling produced a good fit at the Lovedean, Eastergate, Twyford, Findon, Patcham, Newmarket and Housedean sources. Predicted trends suggested that the maximum nitrate concentrations would be seen at abstractions between 2036 and 2044, but that the DWS would not be exceeded at Patcham. Based on the model outcomes a series of measures have been developed and based on the area of coverage and estimated number and type of farm in each catchment with a good model fit, the costs and benefits of the measures have been assessed. The outcomes of this assessment indicate that the most cost-effective measures relate to land-use change (conversion to woodland or biomass production), whilst reduced cultivation systems, use of clover in place of nitrogen in pasture, manure management plans, using precision farming techniques and spreader calibration also have high cost-effectiveness ratios. The savings to abstractors in terms of treatment of raw water versus measures implementation appear to be very significant, however, the timescale for achieving reductions in nitrate is dependant on the flow mechanisms for nitrate through the unsaturated and saturated zone of the aquifer and the presence of rapid pathways. The benefits of the proposed measures include clean water, improved habitats, air quality improvements, climate regulation, water retention, recreation and tourism and aesthetic value. The assessments carried out have been based on datasets with a level of inherent uncertainty which is increased for smaller catchments due to crop and land-use information resolution. The main recommendations of this work are to improve the datasets and associated models through catchment walkover data and to improve the landfill term for GWB assessments and then re-assess the measures. The designed measures, where implemented, should be accompanied by a baseline survey to provide evidence for future measures effectiveness testing including: the level of uptake of the measures; the costs of implementation of the measure; and monitoring of abstracted groundwater, soil waters and unsaturated zone porewaters.

Contents

1. Introduction

1.1 Project Drivers

Groundwater classification undertaken in Cycle 1 and Cycle 2 of the EU Water Framework Directive (WFD) has identified rising trends in nitrate leading to ‘poor status’ for the Test, Itchen, Chichester, Worthing Brighton, Seaford and Eastbourne, East Hampshire, Isle of Wight Southern Downs and Isle of Wight Central Downs Chalk groundwater bodies (GWBs) (Figure 1.1). The Environment Agency has designated Safeguard Zones for some of the public water supply groundwater abstractions which are causing poor status due to rising trends in nitrate. The Environment Agency, Portsmouth Water and Southern Water Services have duties under both the WFD and the Water Supply (Water Quality) Regulations (2010) to mitigate the impact of nitrate in groundwater and surface waters on drinking water supplies and the water environment.

The failing GWBs all sit within the South East River Basin Management Plan (SERBMP) as completed by the Environment Agency (2009) and also overlap the South Downs Way Ahead Nature Improvement Area (NIA), managed by the South Downs National Park Authority (Figure 1.2).

The NIA is planned to protect, restore and reconnect endangered Chalk downland in the National Park and brings together partner organisations to protect wildlife habitats and the environmental (including water environment), economic and social benefits they bring within the NIA. Through working as part of the NIA the project board the South Downs National Park Authority, the Environment Agency, Portsmouth Water, Downs and Harbours Clean Water Partnership and Southern Water, bring a collaborative approach to addressing the problem of nitrate in groundwater, and receiving surface waters, to achieve benefits for all parties. The work reported here has been identified by the project board and will help to focus actions to mitigate and reverse nitrate trends causing poor status of groundwater and surface water bodies. The recommendations made from this work will be used in future implementation of the NIA.

1.2 Project Aims

The principal aim of the South Downs Collaborative Nitrate Modelling Project is the production of compelling evidence regarding nitrate loadings to inform/drive existing or new initiatives to (ultimately) reverse trends in nitrate, improve groundwater quality and deliver sustainable land management practices across the South Downs Way Ahead NIA. These initiatives include potential water company catchment management schemes (funded through the water company Asset Management Plan process), the targeting of environmental stewardship schemes, ‘voluntary’ behavioural change and enforcement by the Environment Agency. AMEC has been commissioned by the project board to carry nitrate modelling, source apportionment, measures assessment and simple cost benefit analysis to support these initiatives. The scope of this work is outlined in the following text.

1.3 Scope of Work

1.3.1 Nitrate Source Apportionment

The first task of the South Downs Collaborative Nitrate Modelling Project is to undertake nitrate source apportionment modelling, using the Environment Agency's source apportionment spreadsheet tool, for seven South East River Basin Districts (RBD) catchments, based on Catchment Abstraction Management Strategy (CAMS) areas (Environment Agency, 2009) (Figure 1.2) including the:

- Cuckmere and Pevensey Levels;
- Adur and Ouse;
- Arun and Western Streams;
- East Hampshire;
- Test and Itchen;
- Isle of Wight; and
- New Forest.

1.3.2 Nitrate Risk Mapping

This first task also includes the production of nitrate risk maps using nitrate leaching from soils, depth to water table and likelihood of rapid recharge for each catchment, where this information is available. The risk mapping based on N-loading and depth to water table would only be produced for areas with gridded water table data available (i.e. groundwater model areas – mainly chalk aquifer) whilst N-loading maps would be provided for all of the RBD catchments. The aim of this work is to provide a means of communicating the extent and location of high risk areas. They are not intended for detailed targeting work as they are only accurate at regional scale.

The second task in this project is to focus more closely on identified areas of concern, i.e. several Safeguard Zones and the River Lavant catchment which feeds into Chichester Harbour. Safeguard Zones are non-statutory areas around public water supplies which are at risk of needing additional treatment due to deterioration of water quality because of pollution. Catchment measures can be targeted within these areas to reverse trends in pollution in compliance with Article 7 of the WFD. Voluntary action to improve and protect water quality by land-owners in the safeguard zone is supported by the Environment Agency (in many cases working in collaboration with water companies and other interested parties).

This project is a pilot study for work that will have to be carried out on all Safeguard Zones under PR14. Therefore, safeguard zones that represent various geological settings, are distributed across the South Downs Way Ahead NIA and include both Southern Water and Portsmouth Water sources have been selected. All abstractions have long term rising trends in nitrate. The following groundwater abstractions have been identified as safeguard zones, and pollutant trends observed in groundwater have been investigated through nitrate source apportionment and nitrate trend modelling (Figure 1.3):

- Twyford (Itchen Chalk);
- Findon and Burpham (Worthing Chalk);
- Lovedean (East Hants Chalk);
- Westergate and Eastergate (Chichester Chalk); and
- Patcham, Newmarket, Housedean and Mossy Bottom (Brighton Chalk).

Twyford is located within the Itchen Chalk and there is supplementary information available from the BGS investigation of nitrate porewater profiles at the nearby Morestead site, (Stuart et al., 2008), which will help verify the nitrate modelling outcomes.

Southern Water sources, Findon and Burpham, are located in the Worthing Chalk, whilst Housedean, Mossy Bottom, Patcham and Newmarket are located in the Brighton Chalk. Portsmouth Water sources, Eastergate and Westergate, are located in the Chichester Chalk and Lovedean is located in the East Hants Chalk. Eastergate and Westergate show very large seasonal fluctuations and high peaks of nitrate, which are likely to be influenced by rapid fissure flow due the presence of solution features in this area.

The River Lavant has also been investigated with respect to nitrate trends as this catchment drains to Chichester Harbour which is at risk from eutrophication due to elevated nitrate levels.

Based on the outcomes of this work and where a good model fit is achieved the reduction in nitrate leaching required to reach target concentrations have been modelled. Simple cost benefit analysis has also been carried out to identify the most cost-effective actions to implement in these catchments.

1.4 Structure of this Report

The report is structure is set out as in the project specification. The source apportionment of nitrate for the GWBs in the seven CAMS areas in the Environment Agency's South East Region is described in Section 2, with a short conceptual understanding of each GWB followed by a description of the results of sources apportionment. Section 2 also includes a discussion of the uncertainty in the model outputs. Section 3 describes the production of maps which show the risk to groundwater from nitrate loading at the land surface. Section 4 covers the sources apportionment of nitrate and modelling of historic and future nitrate trends at 10 PWS abstractions and the River Lavant (Sussex) catchment, and includes a discussion of the proposed measures to achieve GWB chemical status objectives. The cost benefit analysis of the measures proposed in Section 4 is described in Section 5, whilst Section 6 provides a synthesis of the whole report.

Several appendices provide supporting material for the report:

- Appendix A provides detail of the source apportionment model;

- Appendix B uncertainty and sensitivity assessment for source apportionment models;
- Appendix C source apportionment models for N provided as Excel files for each GWB;
- Appendix D nitrate trend model spreadsheet design and set up; and
- Appendix E Results of nitrate modelling by catchment in individual catchment reports.

2. Source Apportionment at 7 SERBD Catchments

2.1 N&P Source Apportionment Spreadsheet

In 2010 AMEC were commissioned by the Environment Agency (England and Wales), SEPA, the Environment Agency (Northern Ireland) and the EPA (Ireland) to carry out a literature survey of sources of nitrate (N) and phosphate (P) loading to groundwater, and to collate the findings in a spreadsheet tool that could be used for source apportionment of N and P in catchments (AMEC, 2010).

The N and P source apportionment spreadsheet has been used in this study to assess agricultural and non-agricultural sources of N in the GWBs in the seven surface water catchments listed in Section 1.3. This Excel based tool uses information on the spatial extent of nitrogen sources, the likely loading value from each source and information about hydrologically effective rainfall and attenuation rates to calculate the contribution from each source to the catchment N budget, the concentration of N in soils and also going to groundwater. The calculations and default values used are discussed in detail in AMEC, 2010, and Appendix A of this report provides a short summary of assumptions made.

The spreadsheet produces a predicted nitrate concentration in leached soil water for the catchment of interest. To "ground truth" the source apportionment calculations the seven surface water catchments were divided into the 17 GWBs reported in Table 2.1 (based on WFD delineated GWBs). An average nitrate concentration for groundwater in each body for the period 2010 to 2013 was calculated based on data from the Environment Agency Groundwater Quality Monitoring Network and compared to the nitrate concentrations in soils predicted from the source apportionment spreadsheet. Data sources used in the spreadsheet ranged from 2005 to 2013 in age, and the time range and format of datasets is provided in Table 2.2.

The following sections of this report provide:

- Sections 2.2 and 2.3 - An overview of the datasets used to complete the spreadsheet including a description of any manipulation of the data prior to use. More detailed description of the calculations carried out in the spreadsheet is provided in Appendix A;
- Section 2.4 - A concise conceptual understanding of each GWB with respect to nitrate fate and transport, grouped by CAMS area. The results of the spreadsheet calculations and a comment on the closeness of fit of the predicted soil nitrate concentration to the average GWB nitrate concentration; and
- Section 2.5 - Assumptions made in using the source apportionment spreadsheet, and the likely sources of errors and uncertainty.

Table 2.1 SERBD Catchments and Associated GWB ID and Names, and Study ID Number

GWB Name	GWB ID	SERBD Surface Water Catchment	Study Name	Study ID
Seaford and Eastbourne Chalk	GB40701G501100	Cuckmere and Pevensey Levels	Seaford and Eastbourne Chalk Block	1
Hastings Beds Cuckmere and Pevensey Levels	GB40702G502100	Cuckmere and Pevensey Levels	Cuckmere and Pevensey Levels Secondary	2
Lower Greensand Cuckmere & Pevensey Levels	GB40701G502600	Cuckmere and Pevensey Levels	Cuckmere and Pevensey Levels Lower Greensand	3
Brighton Chalk Block	GB40701G502500	Adur and Ouse	Brighton Chalk Block	4
Lower Greensand Adur & Ouse	GB40701G502400	Adur and Ouse	Adur and Ouse Lower Greensand	5
Adur & Ouse Hastings Beds	GB40702G502000	Adur and Ouse	Adur and Ouse Secondary	6
Chichester Chalk (Draft WFD Cycle 2 GWB)	GB40701G505200	Arun and Western Streams	Arun and Western Streams Chalk	7
Worthing Chalk (Draft WFD Cycle 2 GWB)	GB40701G505300	Arun and Western Streams		
Littlehampton Anticline East	GB40701G503400	Arun and Western Streams		
Littlehampton Anticline West	GB40701G504900	Arun and Western Streams		
Lower Greensand Arun & Western Streams	GB40701G503100	Arun and Western Streams	Arun and Western Streams Lower Greensand	8
Arun & Western Streams Hastings Beds	GB40702G500600	Arun and Western Streams	Arun and Western Streams Secondary	9
East Hants Chalk	GB40701G502700	East Hampshire	East Hampshire Chalk	10
South East Hants Bracklesham Group	GB40702G503000	East Hampshire	East Hampshire Secondary	11
East Hants Lambeth Group	GB40702G500800	East Hampshire		
South Hants Lambeth Group	GB40702G503700	East Hampshire		
River Itchen Chalk	GB40701G505000	Test and Itchen	Test and Itchen Chalk	12
River Test Chalk	GB40701G501200	Test and Itchen		

Table 2.1 (continued) SERBD Catchments and Associated GWB ID and Names, and Study ID Number

GWB Name	GWB ID	SERBD Surface Water Catchment	Study Name	Study ID
Central Hants Bracklesham Group	GB40702G500900	Test and Itchen	Test and Itchen Secondary	13
Central Hants Lambeth Group	GB40702G503800	Test and Itchen		
IOW Lower Greensand	GB40701G502900	Isle of Wight	Isle of Wight Lower Greensand	14
IOW Southern Downs Chalk	GB40701G502800	Isle of Wight	Isle of Wight Chalk	15
IOW Central Downs Chalk	GB40701G503200	Isle of Wight		
IOW Solent Group	GB40702G501000	Isle of Wight	Isle of Wight Secondary	16
South West Hants Barton Group[2]	GB40702G504000	New Forest	New Forest Secondary	17

IOW = Isle of Wight, T&I = Test and Itchen, EH = East Hants, A&WS = Arun and Western Streams, A&O = Adur and Ouse, C&PL = Cuckmere and Pevensey Levels.
1 At the project inception these GWBs were part of the Chichester-Worthing-Portsdown Chalk which has since been divided into these two areas. In this report they are reported on as one unit.
2 At project inception this GWB was made up of the South West Hants Barton Group. Although the GWB has been updated and in Cycle 2 of the WFD to include the South West Hants Barton Group and SW Hants Solent Group GWBs, the previous GWB boundary has been used for the purposes of this report.

2.2 Overview

The source apportionment calculations are based on the estimation of nitrate loadings from point and diffuse sources at the base of the soil zone, with subsequent attenuation in the unsaturated zone where applicable, to provide estimates of the nitrate loading at the water table arising from each potential source of nitrate. The user is required to enter catchment hydrological and landscape data (such as land use, population etc.). For many model parameters default values are provided, and these may be over-written by the user if local data are available.

Sources of nitrate included in the spreadsheet calculations are:

- Landfill;
- Graveyards;
- Sewage effluent discharges to ground;
- Mains water and sewer leakage;
- Agricultural point sources (e.g. leakage from slurry stores);
- Agricultural diffuse sources (e.g. application of organic and inorganic fertilisers to arable crops and improved grassland); and
- Urban diffuse sources (e.g. application of fertiliser to parks and gardens).

Additional sources of nitrate include atmospheric deposition and, in rural areas, fixation in soil.

The main output of the calculations is a summary, as tables and pie charts, of the proportion of the total nitrate loading at the water table in each catchment which arises from each potential source. In addition, the nitrate concentration in recharge at the water table is calculated. Further detail of the calculations undertaken in the spreadsheet is given in Appendix A of this report.

2.3 Input Data

This section describes the main data sources used to provide the key inputs to the source apportionment spreadsheet. The data sources include spatial information at differing scales and, as noted previously, the data has been clipped to the 17 grouped GWBs which make up the seven surface water catchments to be reported on. The catchments have been reported on in this manner in order to enable a meaningful comparison to be made with average groundwater nitrate concentrations (Section 2.3.6). These preliminary source apportionment spreadsheets can be improved and updated by catchment management officers as more local knowledge and data become available in the future. A table of the complete data inputs to the spreadsheets is shown in Table 2.2.

Table 2.2 Model input data Used in Source Apportionment (SA) Spreadsheets for 17 GWBs Listed in Table 2.1

Catchment Characteristic	Units	Seaford and Eastbourne Chalk	C&PL Secondary	C&PL LGS	Brighton Chalk	A&O LGS	A&O Secondary	A&WS Chalk	A&WS LGS	A&WS Secondary	EH Chalk	EH Secondary	T&I Chalk	T&I Secondary	IOW LGS	IOW Chalk	IOW Secondary	NF Secondary
Catchment Area (based on Cycle 1 WFD GWB boundaries)	ha	12402	27066	1061	25774	5126	35113	56781	22698	4294	26564	17555	142294	31587	10935	6709	18502	32317
Infiltration recharge "lumped" per catchment[1]	mm/yr	344	292	320	355	320	344	400	394	329	416	301	316	301	170	450	329	329
Dominant Soil (Sand, Loam or Clay)[2]		Sand	Sand	Loam	Sand	Loam	Sand	Sand	Sand	Sand	Sand	Loam	Sand	Loam	Loam	Sand	Loam	Loam
Population (based on 2011 census)																		
Sewered population		72731	148175	10006	315826	12500	70483	227485	46781	38000	105281	356985	153819	341068	29437	5444	93057	77225
Sewered population (with discharge of treated effluent to ground)[3]		1533	0	0	192	0	0	349	82	0	48	0	52606	2891	0	0	0	0
Number of people served by septic tanks[3]		2942	2814	443	2087	50	5815	757	546	500	750	250	17355	8146	698	2689	500	5542
Number of people served by package treatment plants		2942	2814	443	2087	50	5815	757	546	500	750	250	17355	8146	698	2689	500	5542
Urban Land Use (OS mapping)																		
Total urban/suburban area (Built up areas and gardens)	ha	1841.5	3109.9	168.8	5151.1	404.6	1478	5166.8	1653.5	904	2332.1	6566.6	4484.4	7510.2	817.5	148.3	2384.1	2984.6
Area gardens	ha	921	1555	84	2576	202	739	2583	827	452	1166	3283	2242	3755	409	74	1192	1492
Area allotments	ha	115	194	11	322	25	92	323	103	57	146	410	280	469	51	9	149	187
Area of paved surfaces draining to ground	ha	460	777	42	1288	101	370	1292	413	226	583	1642	1121	1878	204	37	596	746
Area of buildings and paved surfaces (no drainage to ground)	ha	230	388.5	21	644	50.5	185	646	206.5	113	291.5	821	560.5	939	102	18.5	298	373
Area of sports grounds etc	ha	115	194	11	322	25	92	323	103	57	146	410	280	469	51	9	149	187
Area of roads and paved surfaces (outside urban)	ha	147.13	418.22	12.55	352.45	68.30	486.56	670.30	321.63	65.31	460.04	368.22	1804.66	562.99	162.57	64.59	261.73	396.21
Rural Land Use (from Agricultural Census 2010)																		
Grazed Grass (more than 5 years old)	ha	1631	3804	142	3274	814	3442	4108	1741	174	1857	678	8308	1520	1356	756	1867	891
Cut Grass (used for silage)	ha	1631	3804	142	3274	814	3442	4108	1741	174	1857	678	8308	1520	1356	756	1867	891
Temporary Grass (less than 5 years old)	ha	182	847	42	797	268	1201	1534	654	68	643	221	5619	554	808	338	645	261
Cereal crops[4]	ha	478	350	30	1071	166	680	3033	756	41	2030	236	18052	408	278	166	358	124
Other arable[5]	ha	125	662	42	492	189	815	1497	436	61	893	127	7110	421	233	221	494	476
Bare fallow	ha	101	128	7	294	76	173	572	147	9	222	50	2677	129	155	67	99	72
Rough grazing	ha	1005	1683	111	1721	665	4513	3745	1215	330	2258	1301	12959	2558	685	343	1026	2408
Orchards	ha	1	30	1	10	2	37	24	16	0	0	0	112	0	7	2	6	2
Woodland (calculated from Land use 2007)	ha	1157	3882	29	1300	244	8059	11290	6541	1253	3553	2155	17389	7313	628	1030	2903	10257

Table 2.2 (continued) Data Used in Source Apportionment (SA) Spreadsheets for 17 GWBs Listed in Table 2.1

Catchment Characteristic	Units	Seaford and Eastbourne Chalk	C&PL Secondary	C&PL LGS	Brighton Chalk	A&O LGS	A&O Secondary	A&WS Chalk	A&WS LGS	A&WS Secondary	EH Chalk	EH Secondary	T&I Chalk	T&I Secondary	IOW LGS	IOW Chalk	IOW Secondary	NF Secondary
Ploughed out long term grass (zero unless other info available)	ha	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Winter OSR[6]	ha	313	310	31	563	86	181	1064	243	7	1564	235	10191	349	157	135	277	182
Spring OSR[6]	ha	0	26	0	10	3	13	67	23	3	9	2	149	1	0	0	0	0
Potatoes	ha	3	1	0	7	8	11	106	83	0	16	5	60	9	63	11	9	14
Wheat[7]	ha	687	900	80	1440	406	977	4919	1144	61	2803	451	21056	714	1032	634	1116	489
Vegetables in the open[8]	ha	0.3	8	0.3	51	18	15	435	294	0	45	89	301	38	270	51	61	4
Livestock Numbers (from Agricultural Census 2010)																		
Cattle	hd	2560	7765	257	6131	1490	7571	9424	4259	351	5758	2608	21193	5346	3392	1952	5567	2300
Sheep (includes goats and horses)	hd	11615	22708	711	19367	3586	12427	22041	9062	596	7511	1318	51560	2953	13081	6844	8307	1684
Pigs	hd	240	732	10	1031	366	2326	3441	998	56	1808	367	21910	2337	213	132	321	2155
Poultry	hd	44091	59890	3882	53426	23031	96063	101964	56949	768	110312	21417	1416778	117082	19724	8219	4662	59318
Landfills and Graveyards																		
Area of graveyards (calc)	ha	25	54	2	52	10	70	114	45	9	53	35	285	63	22	13	37	65
Area of graveyards (calc) + OS Map	ha	20	50	2	55	9	65	78	35	10	30	45	120	50	13	10	35	50
Area of landfill (inert)	ha	21	59	19	120	33	67	226	35	28	132	278	239	398	56	12	78	304
Area of landfill (non hazardous)	ha	19	72	2	113	45	11	78	61	0	308	535	136	550	13	3	100	167
Agricultural Point Sources																		
Area of engineered slurry stores	ha	0.25	0.76	0.03	0.60	0.15	0.74	0.92	0.42	0.03	0.56	0.26	2.08	0.52	0.33	0.19	0.55	0.23
Area of unlined slurry stores	ha	0.25	0.76	0.03	0.60	0.15	0.74	0.92	0.42	0.03	0.56	0.26	2.08	0.52	0.33	0.19	0.55	0.23
Area generating farmyard run-off	ha	2.5	5.5	0	5	1	5	6	2.5	0.5	3	1	12.5	2.5	2	1	3	1.5
Area of constructed wetlands	ha	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

1 Infiltration recharge based on 4R recharge model data where GWB is in a regional groundwater model area or on Environment Agency Soil Moisture model.
2 Soil type is used to determine the hydrological characteristics of the soil only. Sand or loam have been chosen as most representative of the thin soils over Chalk.
3 The total population not served by mains sewers is estimated from the difference between the sewered population (information provided by sewerage undertakers) and total population (from parish census 2011). The unsewered population is assumed to be served by septic tanks and package treatment plants in equal number.
4 Includes spring and winter barley, oats, rye, triticale and mixed grains.
5 Is interpreted as non- specified arable crops (based on total area of arable land minus the sum of uncropped arable land, grass under 5 yrs old, cereal crops (rye, triticale, oats barley wheat), oil seed rape (winter and spring), potatoes and vegetables grown in the open).
6 Oil seed rape.
7 Wheat category assumed to include winter and spring sown crops, as not specified in Agricultural Census data.
8 Vegetables grown in the open, does not include poly tunnels or glass houses.

2.3.1 Catchment Area

The catchment models are based on the GWB boundaries as defined for Cycle 1 of the WFD classification exercise. Updates to these boundaries have been made part way through Cycle 2 (and through this project). The main differences are the addition of the Chichester Chalk and Worthing Chalk (with no change to GWB area) and the South West Hants Solent Group and Barton Groups (with some change to GWB area). The boundaries used in this study are those for Cycle 1, as the changes to boundaries should not significantly change the outcomes of this exercise. It is noted that where GWB boundaries overlap coastal areas, especially with a high concentration of urban development and hardstanding, predicted N leaching to groundwater will be overestimated as these areas will ultimately discharge to the sea.

2.3.2 HER and Infiltration Recharge

The source apportionment spreadsheet is based on the conceptual understanding of nitrate being leached from the root zone by hydrologically effective rainfall (HER), i.e. rainfall not removed from the soil through evapotranspiration. Not all of the HER becomes recharge to groundwater (or infiltration recharge) as some will become runoff, or subsurface lateral flow to streams (interflow). If HER and infiltration recharge are not easily available, the spreadsheet tool can provide a crude estimation based on more commonly available data such as total rainfall and potential evapotranspiration (PE). For this work, however, it was not necessary to estimate long term average (LTA) infiltration recharge as this was already available for catchment (as shown in Table 2.2) from the following recharge models:

- Test and Itchen 4R model (250 m resolution, LTA range 1970-2011);
- East Hants and Chichester Chalk 4R model (250 m resolution, LTA range 1970-2011);
- Brighton and Worthing 4R model (200 m resolution, LTA range 1970-2011);
- Isle of Wight 4R model (LTA range 1990-2006); and
- Environment Agency Soil Moisture Model[1] (South East Region) (LTA range 1961-1990).

In order to estimate HER, it was assumed that the proportion of HER that becomes infiltration recharge is a function of the underlying geology of the catchment or waterbody. For Mudstone catchments, this proportion was assumed equal to 0.6; for Chalk and Sandstone catchments it was assumed equal to 0.8. Knowing the infiltration recharge and geology of the catchment, it was then possible to “back-calculate” the HER. Calculated infiltration recharge and estimated HER for each waterbody are shown in Table 2.3. For completeness, estimated PE is also shown (calculated as total rainfall minus HER), although this is not used in source apportionment calculations. An estimated LTA of 850 mm/year was used for all catchments to calculate the PE. Variation in rainfall over the

[1] The Soil Moisture Model (SMD) is based on the soil moisture accounting section of the Catchmod Rainfall Runoff Model and is used to calculate SMD and recharge for South East Region.

catchments will already be included in the modelled infiltration recharge values, and therefore in the back-calculated HER values.

Table 2.3 Catchment Recharge and HER Values Used for Source Apportionment Calculations Based on Infiltration Recharge and Rainfall Average (850 mm/a)

GWB	Infiltration Recharge (IR) (mm/year)	Proportion of HER Reaching the Water Table	Hydrologically Effective Rainfall (HER) (mm/year)	Potential Evapotranspiration (PE) (mm/year)
Cuckmere and Pevensey Levels Chalk	343.90	0.8	429.88	420.13
Cuckmere and Pevensey Levels Secondary	291.90	0.6	486.50	363.50
Cuckmere and Pevensey Levels Lower Greensand	319.70	0.8	399.63	450.38
Adur and Ouse Chalk	355.00	0.8	443.75	406.25
Adur and Ouse Lower Greensand	320.10	0.8	400.13	449.88
Adur and Ouse Secondary	343.60	0.6	572.67	277.33
Arun and Western Streams Chalk	400.00	0.8	500.00	350.00
Arun and Western Streams Lower Greensand	394.00	0.8	492.50	357.50
Arun and Western Streams Secondary	329.30	0.6	548.83	301.17
East Hants Chalk	416.00	0.8	520.00	330.00
East Hants Secondary	300.70	0.6	501.17	348.83
Test and Itchen Chalk	316.00	0.8	395.00	455.00
Test and Itchen Secondary	300.70	0.6	501.17	348.83
Isle of Wight Lower Greensand	170.00	0.8	212.50	637.50
Isle of Wight Chalk	450.00	0.8	562.50	287.50
Isle of Wight Secondary	328.50	0.6	547.50	302.50
New Forest Secondary	328.70	0.6	547.83	302.17

2.3.3 Soils

Information about soil type is used in the source apportionment calculation to account for field capacity and leaching potential of the soil. Soils information for each GWB was summarised from the Environment Agency's Soils Toolkit based on NATMAP, the National Soil Map of England and Wales, 1 km^2 gridded data. The spreadsheet model requires a simple soil classification of Sand, Clay or Loam per catchment. The soil type assigned to each catchment was based on the greatest proportion of land covered (Table 2.2).

2.3.4 Diffuse Sources of Nitrate

Diffuse sources of nitrate to groundwater include nitrate leaching from soils and moving to the water table through the unsaturated zone. In most rural catchments, land use is predominantly agricultural and leaching from agricultural soils forms the majority of diffuse nitrate inputs to groundwater. There will be nitrate leached from other land such as woodland and low-input rough grazing land, but at a much lower rate than from improved grassland or arable land which receives nitrogen fertiliser. This section describes the derivation of estimates of areas of agricultural crops and managed (improved) grassland and the assumptions made about how much N leaches from these land-use areas based on fertiliser input rates. The aerial deposition of N from the atmosphere is already included in the source apportionment spreadsheet, based on the N-CYCLE model outputs for this source.

Land Use 2007

The Centre for Ecology and Hydrology (CEH) Land Cover Map 2007 (LCM2007) dataset is based on remote sensing data and provides an indication of the location and areal extent of different land-use types in 2007. It does not distinguish between crop types on arable land, or between agricultural improved grassland and other areas of improved grassland (e.g. amenity land such as golf courses etc.). LCM2007 does distinguish between improved grassland (which receives nitrogen fertiliser inputs) and semi-natural grassland or rough grazing (assumed not to receive nitrogen fertiliser). This spatial dataset was used to estimate the area in each catchment which is considered to be urban (urban/suburban) and woodland (broadleaved and coniferous woodland). The total urban/suburban area was split between gardens, allotments, paved surfaces draining to ground, buildings and sports grounds based on the proportions suggested in AMEC, 2010. The area of woodland from LCM2007 is a direct input into the source apportionment spreadsheet tool. Other areas of rural land use have been calculated from agricultural census data as described below.

Agricultural Census Data

EDINA agricultural census data for 2010, supplied on a 2 km (i.e. 4 km^2) grid, were used to estimate detailed cropping information and livestock numbers in each catchment. The agricultural census data was used to derive areas of cropped land and crop type in each catchment by clipping the gridded information to catchment boundaries. However, as the catchment boundaries are not consistent with the agricultural census grid squares, the area of each agricultural census grid square within each catchment was calculated and the crop areas and livestock numbers were weighted for the proportion of grid square within the boundary, before calculating a total for each catchment. The mapping of agricultural census categories to the source apportionment input types is shown in Table 2.4.

There are several areas of uncertainty in using this dataset for source apportionment, however, it is the best information available, after actual site walkover data, and therefore is the appropriate dataset to use. However, it is useful to be clear about the sources of uncertainty in the agricultural census data when used in the context of nitrate source apportionment.

Uncertainty in the supplied data - The supplied dataset already has uncertainty associated with it due to the way data has been gathered for each farm in a parish. Farms overlapping parish boundaries or reporting for other farms in neighbouring parishes, or where livestock feed in a different parish to the farm which own and report on them can lead to underestimates or overestimates in reported data. This uncertainty is further exacerbated by the aggregation of the processed 1 km grid dataset to a 2 km grid to protect anonymity (EDINA website, 2014). Where catchments, for example safeguard zones, are less than 4 km^2 in extent the census data becomes much more uncertain, and at this scale should only be used as representative of typical farming in the local area.

Representing crop rotations - Crop rotations are not represented directly through using the census "snapshot" for farming in 2010. It can be assumed, however, that this one year of census data will represent one cycle of a rotation that will be repeated, albeit in different fields in the consecutive years. At the GWB scale the change in crop rotation from year to year is unlikely to provide much variation in the overall cropping data. At the smaller safeguard zone (discussed in Section 4) the scale the effects of crop rotations may be more significant, but it is not possible to account for this with available data, and this represents a source of uncertainty.

Extracting catchment scale data - During the clipping exercise where grid squares overlap the catchment boundary the cropping area calculation method can produce an under or over estimate of the actual extent of crop types.

"Non-owned" or unreported areas - Agricultural Census data only covers agricultural land which is associated with a County Parish Holding (CPH) number. This will include all land which is registered with the Rural Payments Agency as agricultural premises, or where livestock (cattle, sheep, goats or pigs) are kept. Land that is not associated with agricultural premises (for example New Forest National Park land), or common grazing land, may not be included in the calculated area. Equestrian enterprises will be included only if they are registered for Single Farm Payments.

Areas of open water - Similarly areas of open water (lakes and rivers) are also not included in the census data. Blank grid cells, particularly along the coastline, where agricultural census data is not available, also add to the discrepancy between reported area and actual GWB area, although these missing data are relatively small (<2.5% of the catchment area).

These "gaps" in the extent of the Agricultural Census data lead to significant differences between the actual GWB area and the reported area, with the modelled area making up between 62% (New Forest Secondary)and 84% (Adur &Ouse Lower Greensand and Test and Itchen Chalk) of the actual total catchment area. The low value for the New Forest catchment is probably due to large amount of "non-owned" rough grazing land in the New Forest National Park area. The impact of this difference is discussed further in Section 2.5.

Farm visit data for the Portsmouth Water area for 2012 was also supplied by the Downs and Harbours Clean Water Partnership. This included; head of dairy cattle per farm, slurry store type (where known) and information on the location of equestrian centres. The dairy cattle information was used as another means of calculating stocking density over the Chalk grassland parts of the study area and compared well with the numbers calculated from the Agricultural Census data for 2010.

Fertiliser Application Rates

Fertiliser application rates for various input crops were based on recommended rates from the Defra Fertiliser Manual RB209 (Defra, 2010). In practice, fertiliser applications may vary around the recommended rates depending on individual management practices and site soils and climactic conditions, leading to some uncertainty in input data. Although the spreadsheet does allow the user to enter a value for inorganic and organic fertiliser applications it does not differentiate between these (i.e. there is no control on the rate of release of N). The key input figure is therefore the total nitrogen application (organic and inorganic), and the calculations are not sensitive to the assumed proportion of each applied.

Grassland Management System

The spreadsheet calculates N losses from grassland based on soil type and grassland system (i.e. grazed pasture or cut grass for hay and silage; see Table 2.4). Agricultural census data identifies the area of improved grassland over and under 5 years old that is associated with agricultural holdings, but it does not distinguish between cut and grazed grass. For the purposes of estimating grassland areas under each system, improved grassland over 5 years old has been divided equally into "grazed" and "cut", and improved grassland under 5 years old has been assumed to be temporary or rotational grass. LCM 2007 identifies improved grassland (which is assumed equivalent to improved grassland as it is identified in agricultural census data) and various other types of grassland. All other (non-improved i.e. not receiving manufactured or manure based fertiliser applications) grass is assumed to be rough grazing land or semi-natural vegetation which does not receive nitrogen fertiliser.

Model input data derived from these data sources is shown in Table 2.2.

Crop Of-take

The amount of N that is taken up from soils by crops and grass by grazing cattle is based on literature values reported in AMEC (2010). It is noted that for woodland the uptake of N can differ significantly depending on the age of trees, from very high for younger stands to relatively low at more established stands of trees. The only input at forestry sites is atmospheric deposition, and as no information is available on the typical age of trees in catchments, the uptake has been set to zero. Where woodland covers a significant proportion of the catchment the low crop offtake can mean that the N leaching from this land-use becomes significant.

Table 2.4 Mapping of Source Apportionment Tool Input Data to Agricultural Census Categories

Category	EDINA Classification
Grazed Grass	Half of 'Grass over 5 years old'.
Cut Grass	Half of 'Grass over 5 years old'.
Temporary Grass	Grass under 5 years old.
Cereal Crops	Winter and spring barley, oats and minor cereals such as rye and triticale (wheat listed separately).
Other Arable	Non specified arable crops (total arable land minus uncropped arable land, grass under 5 yrs old, cereal crops (including wheat), oil seed rape (winter and spring) and potatoes).
Vegetables grown in the open	Vegetables grown in the open i.e. not under a polytunnel or in glasshouses.
Bare Fallow	Uncropped arable land.

Table 2.4 (continued) Mapping of Source Apportionment Tool Input Data to Agricultural Census Categories

Category	EDINA Classification
Rough Grazing	Rough grazing (all unimproved grassland including Chalk grassland).
Orchards	Orchards.
User-defined crops	Winter oil seed rape, spring oil seed rape, potatoes and wheat.

Note on Land Use Areas Derived from LCM2007 and Agricultural Census Data for 2010

The LCM2007 dataset does not distinguish between different crop types and the agricultural census data has been used to provide the additional detail with regards to different arable crops, and to confirm areas of improved or improved grassland and rough grazing. However, there can be significant discrepancies between the total areas of these land uses derived from the two datasets, due to uncertainty in both datasets and also because agricultural census data will include only land associated with an agricultural holding number. For these reasons, the total areas of arable land and improved grassland in a catchment derived from census data are often smaller than the areas derived from LCM2007 data. There is little than can be done to address the difference in areas at this scale.

The same issue applies at catchment scale, and is discussed in Section 4. However, at this smaller spatial scale it may be possible to refine the estimates of land use through the use of additional datasets such as aerial photography and for some catchments Google Earth images have been for this purpose.

Urban Areas and Surface Water Run-off from Roads and Pavements

The area of urban land and roads in each catchment is calculated from LCM2007 and from the OS master map dataset. The area of gardens, allotments, sports grounds and paved surfaces draining to ground and buildings and paved areas not draining are based on estimated proportions in typical urban and sub-urban areas. The loadings per urban source type are taken from AMEC (2010). These estimated areas are combined with a catchment HER value and leakage rate to produce the urban nitrate input. The area of roads outside of urban areas is calculated using the OS Master Map dataset and the same calculation carried out to produce an N loading from road run-off. The calculated magnitude of this input is strongly controlled by HER and infiltration recharge values as these are used to calculate the concentration of N in run-off from urban land and finally entering groundwater. Therefore, although the loading of N leaving the soil zone from urban land may be greater for larger conurbations, a low infiltration recharge value (for example in the IOW Lower Greensand) will reduce calculated input to groundwater.

2.3.5 Point Sources of Nitrate

The source apportionment spreadsheet requires information on a variety of potential point sources of nitrate, such as mains and sewer leakage, treated sewage effluent discharge, landfill sites (inert and non-hazardous), slurry stores (engineered and unlined) and graveyards.

Mains Water and Sewer Leakage, Treated Effluent Discharges

Population data is used in the source apportionment tool to calculate the inputs of N from sewer leakage, treated effluent discharges to ground and mains leakage.

The population for each GWB was estimated using the 2011 parish level population census data (Office of National Statistics, 2013). OS Maps (1:25 000) were used to provide additional confidence in the population estimates by checking the extent of urban areas, farms and buildings.

The population served by mains water was assumed to be the total population in the GWB, and the leakage rate per head was based on national statistics (AMEC, 2010). This is probably an overestimate since some of the population will have private water supplies (for example in more rural areas of the Test and Itchen Chalk GWBs), but this is unlikely to be a significant source of error in the calculations. The concentration of nitrate in mains water is either assumed to be 75% of the drinking water standard (37.5 mg/l NO_3) or for Chalk GWBs, where groundwater is likely to be the source of mains water the average nitrate concentration for 2010-13 has been used.

Population served by mains sewer (provided by Southern Water) was calculated based on the extent of the sewerage network inside the GWB, with the population served proportioned for this area. To calculate the number of people on private sewerage systems (i.e. septic tanks, package treatment works and cesspit etc.), the total population on mains sewer was subtracted from the total population. About half of the discharges to ground (19 000 m^3/day) in Solent and South Downs Environment Agency area are from Water Companies, and the total discharges to ground (including small private discharges) are about 35 000 m^3/day. Most of the smaller discharges will be from septic tanks, whereas the trade discharges (nursing homes, pubs etc) tend to be larger and have secondary treatment (package treatment plant). In numeric terms about 80% of discharges tend to be septic tanks, but volumetrically there is likely to be an equal split between septic tanks and package treatment works. Cesspits will exist, but as leakage rates should be zero (although this is unlikely) they are not represented as sources of nitrogen.

For GWBs with a more complex boundary (typically secondary aquifers such as the thin and convoluted Lower Greensand outcrop) population and sewer extent data tended to overlap parts of the body boundary. Simple clipping of spatial data did not provide a sensible estimate of population on the sewerage network for these aquifers, and in these cases the distribution of sewerage services was estimated from consented discharges to ground and OS 1:25 000 mapping of domestic buildings. Where the boundaries of parish population data polygons overlaps the boundaries of GWBs a check was made on the location of population centres inside or outside of the GWB. Despite this checking there is likely to be some uncertainty in the population figures, and this is discussed further in Section 2.5.

Landfills

The spreadsheet requires one value of average loading, leakage rate and leachate concentration from landfill across the modelled catchment. The spatial distribution of current and historic landfills was provided by the Environment Agency as a shapefile and with supplementary information on landfill engineering and leachate management where available. Most landfills in the study area are historic and have closed although there are some currently active landfills.

The amount of N from leaching from a landfill in any one year, eventually reaching the water table, is controlled by the type of waste (for the starting N concentration), its age which determines how much the starting term has declined, and the leakage rate which depends on the engineering at the site e.g. unlined, lined, capped etc.

The rate of landfill leachate leakage and nitrogen content has calculated using conservative values from the Environment Agency LandSim manual (Environment Agency, 2003). For the starting leachate concentration a value of 723 mg/l N is used for non-hazardous waste and 28 mg/l N for inert waste. Leakage rates are either set to the infiltration recharge rate for the catchment for non- engineered sites, or to 30 mm/a for sites that have a cap and liner. A reduction in waste leachate concentration due to flushing of waste over time has been applied based on the age of the waste. The reductions, as reported in AMEC, 2010, are as follows based on the date of last input/average year of landfilling:

- 2010 4%;
- 2000 8.5%;
- 1990 16%;
- 1980 18%;
- 1970 21%;
- 1960 27%;
- 1950 32%;
- 1940 37%;
- 1930 42%;
- 1920 48%;
- 1910 59%.

In the spatial datasets landfill waste type and age was usually identified, but no information on landfill engineering was included. The following assumptions were made regarding the age of waste, starting leachate concentration and landfill engineering (for leakage rate) where this data was not provided in spatial datasets or supplementary information:

- For some historic sites no date information was available and here the landfill was assumed to have started in the 1970s (the time when most historic landfill activity appears to have occurred) and was assumed to be unlined and have infiltration recharge as the leakage term (providing a worst case);

- Where the only date available for a historic site was the last date of input this was used in preference to 1970, although the date may be linked to a review of the closed site;
- Landfills with licenses dated or first inputs recorded as after 1990 (where no licence date has been supplied) are assumed to comply with the Environmental Protection Act (1990) and be engineered with a liner and cap, whilst landfills of an age prior to 1990 are assumed to have no engineered protection against leachate generation;
- Where not specified waste is assumed to be non-hazardous, and commercial waste is assumed to be inert.

All leachate that leaks from landfills ends up at the water table unless otherwise specified. Some landfills around Portsmouth and Southampton are known to discharge to the sea and therefore their input is reduced to zero, as is discharge identified as going to nearby surface water. Where landfills are identified as having a leachate management system that means input to the water table is actually negligible, their input has also been reduced to zero.

Slurry Stores

The area of engineered and unlined slurry stores was estimated using the agricultural census data for ‘total cattle and calves’ and farm information provided by Portsmouth Water for the Downs and Harbours Clean Water Partnership area. Based on the farm information provided, the average herd size has been calculated to be 255 head (‘total cattle and calves’/255 = number of herds in each catchment). It is assumed that there is one slurry store per herd and that each slurry store covers 500 m^2 (0.05 ha). Nearly 50% of the slurry stores in the farm information provided by Portsmouth Water are unlined (where construction is unknown it is assumed that the store is unlined). Therefore, in the absence of more detailed information, the calculated area of slurry stores has been split evenly (50:50) between engineered and unlined.

Graveyards

The area of graveyards for each GWB was estimated based on the catchment area (2 500 ha catchment area = 5 ha graveyards) and refined/ confirmed by visual inspection of the OS 1:25 000 scale maps.

2.3.6 Attenuation in the Unsaturated Zone

Natural attenuation of nitrate in the unsaturated zone occurs through microbially mediated denitrification, the reduction of nitrate to nitrite, nitric oxide, nitrous oxide and ultimately to nitrogen gas. In UK aquifers this process typically happens in confined areas, where oxygen has become depleted, although it can happen more locally where the flow of groundwater is impeded by less permeable strata for example clay partings in Chalk or mudstone strata (Environment Agency, 2005). De-nitrification in the unsaturated zone can be significant, and the source apportionment calculations allow for the application of attenuation factors to represent this. Table 2.5 shows typical attenuation rates applied to sources of nitrate, derived from the literature and reported in AMEC (2010).

In the GWBs modelled here de-nitrification is likely to occur at variable rates. The highly fissured unconfined Chalk is unlikely to provide conditions for a significant natural attenuation, although as noted above more localised de-nitrification will occur. The presence of lower permeability formations in some non-Chalk GWBs will retard flow and lead to the development of anaerobic conditions needed for de-nitrification. Observed water quality data, from GWBs which include outcrop of the mudstones of the Hastings Beds can be less than the natural background value of around 4 mg/l $NO_{3,}$ suggesting that nitrate reduction has taken place. Clay rich strata will also provide a substrate for adsorption of ammonium, one of the main products of nitrate reduction, further reducing the concentration of N in the unsaturated zone porewaters. The concentration of nitrate in the Lower Greensand in South East England (Hythe and Folkestone Beds) can vary considerably but one main control is the presence of dissolved oxygen. Where strata are confined, oxygen becomes depleted and nitrate is subsequently reduced to other nitrogen species. Reported concentrations of nitrate reflect this variability in the occurrence of reducing conditions, with values ranging from close to zero to up to 67 mg/l $NO_{3,}$ with median concentrations of between 4 and 16 mg/l NO_3 (Shand et al., 2003). Comparison with average concentrations over a groundwater body can therefore be misleading, especially where geochemical conditions are likely to vary due to processes not represented in the source apportionment model.

For the purposes of this modelling work, **no attenuation has been applied** to calculated nitrate loadings, because of uncertainty in estimating suitable rates. It is clear from a comparison of observed and predicted nitrate concentrations in groundwater that this results in significant over-prediction of nitrate concentrations in GWBs in which denitrification is occurring, as shown in Table 2.7. By contrast, in Chalk groundwater units where less denitrification would be expected, the source apportionment calculations provide a better fit to observations.

Table 2.5 Attenuation Rates in Unsaturated Zone from AMEC, 2010

Land Use	Aquifer Type	Attenuation Rate for Unsaturated Zone
Agricultural land, woodland, grassland, (and urban run-off and roads outside of urban areas)	Chalk	0%
	Intergranular porosity – low clay content	0%
	Intergranular porosity – high clay content	90%
Landfill	Chalk	0%
	Intergranular porosity – low clay content	20%
	Intergranular porosity – high clay content	40%
Sewer leakage	Chalk	0%
	Intergranular porosity – low clay content	40%
	Intergranular porosity – high clay content	90%
Treated sewage effluent	Chalk	0%
	Intergranular porosity – low clay content	40%
	Intergranular porosity – high clay content	80%
Mains leakage	Chalk	0%
	Intergranular porosity – low clay content	0%
	Intergranular porosity – high clay content	90%
Graveyards (assumed the same for animal burials)	Chalk	0%
	Intergranular porosity – low clay content	40%
	Intergranular porosity – high clay content	80%

2.4 Source Apportionment Results

2.4.1 Comparison of Predicted with Modelled Nitrate

Before discussing the outcomes of modelling, the model fit is assessed by comparing predicted nitrate from the source apportionment tool with observed average nitrate concentrations from the Environment Agency's Groundwater Quality Monitoring Network for the period 2010 to 2013. In some cases no nitrate data was available for the period required and earlier data has been used to calculate an average. Details of the data used to calculate average nitrate concentrations for each GWB, and a comparison with predicted concentrations for each GWB are shown in Table 2.6. It is clear that there are significant differences in modelled and predicted values. In general model over-predictions occur in those GWBs with higher clay content, where lower permeability is likely to encourage attenuation in the unsaturated zone. The landfill term for some GWBs is also still uncertain, due to the assumptions made to deal with the lack of information available, particularly in the East Hants Secondary, Test and Itchen Secondary and New Forest Secondary units. The source apportionment calculation of predicted nitrate leaving the soil zone and travelling through the unsaturated zone is based on current day leaching values, whilst the observed nitrate concentrations in the aquifer will depend on a mixture of historic leached N from different parts of the catchment. In catchments with a large thickness of unsaturated zone the lag time between current leached N entering the unsaturated zone and finally reaching the water table could also provide a large difference between observed and predicted nitrate.

2.4.2 Individual Catchment Results

In the following sections the results of source apportionment are reported for the 17 groups of GWBs, discussed by surface water catchment. For each GWB a conceptual understanding of the sources and pathways of nitrate transport is provided and the results of source apportionment reported, with a comment on the likely uncertainties in the catchment data collated. A comment on the catchment schemes already in place is also made, although some, in particular the Environmental Stewardship scheme are not aimed at improving groundwater quality, and, like the now closed Environmentally Sensitive Areas, their future is also uncertain.

A summary of nitrate sources at the larger surface water catchment level is then provided at the end of each section.

Table 2.6 Observed and Modelled Nitrate Concentration by GWB

WFD GWB Name	Number of Sample Points Used	GWB Average Observed Nitrate 2010-2013 (mg/l NO_3)	Study Group Name	Group Average for Comparison with Observed (mg/l NO_3)	Predicted Nitrate Reaching Water Table per Group (mg/l NO_3)	Comment on Model Fit
Seaford and Eastbourne Chalk Block	11	28.9	Seaford and Eastbourne Chalk	28.9	29.9	Model overestimates but good fit to observed
Hastings Beds Cuckmere and Pevensey Levels	6	1.1*	C&PL Secondary	1.1	26.4	Poor fit as no attenuation applied
Lower Greensand Cuckmere & Pevensey Levels	No monitoring points		C&PL LGS		38.7	No observed data available
Lower Greensand Adur & Ouse	No monitoring points		Adur and Ouse LGS		39.1	No observed data available
Brighton Chalk Block	23	33.4	Brighton Chalk	33.4	38	Model overestimates but good fit to observed
Adur & Ouse Hastings Beds	3	1.1*	Adur and Ouse Secondary	1.1	17.1	Poor fit as no attenuation applied
Chichester Chalk	30	28.7	A&WS Chalk	26.2	28.7	Model overestimates but good fit to observed
Worthing Chalk	17	37.1				
Littlehampton Anticline East	No monitoring points					
Littlehampton Anticline West	2	12.8				
Lower Greensand Arun & Western Streams	15	17.7	A&WS LGS	17.7	38.7	Model overestimates (may be some attenuation in formation)
Arun & Western Streams Hastings Beds	1	0.9*	A&WS Secondary	0.9	13.8	Poor fit as no attenuation applied
East Hants Chalk	24	28.2	East Hants Chalk	28.2	32.7	Model overestimates but good fit to observed
East Hants Lambeth Group	No monitoring points		East Hants Secondary	22.8	39.9	Model overestimates (may be some attenuation in formation)
South East Hants Bracklesham Group	1	22.8				
South Hants Lambeth Group	No monitoring points					
River Itchen Chalk	17	34.7	Test and Itchen Chalk	33.7	30.2	Good fit to observed
River Test Chalk	29	32.6				
Central Hants Bracklesham Group	3	0.9*	Test and Itchen Secondary	0.9	46.3	Poor fit as no attenuation applied
Central Hants Lambeth Group	No monitoring points					
IOW Lower Greensand	5	9.8*	IOW Lower Greensand	9.8	62.5	Poor fit as no attenuation applied
IOW Central Downs Chalk	8	31.4	IOW Chalk	28.5	27.4	Good fit to observed
IOW Southern Downs Chalk	4	25.7				
IOW Solent Group	1	43.5	IOW Secondary	43.5	21.1	Model underestimates observed
South West Hants Barton Group	5	14.1	New Forest Secondary	14.1	18.9	Model overestimates (may be some attenuation in formation)

*Very low value probably linked to de-nitrification (see Section 2.3.5).

2.4.3 Cuckmere and Pevensey Levels Catchment

Catchment Conceptualisation and Nitrate Sources

The Cuckmere and Pevensey Levels (C & PL) catchment area covers 528 km^2, and extends from just south of Heathfield to the coast at Newhaven in the west and Hastings in the east. The catchment also includes the coastal towns of Eastbourne, Pevensey, Seaford and Bexhill, and further inland Hailsham and Polegate.

There are three GWBs in the Cuckmere and Pevensey levels: the Seaford and Eastbourne Chalk Block, the Lower Greensand (Cuckemere and Pevensey Levels); and the Hastings Beds (Cuckmere and Pevensey Levels). A large portion of the central part of the catchment is designated as unproductive aquifer (the Gault Clay and Weald Clay) and is therefore not modelled. The Seaford Chalk is at poor status due to nitrate trends in this groundwater, whilst the Lower Greensand and Hastings Beds are both at good status.

The Seaford and Eastbourne Chalk (27066 ha) covers the Chalk outcrop in the southern part of the catchment (Figure 2.1a) including the towns of Seaford, the western part of Eastbourne and East Dean. The GWB includes the eastern extent of the South Downs National Park. The Cuckmere River drains the centre of the GWB to the coast.

The Cuckmere and Pevensey Levels Secondary groundwater unit, (Hastings Beds, Cuckmere and Pevensey Levels) covers the outcrop of the Hastings Beds over 12402 ha in the north of the catchment. The area includes the towns of Bexhill, Hastings and Heathfield, and is drained by Combe Haven in the east and Wallers Haven and Pevensey Haven in the central and north east. The GWB contains the SSSI and Ramsar site of Pevensey Levels, a heavily modified water body where water levels are controlled to maintain protected habitats, manage flood risk and secure water resources.

The Cuckmere and Pevensey Levels Lower Greensand groundwater unit runs from north-west to south-east through the centre of the catchment, including the Lower Greensand outcrop over an area of 1061 ha.

Infiltration recharge to the groundwater units has been calculated using the Environment Agency's Catchmod Model, producing a value of 344 mm/a for the Chalk, 292 mm/a for the Hastings Beds and 320 mm/a for the Lower Greensand.

Point sources of nitrate over all three of the GWBs shown in Figure 2.1a include sewer leakage beneath all major urban centres, treated sewage effluent discharged to ground (some of which will be deregulated) and current and historic landfills. There is one treated effluent discharge to ground at East Dean STW located in the Seaford and Eastbourne Chalk, serving a population of around 1500.

Diffuse sources of nitrate include leaching from agricultural land and run-off from urban land (Land-use 2007, Figure 2.1b). In the Seaford and Eastbourne Chalk and the C&PL Secondary groundwater unit the majority of land use is arable or improved grassland, with significant coastal areas of urban land and significant proportions of woodland. In the Lower Greensand GWB almost half of the catchment is urban land.

The solid and drift geology of the GWB (Figure 2.1b) also controls the fate and transport of nitrate. The Seaford and Eastbourne Chalk groundwater unit is made up of the southerly dipping Upper Greensand and Seaford and Newhaven Chalk formations, with regional groundwater flow following the dip direction. Head deposits are located on the interfluve areas of the Chalk outcrop with alluvium filling north-east – south-west trending valley features. The geochemical conditions in this fissured unconfined aquifer are expected to be oxidizing, minimising the likelihood of nitrate reduction. An average concentration of nitrate of 28.9 mg/l NO_3 is calculated for the period 2010 to 2013, based measurements of nitrate from 11 boreholes from the GWQMN in this GWB, confirming that attenuation of nitrate in the aquifer is not significant (Figure 2.1b).

The C&PL Secondary groundwater unit is made up of the Hastings Beds formation, including both sandstone and clays of the Tunbridge Wells and Wadhurst Clay Groups, with groundwater flow following topography and dip direction towards the south-west. Drift deposits include extensive alluvium beneath the Pevensey Levels (Figure 2.1b). Groundwater quality data suggests that nitrate reduction is common in this GWB with an average value of 1.1 mg/ NO_3 based on data from 6 sample points between 2010 and 2013.

The Lower Greensand groundwater unit is underlain by the formation of the same name, comprising sandstones, siltstones and mudstones (Figure 2.1b). The majority of the outcrop is overlain by head deposits, and although there are no groundwater monitoring points in the unit, it is likely that attenuation of nitrate will take place in this clay rich formation. There are no monitoring points in this GWB.

The soils of each GWB also reflect the underlying geology, with the Seaford and Eastbourne Chalk predominantly overlain by silty or loamy soils, whilst the Lower Greensand GWB is mainly covered in loamy water logged soils (Figure 2.1c). The C&PL Secondary GWB mainly has silty soils (over sandstone) with some areas of loamy soils.

Catchment schemes exist in all three GWBs including: groundwater NVZ and Environmental Stewardship schemes in the Seaford and Eastbourne Chalk; Catchment Sensitive Farming for the Pevensey Levels catchment; Environmental Stewardship schemes and some surface water NVZ coverage in the C&PL Secondary GWB; and Environmental Stewardship schemes in the Lower Greensand GWB (Figure 2.1c).

Results of Source Apportionment

The results of source apportionment are shown in Figure 2.1d, including pie charts of nitrate inputs to groundwater and area of land under different land uses per GWB.

For the **Seaford and Eastbourne Chalk block** the majority of nitrate is sourced from grazed grass (25%), cut grass (14%) and wheat (19%). Winter oil seed rape also provides a high contribution at 10% of the nitrogen budget. Non-agricultural and point sources provide up to 17% of nitrogen entering groundwater, with the greatest contribution from treated sewage effluent (4%), mains leakage (4%) and sewer leakage (3%). Urban land-use makes up just under a quarter of the total modelled area. The predicted concentration of nitrate in groundwater in the Chalk aquifer is 30 mg/l $NO_{3,}$ which is a reasonable fit to the observed average concentration of 28.9 mg/l NO_3.

Grazed grass in the **C&PL Secondary groundwater unit** provides the greatest proportion of diffuse sourced nitrate in groundwater at 26%, followed by cut grass at 15%, reflecting the large area of improved grassland in this area (38% of the land area is grazed or cut grass). Wheat also provides a significant contribution to nitrate in groundwater at 12%. 20% of the nitrate in the GWB is modelled as sourced from non-agricultural or point sources. This includes a contribution from landfills at 5% and 7% from mains leakage. For the C&PL Secondary groundwater unit the predicted nitrate concentration of 26.4 mg/l NO_3 is well above the observed low average value of 1.1 mg/l NO_3, suggesting that significant de-nitrification occurs in the unsaturated zone.

In the **C&PL Lower Greensand groundwater unit** the majority of nitrate is sourced from grazed grass (19%), wheat (19%) and cut grass (11%). Temporary grass (10%) and winter oil seed rape (8%) also provide significant inputs of nitrate to groundwater. Non-agricultural and point sources of nitrate make up 23% of the total nitrogen budget, with the greatest inputs from mains leakage (7%), landfill (6%), sewer leakage (3%) and treated sewage effluent (4%). As previously noted there is no available groundwater quality data to validate the predicted concentration of 38.7 mg/l NO_3, although the chemistry of the Lower Greensand tends to allow de-nitrification to occur in some locations, and therefore this is expected to be an overestimate of actual concentrations.

Overall the greatest contributions of nitrogen in the **Cuckmere and Pevensey Levels catchment** come from improved grassland, wheat and oil seed rape. The large contributions from these crop types reflects the large amount of grassland (around 40%) and arable land (up to 25%) in the aquifer areas in the catchment. Non-agricultural diffuse and point sources are not as significant, typically providing between 17% and 23% of the total nitrogen in groundwater in the catchment, with highest contributions from mains leakage (up to 7%) and landfill (up to 6%).

The **groundwater** contribution of nitrate to the Cuckmere River is likely to dominate discharge to transitional waters where nitrate is a limiting nutrient, and therefore measures should focus on surface run-off and groundwater in the Chalk, rather than the Secondary GWB.

2.4.4 Adur and Ouse Catchment

Catchment Conceptualisation and Nitrate Sources

The Adur and Ouse catchment area extends across 1073 km^2, from the Ashdown Forest and Horsham in the north to the English Channel in the south (Figure 2.2a). The catchment is defined by the surface water catchments of the River Adur in the west, the River Ouse in the east. The coastal cities of Brighton and Hove, and towns of Newhaven and Lewes are located in the south of the catchment whilst the towns of Haywards Heath, Lewes, Newhaven, Burgess Hill and Uckfield are located in the north. The South Downs NIA covers the Chalk escarpment just to the north of Brighton and Hove.

The Adur and Ouse catchment includes the GWBs of the Adur and Ouse Lower Greensand (A&O Lower Greensand) following the outcrop of the Lower Greensand across the centre of the catchment, the Hastings Beds GWB (A&O Secondary unit) to the north of the catchment, and the Brighton Chalk in the south of the catchment (Figure 2.2a). The Brighton Chalk GWB is at poor status due to rising nitrate trends, whilst the two other GWBs are at good status. A significant part of the western catchment is designated as unproductive strata, i.e. is not covered by a GWB, and has not been modelled for nitrogen source apportionment.

Infiltration recharge over the Adur and Ouse GWBs was based on values calculated using the Environment Agency's Catchmod Model for the Adur catchment of 320 mm/a, used for the Secondary GWB, and 343 mm/a for the Ouse catchment, used for the Lower Greensand. For the Brighton Chalk a value of 355 mm/a was provided from the Brighton and Worthing groundwater resources model.

Sources of nitrate in the GWBs are both point and diffuse (Figure 2.2a). The extent of the sewerage network covers the major urban centres, with the remainder of the population assumed to be served by private sewerage undertakings, some of which will have a consent to discharge treated effluent to the water environment (Figure 2.2a), but a significant proportion of which will be deregulated. Current and historic landfills exist in all GWBs although the largest number sits within the Brighton Chalk.

Land-use over the Brighton Chalk is dominated by the urban areas of Brighton and Hove, and other coastal conurbations (Figure 2.2b). The remainder of the GWB is mainly improved grassland of the South Downs, with some areas of rough grassland at high elevations. Patches of arable land and broadleaved woodland are mainly concentrated in eastern and central parts of the Chalk Block. Both the A&O Lower Greensand and A&O Secondary groundwater units are made up of arable land, improved grassland and urban land, with some areas of broadleaved woodland.

The Brighton Chalk includes the Newhaven, Lewes Nodular, Tarrant and Seaford Chalk formations, which dip southwards, controlling the flow of groundwater towards the coast (Figure 2.2b). Small outliers of the overlying London Clay (Lambeth Group) remain on elevated areas of the Chalk near Brighton and Newhaven. Drift deposits are present as head deposits along river valleys and drainage features which form in the southerly part of the GWB, whilst clay with flints deposits are located in elevated interfluve areas (Figure 2.2b). Apart from areas where drift thickness provides less permeable cover, the Chalk aquifer is unlikely to provide much attenuation of nitrate. The A&O Lower Greensand GWB includes the outcrop of the Lower Greensand and small parts of the Folkestone Sandstone outcrop along the southern boundary. Head deposits typically exist over the majority of this outcrop (Figure 2.2b). The A&O Secondary GWB includes the outcrop of the Hastings Beds (Tunbridge Wells and Wadhurst Clay formations), consisting mainly of sandstone and mudstones. The River Ouse is fed by springs issuing from the Tunbridge Wells Sandstone.

The average nitrate concentration from the groundwater quality network (Figure 2.2b) in the Brighton Chalk for the period 2010 to 2013 was 33.4mg/l NO_3. The average concentration of nitrate for the same period for the A&O Secondary GWB was 1.1 mg/l NO_3 whilst there are no monitoring points in the Lower Greensand. The lower concentrations in the A&O Secondary aquifer, suggest that there is some attenuation of nitrate in the unsaturated and saturated zones.

Soil designations over the catchment reflect the underlying solid and drift geology, with the Brighton Chalk being dominated by silty soils over Chalk, the Secondary GWB is mainly covered by silty soils over sandstone, and the Lower Greensand having clay/loam rich soils (Figure 2.2c).

Catchment schemes to improve water quality include a groundwater NVZ covering the Chalk outcrop of the Brighton Chalk, surface water NVZ over parts of the eastern part of the A&O Secondary GWB and in the centre of the catchment, covering the upper reaches of the River Adur (Figure 2.2c).

Environmental Stewardship schemes exist throughout the whole of the catchment, and the River Ouse upstream thinking project, which will explore ways to reduce levels of suspended solids, faecal pollution, fertiliser and pesticide-related chemicals entering the river, is active in the north of the catchment. Previous schemes include the Brighton and Hove Tenant Farmers Project run by Brighton and Hove Council, which provided training and supporting tenant farmers to ensure the quality of groundwater. It is notable that there is no Catchment Sensitive Farming coverage in the Adur and Ouse catchment.

Results of Source Apportionment

In the three GWBs located in the Adur and Ouse catchment the majority of nitrate entering groundwater is from agricultural sources, including both arable land and improved grassland.

For the **Brighton Chalk**, the contribution of nitrate from agricultural sources includes grazed grass (17%), cut grass (10%) and wheat (14%) (Figure 2.2d). The greatest non-agricultural source of N was landfill at (18%), whilst sewer and mains leakage (5% and 10% respectively) reflecting the large urban areas of Brighton and Hove. Predicted nitrate concentration in groundwater in the Brighton Chalk (39 mg/l NO_3) shows a reasonable fit to the observed nitrate concentrations for 2010-13 (33.4 mg/l NO3).

In the **A&O Lower Greensand** GWB, the greatest agricultural contributions to the nitrate budget are from grazed grass (23%), wheat (21%) and cut and temporary grass (13% and 14% respectively). The main non-agricultural source of nitrate is landfill at 8%.

The **A&O Secondary unit** receives the greatest amount of nitrate from grassland (grazed grass 24%, cut grass 14% and temporary grass 17%) and wheat (14%). Non-agricultural and point sources in this GWB make up to 14% of the overall sources of nitrate, with the greatest contributions from mains leakage and treated sewage effluent (4% each), sewer leakage (2%) and landfills (2%).

The predicted concentration of nitrate in the Lower Greensand is 38 mg/l NO_3 and in the Secondary Aquifer is 17 mg/l NO_3. The latter predicted concentration is considerably higher than the observed value in the Secondary GWB of 1.1 mg/l NO_3 supporting the understanding that nitrate attenuation is taking place and producing these very low observed values. As previously noted there is no available monitoring data for the A&O Lower Greensand although there is likely to be some level of denitrification here, and the high predicted nitrate concentration is likely to be an over-estimate.

Overall in the **Adur and Ouse catchment** the majority of nitrogen entering groundwater is sourced from improved grassland (cut and grazed grass), wheat and winter oil seed rape. Non agricultural and point sources can provide up to 37% of the total nitrogen budget, especially where there are significant areas of landfill with leakage to the water table and where high population densities (i.e. Brighton and Hove) provide large areas for mains and sewer leakage. In this catchment the **groundwater** contribution of nitrate to the Adur and Ouse Rivers is likely to mainly come from the Chalk. Therefore measures to address nitrate concentrations in receiving transitional waters, where nitrate is an important control on eutrophication, should focus on surface run-off sources and groundwater in the Chalk.

2.4.5 Arun and Western Streams Catchment

Catchment Conceptualisation and Nitrate Sources

The Arun and Western Streams (A&WS) catchment covers an area of 1484 km^2, extending from Horsham and Petersfield in the north east and west respectively, to the south coast at Chichester Harbour and Selsey Bill in the west and Shoreham by Sea in the east. The majority of the urban development is located along the coast including Chichester, Bognor Regis, Littlehampton and Worthing, and further inland the towns of Petersfield, Arundel, Horsham and Midhurst.

There are several GWBs in the Arun and Western Streams catchment: the Chichester Chalk, the Worthing Chalk and the Littlehampton Anticline East and West Chalk (grouped together as the A&WS Chalk); the Arun and Western Streams Lower Greensand (A&WS Lower Greensand); and the Arun and Western Streams Hastings Beds (A&WS Secondary unit) (Figure 2.3a). Nitrate concentrations have lead to the poor status of the Chichester Chalk, Worthing Chalk and the Lower Greensand GWBs. The Weald Clay formation outcrops in the north-west of the catchment, and the Gault Clay outcrops in between the Chalk and Lower Greensand outcrop, and these areas are designated as unproductive strata and so have not been modelled for source apportionment.

Infiltration recharge has been modelled using the Brighton and Worthing groundwater resources model providing values of 400 mm/a for the A&WS Chalk, and 394 mm/a for the Lower Greensand. For the A&WS Secondary GWB a value of 329 mm/a was calculated using the Environment Agency's Catchmod Model for the River Arun.

Mains sewer exists covering the major urban centres (mainly in the A&WS Chalk and Secondary aquifer groundwater units), whilst the remaining population is assumed to be served by privately run septic tanks, package treatment works or cesspits (Figure 2.3a). Landfills exist in all GWBs, although protection is afforded to the southern outcrop of the A&WS Chalk from superficial head, sand and gravel deposits which overly the southern boundary of the Chichester Chalk and Worthing Chalk and the whole of the Littlehampton Anticline Chalk GWB (Figure 2.3d).

In the southern part of the A&WS Chalk land-use is mainly urban coastal development and arable land, whilst the northern part of the Chalk outcrop and the A&WS Lower Greensand is a combination of arable land, grassland and broad leaved woodland. A & WS secondary has a large area of urban land-use (the town of Horsham) with arable, woodland and grassland making up the remaining area.

The underlying geology in the GWBs controls the transport of nitrate to surface water and groundwater receptors. The A&WS Chalk includes the elevated area of the South Downs, formed from the uplifted Chalk scarp slope of the Littlehampton Anticline, the southerly dipping limb of which is confined beneath the London Clay. The West Sussex Coastal Streams rise on the Chalk escarpment to discharge at the coast. The A&WS Lower Greensand includes the outcrop of the Folkestone Beds and Hythe Formation, whilst the A&WS Secondary unit is made up of the outcrop of the Hastings Beds. The River Rother (a tributary of the River Arun) rises from springs in the Chalk and Upper Greensand and then runs along the outcrop of the Lower Greensand (Figure 2.3a).

Nitrate concentrations based on samples taken from the groundwater quality network between 2010 and 2013 (Figure 2.3b) are shown in Table 2.6, and suggest that there is little attenuation of nitrate in the Chalk (26.2 mg/l NO_3), with variable attenuation in the Lower Greensand (17.7 mg/l NO_3) and active attenuation in the A&WS Secondary unit (0.9 mg/l NO_3).

Soils overlying the northern A&WS Chalk GWBs are mainly silty over Chalk, whilst the southern part of the GWB has soils derived from the London Clay and drift deposits, with deep silty or loamy soils (Figure 2.3c). Soils over the Lower Greensand GWB are typically sandy, affording little protection to groundwater, whilst soil in the Secondary groundwater is mainly silty.

Catchment schemes shown in Figure 2.3c include, Environmental Stewardship schemes, Catchment Sensitive Farming, the Downs and Harbours Clean Water Partnership, NVZ for groundwater over parts of the Chalk and Lower Greensand, and a surface water NVZ over the upper reaches of the River Arun (including the Secondary GWB) and the Westerns Streams area. There is a eutrophic NVZ designated in the area covering discharges to Chichester Harbour (including the southern part of the A&WS Chalk GWB).

Results of Source Apportionment

In the **A&WS Chalk** the majority of nitrate is sourced from wheat (27%), grazed grass (9%) and temporary grass (9%). Cereal crops (oats, rye and barley) provide a similar contribution of 8%. The greatest contributions of non-agricultural nitrate are from urban run-off (1%) and landfill (16%). Overall the non-agricultural/point source contribution to the nitrate budget is 22%. The modelled nitrate concentration in groundwater for the A&WS Chalk GWB (29 mg/l NO_3) provides a good fit to the observed concentration (26.2 mg/l NO_3).

Wheat and grazed grass contribute 17% and 13% respectively of the nitrate in groundwater in the A&WS **Lower Greensand.** Cut grass (7%), temporary grass (10%) and vegetables grown in the open (6%) also provide relatively high contributions. Non-agricultural and point sources provide 29% of the nitrogen budget, with the majority coming from landfill (24%) and mains leakage (2%). The average nitrate concentration in the A&WS Lower Greensand is 17.7 mg/l NO_3, whilst the predicted concentration over-estimates this at 39 mg/l NO_3. Some denitrification may occur in the unsaturated zone or saturated aquifer, reducing the observed nitrate concentrations in groundwater.

In the A&WS Secondary grazed grass (14%), sewer leakage (10%) and mains leakage (21%) contribute the greatest amounts of nitrate to groundwater. Urban and suburban areas make up 28% of the GWB (the town of Horsham) which increases contribution from these urban sources compared to other catchments. Observed average nitrate concentrations for the period 2010 to 2013 in the A&WS Secondary aquifer are very low (0.9 mg/l NO_3) indicating the reduction of nitrate in the saturated aquifer. The predicted concentration of nitrate at the water table is 14 mg/l NO_3, although this value does not account for attenuation.

In the **Arun and Western Streams catchment** the majority of nitrogen in groundwater is sourced from wheat and improved grassland, with significant contributions from urban sources where the area covered by these land-uses is high.

2.4.6 East Hampshire Catchment

Catchment Conceptualisation and Nitrate Sources

The East Hampshire catchment covers 517 km^2, and extends from West Meon in the north to Portsmouth in the south, and Bishopstoke in the west and Horndean in the east. The southern part of the catchment includes Portsmouth Harbour, Langstone Harbour, Hayling Island and Chichester Harbour. The main urban areas in catchment include Portsmouth and part of the eastern extent of Southampton (Eastleigh), the towns of Horndean, Fareham, Chichester and Bishops Waltham. The catchment includes the East Hants Chalk GWB (comprising a north and south area), South East Hants Bracklesham Group, South Hants Lambeth Group and East Hants Lambeth Group GWBs. The Chalk GWB is at poor status due to nitrate concentrations. The latter three bodies make up the East Hants Secondary unit reported on here (Figure 2.4a).

Infiltration recharge over the catchment has been calculated from outputs from the East Hampshire and Chichester Chalk groundwater resource model. For the East Hants Chalk GWB an infiltration recharge value of 416 mm/a has been used, and for the Secondary formations a value of 300 mm/a calculated from the Environment Agency's Soil Moisture Model. An average rainfall value of 850 mm/a was applied over the whole study area.

Point sources of nitrate include the mains sewer network, mainly located beneath urban centres in the East Hants Secondary group, and the southern East Hants Chalk, and Catherington and Horndean in the mainly rural northern East Hants Chalk. Private sewerage undertakings are mainly distributed over the remaining areas of the GWBs (e.g. in the East Hants Chalk GWB) (Figure 2.4a). Land-use over the northern East Hants Chalk GWB is mainly arable or improved grassland (Figure 2.4b). In the combined East Hants secondary GWBs and the southern East Hants Chalk the main land-use is urban with some arable areas. In the western parts of the East Hants Secondary GWBs there is a significant area of rural land including a mix of improved grassland, arable and woodland.

The Chalk and underlying Upper Greensand outcrop in the north of the catchment forms the elevated area of the South Downs and the East Hants Chalk GWB (Figure 2.4b). The Chalk dips towards the south, beneath the Solent, and is overlain by the Sands, Silts and Clays of the Tertiary deposits (Wittering and London Clay Formations and the Lambeth Group Formations). The Chalk has been deformed and the resulting syncline eroded to expose the Chalk in the centre of the catchment, forming the Ports Down to the north of Portsmouth. The overlying Tertiary deposits outcrop in the lower central and coastal areas of the catchment (Figure 2.4b). In terms of nitrate transport the groundwater in the northern East Hants Chalk GWB is unlikely to be attenuated in this unconfined area of the aquifer.

The majority of rivers in the catchment are fed by springs rising on the southern and northern Chalk GWBs, some of which are used for public water supply (e.g. Bedhampton and Havant Springs). Nitrate in groundwater from the Chalk is transported via the rivers in the catchment to Portsmouth Harbour in the south. The southern confined part of the southern East Hants Chalk groundwater is well protected from nitrate infiltration by the overlying London Clays, whilst the northern part of this area of the Chalk is at outcrop.

The East Hants Secondary unit is made up of the outcrop of the Lambeth Group formation in the north and east, and the Bracklesham Formation in the south and east, comprising mainly sands, silts and clays (Figure 2.4b).

There is likely to be some attenuation of nitrate in these formations, although the average nitrate concentration of 22.8 mg/l NO_3 based on data from one monitoring point in the Bracklesham Sands does not necessarily confirm this. However, the presence of less permeable horizons suggests denitrification is likely to occur and that concentrations of nitrate in groundwater could potentially be lower than this observed data suggests.

Soils over the Chalk GWBs are typically silty and can be thin, whilst over the Lambeth Beds the soils are loamy (Figure 2.4c). In the southern East Hants Secondary GWB soils are mainly sandy or loamy.

Catchment water quality schemes include Environmental Stewardship Schemes, the Downs and Harbours Clean Water Partnership, a groundwater and surface water NVZ in the East Hants Chalk, eutrophic NVZ covering the southern Chalk outcrop, and most of the Bracklesham Beds part of the East Hants Secondary GWB (Figure 2.4c).

Results of Source Apportionment

The outcomes of source apportionment for nitrogen in groundwater in for the East Hants Chalk and the East Hants Secondary GWBs are shown in Figure 2.4d.

In the **East Hants Chalk** the majority of nitrate sources are agricultural reflecting the rural nature of this GWB. The highest contributions to the nitrogen budget for this catchment are from wheat (26%), winter oil seed rape (17%) and grazed grass (10%). Overall grassland contributes 21% of the nitrate in groundwater in the catchment. Non-agricultural sources and point sources of nitrogen make up 18% of the nitrate in groundwater in the East Hants Chalk. This includes a large contribution from landfill of 13%, although several historic landfills which accepted non-hazardous waste prior to 1990 actually discharge to Portsmouth Harbour and have therefore not been included in the calculations.

Close to half of the **East Hants Secondary GWB** is urban land, and there are numerous historic and active landfills in the catchment. These factors are reflected in the very high contributions of nitrogen from non-agricultural sources such as landfill (49%), sewer leakage (8%) and mains leakage (10%). It is noted that the concentration of nitrate in mains water for this catchment has been set to the average groundwater concentration in the Chalk of 22.8 mg/l NO_3 as it is assumed that the main supply in this area is by Portsmouth Water who abstract mainly from sources in the East Hants Chalk. In reality this value could vary over the GWB depending on where the supply is sourced from. The very large contribution from landfill reduces the contribution from agricultural sources to around 28% overall (Figure 2.4d).

Observed average nitrate concentrations in the East Hants Chalk groundwater for the period 2010 to 2013 were 28.2 mg/l NO_3, and the model predicts a similar value of 33 mg/l NO_3. In the East Hants Secondary aquifer the observed average nitrate concentration for the same period are 22.8 mg/l NO_3, while the predicted value is 40 mg/l NO_3. The observed value is unlikely to be representative of the whole GWB, and there will be some attenuation of nitrate in this aquifer, but the high loading is probably also over-estimated due to the very large modelled input from landfill. The landfill contribution requires further refinement to quantify the actual input from this source.

2.4.7 Test and Itchen Catchment

Catchment Conceptualisation and Nitrate Sources

The Test and Itchen catchment is made up of the surface water catchments to these Chalk fed rivers and their tributaries (Figure 2.5a). The catchment extends from Southampton Water in the south-east to the edge of Salisbury Plain in the north-west, covering an area of around 1760 km^2, including the towns of Andover, Winchester, Totton, Romsey and Eastleigh, and part of the city of Southampton. Both rivers rise on the Wessex Chalk Downs located in the north and east of the catchment, flowing towards the south to their discharge points into Southampton Water. The rivers are both classified as SSSIs throughout their courses, and the Itchen is also designated as a SAC.

The catchment includes four GWBs, the Test Chalk and Itchen Chalk (grouped for this study as the T&I Chalk unit), the Central Hants Bracklesham Group and the Central Hants Lambeth Group (for this study grouped as the T&I Secondary unit). Both Chalk GWBs are at poor status due to nitrate concentrations, and there is also a substantial plume of solvents in the River Test Chalk. The eastern boundary of the Test & Itchen Chalk GWB extends up to 6 km to the east of the surface water catchment, reflecting seasonal changes in groundwater flow direction.

Infiltration recharge LTA of 316 mm/a over the T&I Chalk GWB has been derived from the Test and Itchen regional groundwater model. For the T&I Secondary GWB a value of 301 mm/a was supplied by the Environment Agency, based on output from the CatchMod model for South East Region. As noted previously, 850 mm/a LTA rainfall has been applied over the whole study area.

Urban areas in both GWB groups are served by mains sewer whilst other areas will be served by private sewage treatment plants, septic tanks or cesspits. Consented discharges to ground are shown along with the extent of mains sewerage network in Figure 2.5a, but this does not include deregulated discharges to ground. Land-use over the T&I Chalk is mainly agricultural, with a high proportion (~60%) of arable land, and much smaller areas of broadleaved woodland (11%) and improved grassland (21%) (Figure 2.5b). In the T&I Secondary unit urban land-use is dominant in the south-east, with a mix of arable, improved grassland and broadleaved woodland in the west.

Transport of nitrate in the underlying aquifers is controlled by the matrix flow and redox conditions. The T&I Chalk is made up of the unconfined Cretaceous Chalk and Upper Greensand (Figure 2.5b). These formations dip towards the south coast, creating the plateau of the Wessex Chalk Downs controlling groundwater flow and to some extent surface water flow towards the south. In the southern more low lying area of the CAMS area outcrop geology consists of the Clays, Silts and Sands of the Bracklesham Group deposits, which overly the down-dip area of the Chalk (Figure 2.5b). Regional groundwater flow direction is typically towards the south and east, mirroring surface water flow. Drift deposits in the catchment consist of clay, silt and sand alluvium in the river valleys and head and clay-with-flints deposits overlying elevated Chalk outcrop.

Soils over the Chalk outcrop are typically shallow and silty to the centre of the catchment, or deep silty clay soils in the northern parts of the catchment (Figure 2.5c). The soils overlying the Secondary aquifers tend to be loamy or loam over gravels.

Catchment schemes to address water quality issues include a groundwater and surface water NVZ over the T&I Chalk, and a eutrophic NVZ over the T&I Secondary unit. The whole of the Test and Itchen catchment is covered by a CSF scheme, and there are Environmental Stewardship schemes through the whole area (Figure 2.5c).

Results of Source Apportionment

For the **T&I Chalk** the outcomes of source apportionment show that the majority of nitrate leaching to groundwater is from wheat (31%), winter oil seed rape (19%), and grazed grass (10%), which is as expected given that the majority of the catchment is covered in arable land (Figure 2.5d). Point sources (landfills, treated sewage effluent discharges to ground) and non-agricultural sources (urban sources, mains leakage etc.) contribute 11% of nitrate leaching to groundwater in the catchment. The observed average nitrate concentrations for the period 2010 to 2013 for the T&I Chalk are close at 33.7 mg/l NO_3, to the predicted concentration of 30 mg/l NO_3 calculated from the source apportionment exercise.

In the **T&I Secondary unit** the main sources of nitrate are landfill (56%), mains leakage (8%) and wheat (6%) (Figure 2.5d). The very high proportion of nitrate derived from landfill and mains leakage sources is due to the lack of other significant sources in this groundwater unit. The high mains and sewer leakage similarly reflects the large area of the catchment covered by the sewerage network and mains network supplying Southampton. As noted previously the majority of groundwater and surface run-off in urban areas close to the coast will discharge to the sea, and the actual loading of N to the aquifer is likely to be overestimated. For the T&I Secondary unit the observed nitrate concentration of 0.9 mg/l NO_3 is significantly lower than the predicted concentration of 46 mg/l NO_3. The average nitrate concentration value suggests that attenuation of nitrate in the unsaturated zone is significant in this aquifer.

2.4.8 Isle of Wight Catchment

Catchment Conceptualisation and Data Sources

The Isle of Wight catchment covers the whole of the island, an area of 380 km^2, including the surface water catchments of the Western Yar, Eastern Yar and the River Medina. The main urban areas are located at Newport in the centre, Totland in the west, East and West Cowes in the north, and east and south coastal towns and villages of Ryde, Bembridge, Sandown, Shanklin and Ventnor (Figure 2.6a).

The principal aquifers of the Chalk and Upper Greensand at outcrop form two of the GWBs on the island. This GWB is at poor status due to rising nitrate. The northern sands and clays of the Bembridge Formation and the Lower Greensand make up two further GWBs (Figure 2.6a). For the purposes of the source apportionment exercise the two Chalk and Upper Greensand GWBs have been grouped as the natural background geochemistry of the water in these principal aquifer outcrops will be similar (as agreed with the Environment Agency). The remaining GWBs are grouped as the IOW Lower Greensand and IOW Secondary units.

Recharge across the island has been calculated by the 4R model for the Isle of Wight held by the Environment Agency. An LTA rainfall value of 850 mm/a has been used for the total study area, although the reported annual average values for the individual groundwater units are 877 mm/a for the Central Chalk, 846 mm/a for the Southern Downs Chalk and a variable value between 700 mm/a and > 900 mm/a for the Lower Greensand. Infiltration recharge from the 4R model was 450 mm/a over the Central Chalk, 420 mm/a for the Southern Downs Chalk and 170 mm/a for the Lower Greensand.

There are several landfills on the island, both historic and active, most of which are concentrated in the more populous eastern side of the island. Urban areas are served by sewerage networks (Figure 2.6a). The Isle of Wight is mainly rural, with the majority of land in the south and east of the catchment is used for arable crops and improved grassland with more improved grassland and rough pasture in the east of the catchment. Pockets of broadleaved woodland exist across the catchment, including Brighstone and Parkhurst Forests (Figure 2.6b).

The island's solid geology consists of a folded and deformed syncline, the limbs of which are made up of Chalk and Upper Greensand (the central ridge running east-west across the island and outcropping in the south in the Southern Downs) and the core consists of the underlying Lower Greensand Formation Sands and Clays (Figure 2.6c). In the north the Chalk and Upper Greensand are overlain by the Reading Beds Formations (Hamstead Beds and Bembridge Marls). Superficial deposits consist of large extents of raised beaches (Marine and Plateau Gravels) on the northern coast of the island with other deposits consisting of alluvium and river terrace gravels along river valleys.

Nitrate data from 17 Environment Agency groundwater quality monitoring points on the island, for the period 2010 to 2013 were used to calculate average concentrations for each GWB (Figure 2.6c). Average nitrate concentrations in the Lower Greensand unit are 9.8 mg/l NO_3 reflecting the potential reducing nature of the clays and silts making up this aquifer unit. In the Central and South Downs Chalk unit the average nitrate concentration is 28.5 mg/l NO_3 reflecting the oxidising conditions in this aquifer, whilst the IOW Secondary GWB average nitrate is 43.5 mg/l NO_3 is based on one monitoring point in the productive part of this aquifer. Concentrations in this GWB are likely to be variable with denitrification producing lower concentrations in places.

Soils over the IOW Chalk are silty and can be shallow, whilst the IOW Lower Greensand is overlain by loamy soils, and the IOW Secondary group with wet loamy clayey soils (Figure 2.6c). Catchment measures already in place include groundwater and surface water NVZ over various parts of the island, covering the majority of the Chalk aquifer, CSF delivered through the Isle of Wight Catchment Partnership over the whole island, and Environment Stewardship Schemes at several locations.

Results of Source Apportionment

For the **IOW Lower Greensand** the largest proportions of catchment nitrogen are sourced from grazed grass (21%), wheat (21%) and temporary grass (17%) (Figure 2.6d). These sources reflect the rural nature of this area and the high concentration of arable land and dairy pasture in the south of the island. Vegetables grown in the open provide up to 8% of the nitrogen budget. The greatest nitrogen sources in the **IOW Chalk** include wheat (28%), grazed grass (18%) and cut and temporary grass (10% and 15% respectively) (Figure 2.6d).

In the **IOW Secondary** the greatest contributions are from grazed grass (22%), wheat and cut grass (16% and 13% respectively). The inputs from these diffuse sources reflect the extent of the groundwater unit covered by these land-uses (Figure 2.6d). The groundwater body is also highly populated and non-agricultural sources make up to 27% of the N budget, mainly from landfill (12%), mains leakage (8%) and sewer leakage (4%).

For the Chalk the predicted values are in good agreement with observations (29 mg/l NO_3 observed compared to 27 mg/l NO_3). For the IOW Lower Greensand formation agreement is less good (63 mg/l NO_3 predicted versus 9.8 mg/l NO_3 observed). The average nitrate concentration of 43.5 mg/l NO_3 for the IOW Secondary GWB is based on one monitoring point, and is under-estimated by the predicted concentration of 21 mg/l NO_3.

2.4.9 New Forest Catchment

Catchment Conceptualisation and Data Sources

The New Forest catchment covers the Rivers Lymington, Beaulieu, Danes Stream, and Avon Water. The catchment has an extent of approximately 450 km^2 and covers the area between the A31 corridor between Ringwood and Southampton, and the south coast between Christchurch in the west and Calshot in the east. The catchment includes the New Forest National Park, and urban areas of Brockenhurst and Lyndhurst, parts of Southampton and Hythe in the north and east and the coastal towns of New Milton and Lymington in the south. The GWB in the catchment is the South West Hants Barton Group, which is at good status, and named the New Forest Secondary for this report (Figure 2.7a).

Recharge estimations are based on an average rainfall value for the whole study area of 850 mm/a (although the value for the individual catchment is 862 mm/a (Marsh and Hannaford, 2008). A value of infiltration recharge of 329 mm/a was derived using the Environment Agency’s Soil Moisture Model (CatchMod). Hydrologically effective recharge (water leaving the soil zone) and PE values were back-calculated from infiltration recharge using an estimate of 60% of HER becoming infiltration recharge, and the remainder becoming PE.

Nitrate sources include mains sewers beneath the urban areas of Hythe, Lymington and Brockenhurst and Lyndhurst, mains leakage and landfills (e.g. near Lymington) (Figure2.7a). The majority of the north and central parts of the catchment are covered with broadleaved or coniferous woodland, or dwarf shrubland as part of the national park area (Figure 2.7b). In the south east improved grassland, extends southwards, turning to arable and urban land closer to the coast. In the south west of the catchment arable land exists with pockets of improved grassland and broadleaved woodland.

The New Forest catchment is underlain by the Paleogene age Headon and Osbourne beds in the south (Clays and Silts), and the underlying Becton and Chama Sands in the north (Sands and Silty Clays) (Figure 2.7b). The superficial drift cover in the south of the catchment comprises River Terrace deposits and Tidal Flat deposits at the south coast, whilst in the north there is no drift cover.

The groundwater quality monitoring network in the New Forest catchment is made up of nine locations (Figure 2.7b). An average nitrate concentration of 14.1 mg/l NO_3 was calculated covering the period 2010 to 2013.

Soils in the New Forest Secondary unit are mainly loam based (Figure 2.7c). Catchment measures in place to address water quality issues include two surface water NVZs and a eutrophic NVZ. Environmental Stewardship Schemes exist over the whole catchment.

Results of Source Apportionment

The distribution of all sources providing an N loading from the soil zone in the **New Forest Secondary unit** is shown in Figure 2.7d. The highest inputs of N to the catchment are from landfill (44 %) grazed grass (8%) and wheat (10%). The large proportion of nitrate sourced from landfill reflects the comparatively low input of nitrate from other sources in this largely forested and urban catchment.

Average groundwater concentrations of nitrate for the period 2010 to 2013 are 14.1 mg/l NO_3, whilst the source apportionment tool predicts a nitrate concentration of 19 mg/l NO_3 as N, over-estimating the N leaching to groundwater. It is likely that denitrification occurs in the underlying aquifer where the permeability of strata is variable, and the observed nitrate concentration reflects this, whilst this phenomena is not represented in the model.

2.5 Uncertainty and Sensitivity Analysis

2.5.1 Uncertainty in Model Parameters

Uncertainty in the modelled source apportionment of nitrate in the catchments, and the predicted nitrate concentration in groundwater will come from the raw datasets themselves and their manipulation to provide inputs to the model. Assumptions made in the model calculations also produce some uncertainty in the calculated outputs and these are discussed in AMEC, 2010. In this section and in Appendix B of this report the uncertainty in the various model inputs is discussed and sensitivity analysis of the model to inputs with a high or moderate level of uncertainty is carried out.

The level of uncertainty in input data is based on the variation in input data values, checking between values reported for different datasets (e.g. for population data), and on professional judgement. Where the data inputs supplied have been based on national datasets provided in AMEC, 2010, the level of uncertainty has been assumed to be low.

A detailed analysis of the main inputs, the format, information extracted, source of uncertainty, impact on calculations and level of uncertainty is provided in the table in Appendix B. As a result of this analysis the following datasets were considered to provide a moderate or high level of uncertainty (e.g. more than 20% variation):

- Underestimation of the total land area under different crop types;
- Underestimation of livestock densities;
- Underestimation of population on mains water/sewer;
- Distribution of private sewerage treatment between septic tanks and package treatment works;

- Uncertainty over landfill liner presence and hence leakage rates from base of landfill;
- Uncertainty over concentration of leachate from landfill and reductions applied for flushing;
- Attenuation rates for aquifers with an estimated proportion of clay; and
- Fertiliser application rates (inorganic and organic).

The sensitivity of the model to the potential range of values from each of these datasets was assessed for the A&O Chalk and the New Forest Secondary models. The outcomes of this analysis are discussed further in the next section and in Appendix B of this report.

2.5.2 Sensitivity Analysis

Sensitivity analysis was carried out for two catchments by varying the data inputs where there is greatest uncertainty. For inputs with a low level of uncertainty sensitivity analysis has not been carried out. The greatest impact on model output was from the variation in leakage rates from landfill. Changing the leakage rate to reflect the lack of an engineered cap or liner at a landfill site, by using the infiltration recharge value for the catchment can increase the landfill loading term by 10% to 25%. The model sensitivity to all other datasets with a high level of uncertainty was never greater than 2%, and therefore considered negligible (Appendix B). Clearly a good understanding of fate and transport from landfill sources is needed to improve confidence in model outputs, and where possible site specific information on waste age and leakage to the water table has been included where available.

2.6 Summary and Recommendations for Further Work

Source apportionment of nitrate over 17 GWBs linked to the South Downs National Park NIA and contained within the South East River Basin District indicates that nitrate contributions are mainly sourced from agricultural land, but landfill (albeit based on uncertain data inputs) and mains leakage can be significant sources. For most GWBs, wheat, winter oil seed rape, cereals and grassland (grazed, cut and temporary receiving fertiliser inputs) make up the bulk of the N budget.

Uncertainty - The uncertainty in the inputs from landfill can be high, especially where the engineering design and leachate concentration is not well constrained, which is the case for most historic sites. This impacts the results of source apportionment in the Brighton Chalk, A&WS Lower Greensand and Chalk, East Hants Secondary, Test and Itchen Secondary and the New Forest Secondary GWBs. Further work is recommended to refine the landfill input to these models before planning action based on the outputs for these specific catchments.

Denitrification is likely to occur in the C&PL Lower Greensand and Adur and Ouse Lower Greensand although no monitoring data is available to confirm this. Denitrification is confirmed by very low observed nitrate concentrations in the C&PL Secondary, A&O Secondary, A&WS Secondary (based on one monitoring point), Test and Itchen Secondary and the IOW Lower Greensand. The presence of denitrification of nitrate suggests that further management of nitrate leaching is not necessary in these catchments.

Current WFD threshold exceedance (leading to failure of the general chemical test for GWBs) - The IOW Secondary unit is the only GWB with an observed concentration exceeding the WFD threshold value, although the sole monitoring point is not representative of the whole GWB. For classification purposes this body will be grouped with other geochemically similar aquifers, and it is likely that there will be some denitrification in less permeable parts of this aquifer.

Predicted WFD threshold exceedance - Predicted nitrate leaching concentrations in the Brighton Chalk, C&PL Lower Greensand, Adur and Ouse Lower Greensand, A&WS Lower Greensand, East Hants Secondary and Test and Itchen Secondary all exceed the WFD threshold value. In the A&WS Lower Greensand, East Hants Secondary and Test &Itchen Secondary the predicted value is likely to be affected by the large landfill contribution and could be an over-estimate of actual leaching rates. Denitrification has either been identified as occurring or likely to occur in the Secondary and Lower Greensand GWBs potentially reducing the risk of future WFD threshold exceedance in these aquifers. Therefore the focus of action to reduce nitrate leaching from this list should be the Brighton Chalk. In some GWBs the WFD status objectives failure is linked to the drinking water objective, i.e. in GWBs containing the Safeguard Zones covered in Section 4.

Impact on surface waters - Where a river has a significant baseflow contribution from the underlying aquifer and discharges into transitional waters where eutrophication is thought to be caused by elevated nutrients, the groundwater nitrate contribution should be included in actions to deal with the surface water problem. In general,Chalk baseflow contribution to rivers is typically highest (60-90%). In the east of the study area, quite a few rivers rise from springs issuing from Secondary aquifers with baseflow contributions of up to 50%. The River Adur and River Cuckmere both rise on springs from the Lower Greensand, although the small extent of outcrop of this formation means that the baseflow contribution is between 30-40% (Marsh and Hannaford, 2008). The potential for denitrification in the Lower Greensand and Secondary GWBs means that the contribution of nitrate, although variable, is generally expected to be lower than from the Chalk. The focus of actions to control groundwater nitrate contribution to transitional waters should therefore mainly be on the Chalk GWBs, although Secondary GWBs with high baseflow contributions should also be assessed (e.g. through monitoring to identify the likely contribution from groundwater).

Recommendations by GWB for further investigation are provided below in Table 2.7. In Section 3, where the outcomes of source apportionment indicate that actions to reduce nitrate should be taken (i.e. the nitrate attenuation is not present and the uncertainty in the landfill term is relatively low), the nitrate risk map has been used in conjunction with source apportionment to identify potential high level actions for further consideration by the project board.

Table 2.7 Interpretation of Source Apportionment Modelling Work and Recommendations for Model Refinement and Future Actions

Study Group GWB	Average Nitrate Observed Nitrate 2010-2013 (mg/l NO_3)	Predicted Nitrate Reaching Water Table (mg/l NO_3)	Actions to Achieve and Maintain WFD Threshold of 37.5 mg/l NO_3 GWB Average
Seaford and Eastbourne Chalk*	28.9	30	Average nitrate (2010-13) around 10 mg/l NO_3 below threshold, whilst the predicted value is within the same range as the observed. Actions should focus on maintaining leaching rates through the NIA landscape assessment and improvements in the efficiency of N applications on arable crops through farm engagement. The River Cuckmere receives baseflow from the Chalk so nitrate concentrations may impact transitional surface water quality.
C&PL Secondary	1.1	26	Significant attenuation so no action required.
C&PL LGS	No observed data available	39	Predicted values are above threshold although impacts of denitrification are unknown but there is likely to be some reduction of concentrations at the water table (aquifer is comparable to the A&WS LGS). The River Cuckmere rises from LGS springs and so nitrate concentrations may impact transitional surface water quality, albeit much further downstream and surface water monitoring data could be checked to confirm this.
Adur and Ouse LGS	No observed data available	39	Predicted values are above threshold although impacts of denitrification are unknown but there is likely to be some reduction of concentrations at the water table (aquifer is comparable to the A&WS LGS).
Brighton Chalk*	33.4	38	Average nitrate (2010-13) around 4 mg/l NO_3 below threshold whilst the predicted value suggests that future concentrations will exceed the WFD threshold. Uncertainty in landfill term may lead to a change in prediction, so further refinement required for the landfill term. Actions should focus on maintaining leaching rates through the NIA landscape assessment and improvements in the efficiency of N applications on arable crops and grassland through farm engagement. Significant contribution from mains and sewer could be reduced by working with water company. The River Ouse receives baseflow from the Chalk so nitrate concentrations may impact transitional surface water quality.
Adur and Ouse Secondary	1.1	17	Significant attenuation so no action required.
A&WS Chalk*	26.2	29	Average nitrate (2010-13) around 10 mg/l below threshold, whilst predicted concentration suggests a future increase below threshold. Uncertainty in landfill term may lead to a change in prediction, so further refinement required for the landfill term. Actions should focus on maintaining leaching rates through the NIA landscape assessment and improvements in the efficiency of N applications on arable crops and grassland through farm engagement. The Rivers Arun and Lavant receive over 60% baseflow from the Chalk so groundwater nitrate concentrations are likely to impact transitional surface water quality.

Table 2.7 (continued) Interpretation of Source Apportionment Modelling Work and Recommendations for Model Refinement and Future Actions

Study Group GWB	Average Nitrate Observed Nitrate 2010-2013 (mg/l NO_3)	Predicted Nitrate Reaching Water Table (mg/l NO_3)	Actions to Achieve and Maintain WFD Threshold of 37.5 mg/l NO_3 GWB Average
A&WS LGS	17.7	39	Average nitrate (2010-13) around 20 mg/l NO_3 below threshold whilst predicted concentrations suggest future increase above threshold. Landfill term is uncertain and requires further refinement and the level of attenuation should be assessed. Once this work is complete, and the model updated, depending on predicted concentrations action will be required to maintain nitrate below threshold.
A&WS Secondary	0.9	14	Significant attenuation so no action required.
East Hants Chalk*	28.2	33	Average nitrate (2010-13) around 10 mg/l NO_3 below threshold whilst predicted suggest future increase, so action required to maintain nitrate below threshold by investigating loading from arable land (wheat, other cereals and oil seed rape growing) where the contribution is greatest, and identifying efficiencies in N application.
East Hants Secondary	22.8	40	Average nitrate (2010-13) around 15 mg/l NO_3 below threshold (based on one monitoring point) whilst predicted concentration suggests a future increase above threshold. Uncertainty in large landfill term requires further refinement as this affects the predicted value. Once model is updated and predicted concentrations reviewed, further actions (if any) to maintain nitrate below threshold should be identified if necessary. Surface water monitoring where baseflow index is significant could confirm denitrifcation.
Test and Itchen Chalk*	33.7	30	Average for 2010-13 at around 4 mg/l NO_3 below threshold and predicted leaching value is a similar concentration. Actions should focus on maintaining leaching rates through the NIA landscape assessment and improvements in the efficiency of N applications on arable crops through farm engagement.
Test and Itchen Secondary	0.9	46	Significant attenuation so no action required on the ground, although large uncertainty in landfill term should be refined.
IOW Lower Greensand	9.8	62	Significant attenuation so no action required.

Table 2.7 (continued) **Interpretation of Source Apportionment Modelling Work and Recommendations for Model Refinement and Future Actions**

Study Group GWB	Average Nitrate Observed Nitrate 2010-2013 (mg/l NO_3)	Predicted Nitrate Reaching Water Table (mg/l NO_3)	Actions to Achieve and Maintain WFD Threshold of 37.5 mg/l NO_3 GWB Average
IOW Chalk*	28.5	27	Average for 2010-13 at around 10 mg/l NO_3 below threshold and predicted leaching value is a similar concentration. Action required to maintain nitrate at these levels, below the threshold.
IOW Secondary	43.5	21	Average concentration for 2010-13 already above threshold value based on one monitoring point. This groundwater body is made up of a number of geological units and the sole monitoring point abstracts from the Bembridge Limestone so no overarching conclusions can be made, however, local investigations should be carried out in the outcrop of the Bembridge Limestone.
New Forest Secondary	14.1	19	Average for 2010-13 around 22 mg/l NO_3 below threshold whilst predicted value suggests a future increase. Further work should be done to reduce uncertainty in the landfill term and quantify any level of attenuation. Once complete further actions can be planned to maintain nitrate .below threshold.

* GWB at poor chemical status due to nitrate in interim Cycle 2 of WFD classification.

3. Nitrate Risk Mapping

This section has been removed until licensing issues with the NEAP-N model inputs used have been resolved by the Environment Agency. For further information contact Polly Wallace at the EA.

4. Nitrate Modelling at Groundwater Safeguard Zones and the River Lavant

4.1 Introduction

Modelling of nitrate in groundwater has been carried out at the following PWS abstractions, and also at the River Lavant, to identify the main sources and controls on trends:

- Twyford (Southern Water -Itchen Chalk);
- Findon and Burpham (Southern Water - Worthing Chalk);
- Lovedean, Westergate and Eastergate (Portsmouth Water – East Hants Chalk and Chichester Chalk); and
- Patcham, Newmarket, Housedean and Mossy Bottom (Southern Water - Brighton Chalk).

The River Lavant discharges to Chichester Harbour, a protected area, where eutrophication of transitional waters has been linked to rising nitrate concentrations in up-catchment groundwater. WFD targets for nitrate in the protected area will depend on the salinity and turbidity of these waters. An estimate for the dissolved inorganic nitrogen threshold (at the good/moderate status boundary) of around 0.5 mg/l as a winter mean and 1.5 mg/l as a 99%ile in the harbour waters has been made by the Environment Agency. Although this is very low in comparison to observed "background" values in groundwater which are derived from normal soil breakdown (around 3-4 mg/l NO_3), the water in Chichester Harbour will also include dilution from other rivers, seawater and rainfall. Therefore it may be more realistic for the target for the River Lavant to be to reverse trends in nitrate, rather than achieve such a low threshold value.

In order to identify where to most effectively focus effort to manage nitrate concentrations in groundwater, source apportionment modelling and trend assessment has been carried out for each catchment. The N&P Source Apportionment Spreadsheet tool, has been used to model contributions of nitrate from identified sources of nitrate in each catchment (Section 2 and Appendix A and AMEC, 2010). The nitrate trend model spreadsheet developed by AMEC (2008) and used in the WAgriCo approach to assessing nitrate concentrations at PWS abstractions in the Wessex and Lincolnshire Chalk (Rukin et al., 2010, AMEC, 2012, Appendix D of this report) has been used to model historic nitrate concentrations. Where there is a good fit to observed concentrations the model has been used to identify the nitrate leaching reductions needed to achieve:

- Average concentrations at or below the 37.5 mg/l NO_3 threshold value (for assessment of WFD related chemical status); and/or
- No exceedance of the 50 mg/l NO_3 drinking water standard (DWS);
- A reversal in trend for the River Lavant.

In this section data preparation and model set up are described, along with catchment delineation, model sensitivity and uncertainty, with a discussion of the over-arching results. Abstraction and catchment characterisation, followed by the results of modelling and recommended further investigation are described for each source in Appendix E.

4.2 Input Data Requirements

4.2.1 Source Apportionment

In addition to the datasets collated for the GWBs, described in Section 2.3, some farm visit information supplied by the Environment Agency and Portsmouth Water for the Twyford, Patcham, Newmarket, Housedean, Eastergate and Westergate catchments has also been used in building the source apportionment models. It is noted that this information does not cover the whole of each catchment, but does provide information on N applications rates and head of cattle at some farm. This has been used to confirm rates and livestock density in the models which are based on RB209 and Agricultural Census data. At the time of writing no such information was available for farms in the Lovedean, Findon, Burpham or Mossy Bottom catchments and here fertiliser inputs based on RB209 recommended application rates, including NVZ limits where applicable, have been applied.

4.2.2 Nitrate Trend Model

The nitrate trend models required the following further datasets:

- Observed historic nitrate concentrations at abstraction boreholes and at various points on the River Lavant for use in model calibration (supplied by Environment Agency, Southern Water and Portsmouth Water);
- Topography for use in depth to water table calculation (OS panoramic topography layer 1: 50 000);
- Depth to Chalk water table for dry, wet and average stress periods. Groundwater level data were obtained for the Test and Itchen, Brighton and Worthing and East Hants Chichester Chalk (EHCC) groundwater models for the relevant stress periods;
- Land Cover Map 2007 for use in identification of relevant historic leaching trend based on arable, improved grassland, urban, semi-natural vegetation or woodland (CEH, 2011);
- Dominant soil type in the catchment to identify any retardation of N transport in the soil zone (based on NATMAP dataset from the Environment Agency Soils Tool Kit);
- Unsaturated zone moisture content of 30% for the Chalk as a proxy for the effective porosity for use in the calculation of time of travel through the unsaturated zone (Allen el al., 1997). It is noted that this value can vary for the Chalk with an inverse relationship with the level of deformation by folding and faulting. In Dorset reported ranges of 21% to 45% are provided by Alexander, (1981), whilst a more recent investigation in the Brighton Chalk , north of Patcham, suggests a range of moisture content of between 20-35% (Adams et al., 2008);

- Historic groundwater levels from the Catherington, Chilgrove, Rogers Farm, Clanville Lodge and Houndean observation boreholes identified in Figure 4.1, to fit nitrate fluctuation due to water table fluctuation (data supplied by the Environment Agency);

- Infiltration recharge to the Chalk based on long term average (LTA) values from the 4R models for Test and Itchen, Brighton and Worthing and East Hants Chichester Chalk groundwater models.

For each model the spatial datasets have been clipped to the catchment area (Section 4.2.2) for each abstraction or the River Lavant and the resulting smaller datasets used to create inputs to the source apportionment and nitrate trend tools.

4.2.3 Catchment Delineation

The Twyford, Eastergate, Westergate and Lovedean abstractions sit within the Test and Itchen and East Hants Chichester Chalk (EHCC) groundwater models, and for these sources outputs from the Flowsource programme (© Groundwater Science) have been used to delineate catchments to the boreholes based on abstraction rates agreed with Portsmouth Water and Southern Water (Table 4.1). The Findon, Burpham, Patcham, Mossy Bottom, Housedean and Newmarket abstractions are within the Brighton and Worthing Chalk model which, as noted previously was not deemed complete enough at the time of modelling to use the Flowsource programme, and instead the boundary of the SPZ 2 to the sources has been used. This is the default boundary for Safeguard Zones delineated by the Environment Agency. The modelled catchments to all sources are shown in Figure 4.1.

There will be a greater level of uncertainty in the catchments to sources based on SPZ 2 compared to Flowsource outputs. SPZ 2 is based on the 400 day travel time zone to the abstractions or on 25% of the total capture zone, at the full licensed pumping rate. For most sources the actual abstraction rates are lower than the total licence used to create SPZ 3, and so in some cases SPZ 2 may be more representative of the actual catchment to the abstraction than using SPZ 3. The Flowsource based total capture zones are produced using reported actual pumping rates so will be a better fit to the actual catchment.

Generally the SPZ 2 area provides a good fit or slightly less than the “water balance” to the actual abstraction rates in Table 4.1, suggesting that in some cases the boundaries could be too small. The Flowsource derived catchments all exceed this simple sense check on catchment area because variation in transmissivity and recharge represented in groundwater models is not included in the water balance calculation. The output Flowsource catchments will be closer to the area required for an actual water balance based on variable recharge and aquifer properties over the catchment.

For the River Lavant the surface water catchment boundary, as supplied by the Environment Agency, has been used.

Flowsource Catchments

For each model cell the Flowsource programme identifies the proportion of water in any one stress period (here one month) which will be “captured” by the model cell(s) in which the abstraction of interest sits. This calculation is used with the “cell by cell” flow information from the MODFLOW model to calculate:

- How much water starting in model cells as recharge to the water table or released from storage, will be captured by the abstraction cell (the source of the water at the abstraction);

- The proportion of water flowing through each model cell captured by the abstraction cell i.e. the pathway of water;

- The proportion of the total modelled period that water captured from model cells exceeds a specified threshold (for example the proportion of time that more than a specified volume of water from a model cell ends up at the abstraction).

These outputs have been used to identify the catchments to the Eastergate, Westergate, Lovedean and Twyford sources as follows:

- Calculated groundwater levels for the whole modelled period (1970 to 2012) from a "Recent Actual" run of the Test and Itchen and EHCC MODFLOW models where the Twyford, Lovedean, Eastergate and Westergate abstractions are located, were set to the pumping rates in Table 4.1;

- Flowsource was used to calculate the captured fraction of water from model cells which end up at the model cells containing the boreholes at these sites;

- Capture fractions were used to calculate the: volume of water starting at each model cell representing release from aquifer storage and recharge at the water table, i.e. the source of water or the "volume from"; and the volume of water flowing through the faces of each model cell i.e. the pathway of water or the "volume through", which ends up at the model cells containing the abstractions;

- The volume of water from and flowing through each model cell face for the dry and wet stress periods and the LTA value were displayed as a raster file in GIS (Figure 4.2 and Figure 4.3 respectively) along with the proportion of modelled time the volume flowing through model cell faces contributed > $1m^3/d$ to the abstraction cell (Figure 4.4);

- The catchment to each abstraction was based on a combination of these outputs (with preference for volumetric outputs) and a comparison made to the current SPZ3;

- A final comparison with a simple water balance to check that the area of delineated catchment was close to or exceeded the area of land and recharge required to supply the abstraction rate.

The Flowsource delineated catchments for Twyford, Lovedean, Eastergate and Westergate are shown in Figure 4.5 with existing SPZs. In some cases a good agreement with the SPZ 2 extent was found (e.g. Twyford), but elsewhere the defined catchment was much larger and wider (Eastergate and Westergate). This difference reflects the use of particle tracking to define SPZs and the use of Flowsource which typically provides a much wider catchment (due to numerical dispersion linked to the model grid). The conceptual understanding of flow regimes has also changed. For example, the inclusion of the River Itchen in the Twyford Flowsource catchment reflects the current conceptual understanding that this abstraction impacts river flows.

These final catchments were agreed with the Environment Agency, SDNP Authority, Portsmouth Water and Southern Water, and the boundaries used to clip spatial dataset inputs for nitrate trend and source apportionment modelling.

Table 4.1 Abstraction Rate, Catchment Area and Basis of Delineation

Source Name	Abstraction Rates (ML/d)*	Infiltration Recharge (mm/a)**	Water Balance Area (km^2)	Modelled Catchment Area (km^2)	Basis of Catchment	Comment on Catchment
Burpham	11.1	454.84	9	4.5	SPZ2	Smaller than water balance.
Eastergate	9.3	457.61	7	45.3	Regional GW model and Flowsource	6-7 times greater than water balance.
Findon	7	521.37	5	4.1	SPZ2	Good fit to water balance.
Housedean	5	459.47	4	2.5	SPZ2	Smaller than water balance.
Lovedean	4	465.98	3	13.9	Regional GW model and Flowsource	4 times greater than water balance.
Mossy Bottom	3.3	464.4	3	1.9	SPZ2	Good fit to water balance.
Newmarket	12	458.06	10	3.6	SPZ2	Smaller than water balance.
Patcham	9	418.99	8	8.9	SPZ2	Good fit to water balance.
River Lavant		495		91.1	WFD catchment	
Twyford	20	357.75	20	34.9	Regional GW model and Flowsource	Larger than water balance.
Westergate	6.2	470.8	5	37.9	Regional GW model and Flowsource	7-8 times greater than water balance.

4.2.4 Model Build

Nitrate Trend Models

The build of the trend models is covered in detail in Appendix D, whilst the results of trend modelling for each catchment are reported in Appendix E.

In summary each catchment is divided into a 200 or 250 m grid which is used to sample spatial datasets of topography, depth to water table in the Chalk (LTA, high and low water table), total effective rainfall, infiltration recharge, soil type (NAT MAP/ Soils Tool kit) and land use (Land Cover Map 2007) within each catchment boundary. Distance of each grid square from the point at which observed nitrate data is collected is also calculated.

The unsaturated zone and saturated zone travel time to the abstraction are calculated based on unsaturated zone thickness and porosity, and this is used to calculate the starting nitrate concentration based on the year the water left the soil zone and the land use (in 2007) assigned to each grid square (e.g. arable land, improved grassland, woodland, urban land and semi-natural vegetation). For each year a sum of nitrate arriving at the abstraction point is calculated based on the changing levels of N leaching from arable and improved grassland over the period 1900 to 2012. Leaching from other land uses (semi-natural vegetation, woodland and urban areas) is assumed to remain constant in this period.

Long term trends in nitrate concentrations in pumped water are calculated for the period 1945 to 2012, based on the long term trend in soil leaching, land use in the catchment and the delay for water to move through the unsaturated zone to the water table. This long term trend is then predicted forward to 2035 using a polynomial fit to historical values and on the leaching rates in 2013 i.e. assuming that nothing changes in the future.

Fluctuations in water table are overlaid on the modelled nitrate signature to reflect the seasonal fluctuations typically observed in nitrate concentrations. Seasonal variation in nitrate concentrations (simulated based on fluctuations in water levels) is calculated according to the period for which water level data are available; typically starting around 1970. Water levels are used from observation borehole hydrographs which are representative of regional water levels, not impacted by abstraction, and have a long record. Predictions of future seasonal variations in nitrate in pumped water are based on repeating historical water level data (including drought and wet periods) for the last 20 years, and hence forecast nitrate concentrations cover the period 2013 to 2032. The modelled trend is adjusted to reflect time-lag in the aquifer response to infiltration recharge events (typically 10-30 days).

Information on point sources of nitrate such as landfills and consented discharges are also included in the model as constant sources of nitrate.

For model calibration observed nitrate data at the abstraction is used. Where there are multiple boreholes at an abstraction only one borehole's dataset has been used for model comparison. This is because the impact of construction and differing abstraction regimes can lead to very different nitrate trends at neighbouring boreholes. Also data supplied for different boreholes is usually for differing dates, so using an average of datasets does not provide a real average where daily samples are not available. The modelled borehole was selected based on continuous record, high nitrate and/or the significance of contribution to supply (e.g. Twyford Well at Twyford).

Acceptance Criteria

The acceptability of a model simulation is based on the following criteria:

- Shape of trend (slope of modelled trend following slope of observed trend) controlled by the rate at which nitrate is moving through the system (input parameters: moisture content, infiltration recharge);
- Match to the average nitrate concentration, controlled by land-use mapping and leaching trends for arable and improved grassland (input parameters: categorisation of catchment by land use type, and depth to water table, arable and improved grassland leaching trends);
- Matching of peak and trough occurrence (not amplitude) controlled by the seasonal fluctuation in water table (input parameters: calculated nitrate trend, groundwater levels at local observation borehole with applied lag date for difference in response time to recharge at the abstraction borehole);
- Matching of amplitude of peak and troughs in concentration (input parameters: constant k_1 used to relate nitrate concentration change to amplitude of water level variation at the modelled abstraction borehole as described in Appendix D).

For a modelled trend to be considered a "good fit" the model must at least match the average nitrate, shape of trend and pick up the timing of peak and trough concentrations. The absolute amplitude of concentrations is more difficult to achieve due to the variability in the relationship between abstraction borehole groundwater level and nitrate concentrations.

Scenario Modelling

The purpose of the nitrate modelling is to understand the required reduction in nitrate concentrations to bring levels to equal or be less than 37.5 mg/l NO_3, and/or reverse upward trends. From a water company perspective there is also a need to prevent exceedances of the DWS by peak concentrations. The nitrate trend model can predict future nitrate concentrations based on percentage reductions in arable and improved grassland leaching over the whole catchment. Where a good model fit is achieved, the trend model is used to identify the percentage reduction in nitrate leaching (over the whole catchment) required to return or retain average nitrate concentrations at or below the WFD threshold and/or to reduce peak nitrate concentrations to below the DWS.

Another output from the nitrate trend models is a calculation of the age of water arriving at the abstraction point and what land-use dominates the grid square that the water derives from. This information can be used to identify the likely timescale for the impact of measures to be seen, and also used with spatial maps of the catchment to identify areas where changes in land-use could have a relatively rapid impact on observed nitrate concentrations. Where it is predicted that the required reductions in nitrate cannot be achieved within the model forecast period (i.e. before 2032) a best estimate on the timing of reduction is made based on the Age of Waters plot from the trend model. For sites with a poor model fit linked to incorrect delineation of the catchment boundary the Age of Waters plot may not capture all of the water arriving at the abstraction, and the timing of the impact of benefits will be uncertain.

Nitrate Source Apportionment

In order to focus the implementation of measures on activities which provide the greatest contribution of nitrate to groundwater in the catchments being investigated, source apportionment of the main sources of nitrate has been carried out. This follows the same methodology outlined in Section 2 of this report, but more site specific information has been made available (i.e. farm data specific to the catchments). Data inputs to the 11 source apportionment spreadsheets are shown in Table 4.2. Predicted nitrate concentrations from the source apportionment spreadsheets are compared to average observed nitrate concentrations at the abstraction points to identify the goodness of fit of the models. It is expected that as there will be a difference between nitrate predicted to be leaving the soil zone and nitrate already at the water table (i.e. the observed concentrations). Porewater arriving at the water table in the period 2010-2013 (used to calculate average observed values) will result from historic land management, the age of which will be related to the time of travel through the unsaturated zone. The predicted average leaching over catchments gives an indication of likely concentrations at the water table at a point in the future, although the accuracy of the prediction will be reduced by uncertainty in the model. Comment on uncertainty in the model inputs linked to catchment size, particularly the Agricultural Census data, is made in Section 4.3. The results of source apportionment modelling for each catchment are reported in Appendix E of this report.

4.2.5 Assumptions made in Model Build

The assumptions that have been made in the trend model and source apportionment model set-up are as follows:

- Multiple boreholes at the PWS source may represent groundwater being drawn from different parts of the catchment, but this is not represented in either model;
- Abstraction rates and regime at the source has stayed the same over the modelled trend period (in reality this is not the case for many sources);
- Any attenuation of nitrate that takes place in the highly fissured Chalk aquifer is not significant enough to be modelled. At the Eastergate and Westergate catchments the presence of overlying Superficial Drift deposits and the Lambeth Group and London Clay Formations will provide attenuation of nitrate in any water infiltrating and leaking into the underlying Chalk, but the volume of this leakage is assumed to be negligible compared to the water from the unconfined aquifer;
- Transport of nitrate is mainly under “piston-flow” or “plug-flow” through the Chalk matrix – bypass or fissure flow has not been modelled;
- Crop rotations are represented in the trend models by the historic arable and improved grassland nitrate leaching trends, both of which have been constructed from empirical information (historic fertiliser usage and livestock density, nitrate porewater profiles for the Chalk), and then adjusted based on observed nitrate at several Wessex Water catchments. This means that the leaching trends will implicitly represent the impact of crop rotation on N leaching. The source apportionment models represent a “snap-shot” of land-use and therefore will not fully represent a crop rotation, but it is assumed that the crop types included in each catchment are representative of typical cropping;
- The trend and source apportionment models are set up based on the current land-use situation. Any historic changes in land-use are not reflected, although these could be significant;
- The only source of water to the boreholes is groundwater. Surface water inputs (leaky river beds) are not included in the model, although they can be represented. At Burpham a “river leakage” input has been attempted by using a 15% dilution factor based on the conceptual understanding of the abstraction, although recent river water quality data suggests that groundwater and surface water nitrate concentrations are similar;
- Where the SPZ 2 is used as the catchment boundary this is representative of the total capture zone to the abstraction when pumping at a typical rate.

In reality land-use change is likely to have happened in some of the catchments over the past 60-70 years with the change from dairy farming to more economically beneficial arable farming. Abstraction rates may have changed with outages in abstraction, and this can have an impact on the fit of the nitrate trend predicted.

Table 4.2 Catchment Data Used in Source Apportionment Models

Catchment Characteristic	Units	Lavant (Sussex)	Burpham	Findon	Housedean	Mossy Bottom	New Market	Patcham	Eastergate	Westergate	Lovedean	Twyford
Catchment Area	ha	9114	445	411	252	193	723	894	4527	3794	1398	3498
Infiltration recharge (one value for each model area)	mm	495	455	521	459	464	458	419	458	471	466	358
Soil (Sand, Loam or Clay)	n/a	Sand	Sand	Sand	Sand	Sand	Sand	Sand	Sand	Sand	Sand	Sand
Population on Mains Sewer Network and Septic Tank/Treatment Package Plant												
Sewered population		12017	175	1050	95	0	25	1150	2200	1300	50	1600
Sewered population (with discharge of treated effluent to ground)		0	0	0	0	0	0	93	0	0	0	36540
Number of people served by septic tanks		1137	5	25	5	15	22	25	150	100	175	450
Number of people served by package treatment plants		1137	0	25	0	0	23	25	150	100	175	450
Urban Land Use												
Total urban/suburban area (Built up areas and gardens)	ha	333	0	40	0	0	3	39	125	65	7	36
Area gardens	ha	167	0	20	0	0	1	19	63	32	3	18
Area allotments	ha	21	0	2	0	0	0	2	8	4	0	2
Area of paved surfaces draining to ground	ha	83	0	10	0	0	1	10	31	16	2	9
Area of buildings and paved surfaces (no drainage to ground)	ha	42	0	5	0	0	1	5	16	8	1	5

Table 4.2 (continued) Catchment Data Used in Source Apportionment Models

Catchment Characteristic	Units	Lavant (Sussex)	Burpham	Findon	Housedean	Mossy Bottom	New Market	Patcham	Eastergate	Westergate	Lovedean	Twyford
Urban Land Use (continued)												
Area of sports grounds etc	ha	21	0	2	0	0	0	2	8	4	0	2
Area of roads and paved surfaces (outside urban)	ha	82	4	7	2	0	7	13	56	42	26	44
Rural Land Use (from Agricultural Census 2010)												
Grazed Grass	ha	408	70	52	47	23	139	132	230	200	115	254
Cut Grass	ha	408	70	52	47	23	139	132	230	200	115	254
Temporary Grass	ha	196	15	7	11	5	33	32	117	105	25	87
Cereal crops	ha	748	21	27	16	10	67	11	201	219	106	382
Other arable	ha	242	12	13	7	5	28	5	153	127	50	302
Bare fallow	ha	83	2	14	5	1	22	4	46	42	9	35
Rough grazing	ha	358	44	44	20	14	47	90	265	217	142	303
Orchards	ha	0	0	0	0	0	1	0	0	0	0	2
Woodland (calculated from Land use 2007)	ha	3240	9	24	23	5	35	65	1604	1329	254	289
Ploughed out long term grass (Zero unless other info available)	ha	0	0	0	0	0	0	0	0	0	0	0
Winter OSR	ha	122	7	13	10	3	40	15	51	42	140	226
Spring OSR	ha	12	0	1	0	0	0	1	2	2	0	2

**Table 4.2 (continued)	Catchment Data Used in Source Apportionment Models**

Catchment Characteristic	Units	Lavant (Sussex)	Burpham	Findon	Housedean	Mossy Bottom	New Market	Patcham	Eastergate	Westergate	Lovedean	Twyford
Rural Land Use (from Agricultural Census 2010) (continued)												
Potatoes	ha	17	0	0	0	0	0	0	6	6	0	0
Wheat	ha	557	34	39	18	13	59	36	460	359	180	404
Vegetables grown in the open	ha	40	0	0	1	0	3	0	17	11	0	8
Livestock Numbers (from Agricultural Census 2010)												
Cattle	hd	1071	146	80	89	45	275	179	594	519	363	711
Sheep and goats	hd	2648	350	312	281	80	896	601	1606	1367	605	681
Pigs	hd	447	17	22	13	10	41	30	81	93	29	736
Poultry	hd	1660	2284	5492	1001	256	2413	2153	521	439	442	66056
Landfills and Graveyards												
Area of graveyards (calc)	ha	18	1	1	1	0	1	2	9	8	3	7
Area of graveyards (calc) + OS Map	ha	10	1	2	1	0	0	3	5	3	1	3
Area of landfill (inert)	ha	23.6	0	0	0	0	0	0	85.98	61.36	0	0.16
Area of landfill (non hazardous)	ha	9.1	0	0	0.20	0	0	3.69	7.88	8.32	0	4.91
Agricultural Point Sources (calculated from Livestock numbers)												
Area of engineered slurry stores	ha	0.11	0.01	0.01	0.01	0.00	0.03	0.02	0.06	0.05	0.04	0.07
Area of unlined slurry stores	Ha	0.11	0.01	0.01	0.01	0.00	0.03	0.02	0.06	0.05	0.04	0.07
Area generating farmyard run-off	Ha	0.5	0	0	0	0	0	0	0.5	0.5	0	0.5
Area of constructed wetlands	Ha	0	0	0	0	0	0	0	0	0	0	0

4.3 Model Output Assessment

4.3.1 Nitrate Trend Models

The outcomes of nitrate trend modelling are summarised in Table 4.3a and 4.3b and discussed for individual catchments in Appendix E. A good fit to observed nitrate concentrations is achieved for Twyford, Lovedean, Eastergate, Newmarket, Findon and Patcham although some of these predicted trends can be slightly shallow (i.e. do not rise quickly enough) compared to the observed trends. Of these, only Newmarket and Patcham have not yet exceeded the DWS. At Patcham future exceedance of the DWS is not predicted, but at Newmarket concentrations will exceed DWS by 2035. The model fit is less good at Burpham and the River Lavant where the nitrate concentration is overestimated (probably due to surface water inputs), at Housedean and Mossy Bottom where the concentration is underestimated (linked to uncertainty in land-use and catchment size) and at Westergate where the observed concentration of nitrate is underestimated, although the timing of peaks is modelled. Nitrate concentrations have already exceeded the DWS at Housedean, whilst at Burpham concentrations are likely to exceed the DWS by 2015, and at Mossy Bottom by 2020.

It is notable that there are significant uncertainties in agricultural census land use versus Land Cover Map 2007 in the Housedean, Mossy Bottom, Burpham and Patcham catchments, as discussed for the source apportionment models above. In some cases this could be explained by historic land-use change and/or by the input of surface water either through connection to the groundwater abstraction, or as part of more dilute river flow concentrations leading to a lower observed nitrate trend (e.g. Burpham and the River Lavant).

As noted previously, at Housedean and Mossy Bottom the checking of aerial images (Google Earth for 2007) of the catchment with Land Cover Map 2007 suggested that there was some incorrect mapping of woodland and improved grassland areas. In reality this may be an issue for all catchments, but in these small catchments (Housedean 2.52 km^2 and Mossy Bottom 1.9 km^2) the impact of incorrect land-use categories on the trend model will be more significant. An alternative nitrate trend model for Housedean and Mossy Bottom has been set up based on land-use interpreted from the aerial images. For both updated models the trend fit to observed concentrations is better, but further checking of catchment land use should be carried out to improve confidence in the outputs. Nitrate concentrations in the River Lavant will be influenced by inputs from groundwater and also direct inputs to surface water (runoff and discharges). The latter are not included in the model of groundwater nitrate concentrations. Therefore the Lavant model is expected to overestimate the concentration of nitrate in the river. Application of 25% dilution (based on a BFI for the Lavant of 75%) from surface water helps to improve the model fit. The variability in abstraction rate at Mossy Bottom will impact on the spatial extent of the catchment with time, affecting the model fit at this source (pers comm. Mike Packman, Southern Water).

Seasonal adjustment of the underlying modelled trends by using groundwater level fluctuations with a lag time and a factor to represent the relationship between groundwater levels and nitrate at abstractions have been applied with varying success. The application of seasonal variations works well, picking up the two prolonged dry periods of 1996 to 2001 and 2003 to 2005. Application of a factor to represent the amplitude of peaks and troughs in nitrate is less successful reflecting the variation in controls on nitrate concentrations locally to the abstractions. For example at Twyford peak and trough nitrate concentrations at the three different abstraction points can be significantly different. Similarly at Eastergate and Westergate, the consistent difference between the two abstractions of around 10 mg/l NO_3 is not understood well. These trend characteristics could be controlled by changes in abstraction rate leading to changes in catchment or flow regime or borehole construction differences leading to supply from specific flow horizons. The use of by-pass flow from the 4R recharge models could also help to pick up historic spikes in concentration which are not linked to seasonally high water tables.

Predicted Nitrate Leaching Scenarios

As noted in Section 4.1, for catchments with a good model fit, the nitrate trend models have been used to identify the magnitude of reduction in nitrate leaching from the soil zone required to bring concentrations to 37.5 mg/l NO_3 or to reduce peak concentrations to below the DWS (summarised in Table 4.3b). A good fit is achieved at Twyford, Lovedean, Eastergate, Housedean (with some uncertainty over land-use), Newmarket, Findon and Patcham, and predictions on nitrate leaching and measures to address concentrations have been investigated further. Observed concentrations are not modelled at Westergate, and this is possibly linked to borehole construction. The delineated catchment overlaps significantly with Eastergate and for the purposes of model assessment and measures development the two abstractions are dealt with together. Based on model scenarios to reduce or maintain **average** concentrations at or below the WFD threshold of 37.5 mg/l NO_3 would require:

- 40-60% reduction in nitrate leaching in the Lovedean catchment;
- 100% reduction in the Newmarket catchment to achieve threshold soon after 2035;
- Housedean is not predicted to achieve the WFD threshold prior to 2032, even with 100% reduction in nitrate leaching;
- At the Twyford catchment, even 100% reduction does not bring the predicted concentrations below the threshold before 2032. The maximum in nitrate leaching from arable land and grassland nationally occurred in 1985 and 1990 respectively (Appendix D) and the average age of waters at Twyford is 47 years (Appendix E). Therefore the peak in the underlying trend in nitrate concentrations travelling through the unsaturated zone will start to plateau in 2031 to 2036 and probably decrease after this point;
- Eastergate and Westergate average concentrations are already slightly below the threshold value, and are predicted to continue to be at this level up to 2032 therefore to achieve the WFD threshold nothing further is required to address the long term trend;
- At Findon average concentrations are likely to continue rising and exceed the WFD threshold, and even a theoretical 100% reduction in nitrate leaching over the whole catchment will only produce a downturn in average concentration trend by 2025; and
- At Patcham average concentrations are predicted to remain below the WFD threshold into the future.

Seasonal peaks and isolated spikes in nitrate concentrations at several sources have exceeded DWS. The trend model can be used to identify the likely timing of peak nitrate, but in some cases the trend is predicted to continue rising outside of the model period (to 2032). The size and timing of future peaks in concentration after 2032 can be roughly estimated based on the amplitude of historical peaks, the average age of waters and the timing for the impact of "maximum nitrate" i.e. the 1985 (arable) -1990 (grassland) period of maximum nitrate application at the land surface to arrive at the water table (based on a 1m/yr downward travel through the unsaturated zone). This will give a rough idea of likely required reduction in concentration and has been assessed along with trend model required reductions to retain peak concentrations below the DWS. Based on this assessment the predicted required reductions are as follows:

- Lovedean trend model indicates 60-70% reduction to bring spikes / peaks below DWS by 2024. There are predicted interim peaks in concentration of up to 58 mg/l NO_3 which would require a reduction of 8 mg/l NO_3 to stay below the DWS. Predicting forward manually using the average age of waters of 54 years maximum concentrations in nitrate in the unsaturated zone will reach the water table between 2039 and 2044;

- Newmarket – the trend is not predicted to exceed the DWS prior to 2032, but using the average age of waters of 50 years, maximum concentrations in nitrate in the unsaturated zone will reach the water table between 2034 and 2039. Extrapolation of the baseline trend and adding on the amplitude of peaks in nitrate suggests future seasonal peak concentrations of 55 mg/l NO_3 by 2034. Concentrations should then fall after 2039 and should subsequently bring seasonal peaks below the DWS;

- Housedean – based on 2001 land-use from aerial images (and therefore uncertain trend model outputs) the nitrate trend will continue to exceed the DWS with seasonal peaks taking concentrations predicted to be up to 2-3 mg/l NO_3 above this limit but the trend is likely to flatten by 2030. The average age of waters is 42 years with predicted maximum nitrate at the water table between 2027 to 2032 and downturn in concentrations after this point;

- Twyford – the main trend will continue to exceed DWS until after 2032 even with 100% reduction in leaching. Maximum concentrations in nitrate in the unsaturated zone will reach the water table between 2031 and 2036;

- Eastergate peaks are predicted to drop below DWS by 2024 suggesting that no reduction is required. At Westergate, which has concentrations around 10 mg/l NO_3 greater than at Eastergate, manual extrapolation of peaks indicates that there will continue to be exceedances of the DWS of up to 5 mg/l NO_3 to 2032. The trend model has not been used to identify percentage reductions at Westergate as the model fit is not good. The model and observed data suggest that there are likely to be interim peaks of just over 60 mg/l NO_3 at Eastergate and 70 mg/l NO_3 at Westergate (manually extrapolated from historic peaks) and these would require a reduction in nitrate of around 10-20 mg/l NO_3 to stay below the DWS. The historic maximum nitrate will pass through the unsaturated zone by 2033-2038 suggesting that peaks at Westergate will continue up until the end of this period;

- Findon – even with a 100% reduction in N leaching modelled peaks in concentration will continue to exceed the DWS until after 2032. Predicting forward manually using the average age of waters of 38 years with mainly arable land, maximum concentrations in nitrate in the unsaturated zone will reach the water table between 2023 and 2028. Manual extrapolation of peaks in concentration indicates that seasonal peak concentrations there will continue to be exceedances of the DWS over this period of up to 15 mg/l NO_3;

- At Patcham modelled concentrations do not exceed the DWS before 2032. The average age of waters at Patcham is 55 years and mainly from grassland, and based on peak N leaching from arable land in 1985 and 1990 from grassland (Appendix D), the concentration of nitrate here is likely to reach a peak between 2048 and 2053. By visually extrapolating the modelled trend forward to this period, following the baseline curve, the concentration is likely to be just over 30 mg/l NO_3. Adding the amplitude of seasonal peak concentrations suggests a maximum value of 40-45 mg/l NO_3 before concentrations fall after 2053. Therefore the trend at Patcham is unlikely to exceed the DWS based on current leaching concentrations.

The model fit is less good at Burpham and the River Lavant where the nitrate concentration is overestimated, and at Mossy Bottom where the concentration is underestimated. For these catchments the required reduction has not been modelled, instead the timing of "maximum nitrate" based on the modelled trend and the age of waters plot, has been carried out (Table 4.3b):

- At Burpham the age of waters can be very low, and the maximum concentrations of nitrate could be seen between 2021 and 2026. This suggests that implementing measures at Burpham would produce a reduction in observed nitrate by 2032;
- At Mossy Bottom the age of water arriving at the abstractions is on average 46 years old, suggesting that measures will have an impact after 2031. Nitrate leaching reduction is only likely to lead to a decrease in peak amplitude by 2032;
- In the River Lavant catchment there is significant uncertainty over the degree to which river water quality at the bottom of the catchment is influenced by groundwater (as opposed to direct inputs from STWs and runoff), and the model fit is not good enough to provide confidence in predictions. However, a significant proportion of inputs to groundwater is via young water, which suggests that measures to reduce nitrate inputs to groundwater would result in trend reversal (at least in groundwater) on a relatively short timescale (between 2036 and 2041).

Uncertainty

Land-use change can bring a large amount of uncertainty to the modelled trend, as the model assumes that there are no changes in land-use with time. Where extensive conversion of pasture to arable land has taken place, this can significantly change the nitrate trend observed in groundwater. Catchment delineation using the Flowsource model has probably helped in terms of using the latest conceptual understanding of groundwater flow in the Chalk. SPZ 2 catchments could be too small, and therefore exclude more distant parts of the catchments which contribute older water to the abstraction, resulting in dilution of predicted trends. For trend models where the catchment is based on SPZ 2, it is recommended that the catchment should be delineated using the relevant groundwater model and the Flowsource programme to improve confidence in the catchment extent, and to identify areas of the catchment contributing the greatest volumes of water to the abstraction.

Finally, it is noted that the quality of fit of the trend models to observed nitrate concentrations is generally improved by using water level data from observation boreholes close to the abstraction. Short term (2 or 3 year) variations in nitrate concentration caused by, for example, two successive dry winters, can cause locally significant variations in groundwater levels, affecting nitrate concentrations at nearby sources, which are not seen at regional scale. Here local observation boreholes have been used, and do provide a good fit to more local variations in nitrate.

The range of time lags used in the models is typically between 10 and 30 days with a multiplier for the "amount" of groundwater fluctuation applied at between 0.09 to 0.28 (Table 4.3a). The lag time represents the lag time between groundwater levels at the observation borehole and peak nitrate at the abstraction and is between 10 and 30 days. The multiplier for the amount of groundwater fluctuation relates nitrate concentration change to water level difference from the historical minimum value for that borehole. The groundwater level fluctuation at observation boreholes, chosen specifically such that the water table is impacted by abstraction, will arguably be greater than that at an abstraction borehole were the water table is artificially controlled by the abstraction. The multiplier allows the user to qualitatively assign a reduction in the amplitude of groundwater level fluctuation to account for this difference between abstraction and observation borehole.

Table 4.3a Outcomes of Nitrate Trend Modelling – Model Set Up

Source Name	Comment on Final Model Fit	Additional Changes Made from Baseline Model	Lag Time (days)[1]	Multiplier Factor (unitless)[2]	Moisture Content (%)
Burpham	Good fit to model with dilution and land use change represented in catchment	Original fit too high. Added in 15% dilution to represent "river" input and altered land-use to grass-land at the top end of the catchment, as per historic land-use data from 1934. This improves the fit.	30	0.09	28%
Eastergate	Good model fit	No changes.	30	0.2	30%
Findon	Good model fit	Porosity decreased to 28%.	10	0.28	30%
Housedean	Good model fit	Poor original fit due to low trend and slope in wrong place. LCM2007 comparison to aerial photos indicates some errors in mapping. Land-use in trend model updated aerial photo extent of Arable in 2007 to improve trend.	15	0.1	20%
Lovedean	Good model fit	None.	30	0.2	30%
Mossy Bottom	Good model fit (but uncertainty in changes made)	Original fit poor and Southern Water note that abstraction changes a lot at this source so catchment is variable. Land Cover Map 2007 compared with aerial pictures suggests problems with LCM mapping, so trend model updated to remove areas of woodland not on 2007 aerial images. This shows an improved fit to observed and future predicted upward trend. However, the observed data doesn't appear to have an upward trend.	30	0.25	25%
Newmarket	Good model fit	Improved model fit using 20% porosity.	20	0.1	20%
Patcham	Good model fit	Shape of trend OK but general slight over-prediction, improved with use of higher moisture content. Need to check point source terms e.g. landfill.	30	0.15	35%
Twyford	Ok fit	Reasonable fit but under-predicts seasonal peaks, probably reflecting the differences between boreholes/Twyford well. Would provide a good fit to borehole 2.	20	0.21	30%
Westergate	Reasonable but too low compared to Eastergate	None although note that difference in fit here and at Eastergate could be linked to borehole depth.	30	0.2	30%
River Lavant	Ok fit (uncertainty in surface water impact)	Too high as modelling GW concentrations and not including dilution in SW i.e. a BFI based 20% reduction would give a better fit.			30%

1 For distance to observation borehole. 2 For GWL fluctuation at abstraction point compared to observation borehole.

Table 4.3b Outcomes of Nitrate Trend Modelling – Model Fit and Predictions

Source Name	Model Fit Good Enough for Predictions	Further Work Required	When Will Site Exceed DWS	When Will Average Nitrate Exceed WFD Threshold	Age of Waters Range (Years)	Age of 50% of Waters	Time for Arable and Grassland Peak N Applications to go Through Unsaturated Zone 1985 and 1990)	Time for Maximum Nitrate Within Modelled Period or Extrapolated	Nitrate Trend Model Uncertainty	How Much Reduction to Achieve Average Annual 37.5 mg/l NO_3	How Much Reduction Required to ensure Nitrate Peaks are below DWS?
Burpham	No (uncertainty in conceptual understanding).	Yes - need to identify timing of land-use change in catchment. River water quality upstream of abstractions could provide dilution.	Peak concentrations at Borehole 3 have already exceeded DWS, and peak concentrations at borehole 2 are likely to exceed soon.	Current average is below threshold, and predicted average unlikely to exceed threshold, as trend is quite spikey and majority of concentrations are close to or below 37.5mg/l NO_3.	0-90 but mainly 5 to 50.	36	Between 2021 and 2026.	Within model period.	Large uncertainty in trend model as significant land-use change over 40-50% of catchment from low intensity pasture to arable land prior to 2001. Conceptual understanding of inputs from river water upstream of abstraction.	Model uncertainty to great too poor to use for predictions.	Model uncertainty to great too poor to use for predictions.
Eastergate	Yes.	No.	DWS already exceeded by seasonal peak in concentration.	Average value predicted forward is already at 37.5.	5-100.	46	Between 2031 and 2036.	Within model period.	Model ok.	Average value predicted forward is already at 37.5.	Peaks predicted to drop below DWS by 2024 with no reduction.
Findon	Yes.	No.	DWS already exceeded by seasonal peak in concentration.	Predicted to exceed WFD threshold by 2014, but to reduce by 2020.	18-95 but mainly 15-50.	38	Between 2023 and 2028.	Within model period.	Model ok.	Average nitrate predicted after 2024 is less than threshold with no additional reduction in nitrate.	90-100% reduction over whole catchment required to bring nitrate spikes down below DWS by 2035.
Housedean	Yes (although some uncertainty in land use).	Confirm changes to land-use with catchment walkover.	DWS already exceeded by seasonal peak in concentration.	Will exceed WFD threshold in 2017.	20-100 but mainly 35 to 85.	42	Between 2027 and 2032.	Within model period.	Land use areas uncertain.	Even 100% reduction will not bring average below threshold until after 2035.	Reductions will only produce a downturn after 2032, and depending on the level of reductions peak concentrations should fall off after this period.
Lovedean	Yes.	No.	Not yet exceeded, but peaks predicted to exceed DWS in 2014.	Predicted to exceed by 2018.	30-100 but with some 15-30.	54	Between 2039 and 2044.	Extrapolated.	Model ok.	Average value around 37.5 mg/l with 40-60% reduction by 2024.	60-70% reduction to bring occasional spike below the DWS by 2024. Interim peaks could be up to 58 mg/l NO_3.
Mossy Bottom	No (uncertainty in conceptual understanding).	Improve land use understanding with walkover survey, compare modelled nitrate to abstraction rates to understand impact of changing abstraction.	DWS already exceeded by seasonal peak in concentration.	Predicted to exceed by 2014.	35-95 but mainly to 70.	46	Between 2031 and 2036.	Within model period.	Trend uncertain due to change in abstraction and land-use mapping errors.	Model uncertainty to great too poor to use for predictions.	Model uncertainty to great too poor to use for predictions.
Newmarket	Yes.	No.	Not yet exceeded, but predicted to exceed after 2032.	Will probably exceed Threshold by 2018.	20-100 but mainly 30-90.	50	Between 2034 and 2039.	Extrapolated.	Model ok	Model indicates that average nitrate will rise above threshold by 2018, and a 100% reduction in N leaching over the whole catchment will lead to a reduction in average concentrations by 2035.	Model indicates that the underlying trend will peak between 2034 and 2039, and seasonal peaks may exceed the DWS during this period. A 30% reduction flattens the upward trend after 2032, and is likely to keep peak concentrations below DWS.
Patcham	Yes.	Refine landfill term.	Not exceeded and not predicted to in the future.	Does not exceed threshold and is not predicted to.	5-100.	63	Between 2048 and 2053.	Extrapolated.	Model ok.	Average nitrate unlikely to exceed threshold in future.	Model values do not exceed DWS within model period and are not predicted to in the future based on current leaching.

Table 4.3b (continued) Outcomes of Nitrate Trend Modelling – Model Fit and Predictions

Source Name	Model Fit Good Enough for Predictions	Further Work Required	When Will Site Exceed DWS	When Will Average Nitrate Exceed WFD Threshold	Age of Waters Range (Years)	Age of 50% of Waters	Time for Arable and Grassland Peak N Applications to go Through Unsaturated Zone 1985 and 1990)	Time for Maximum Nitrate Within Modelled Period or Extrapolated	Nitrate Trend Model Uncertainty	How Much Reduction to Achieve Average Annual 37.5 mg/l NO_3	How Much Reduction Required to ensure Nitrate Peaks are below DWS?
Twyford	Yes.	No.	Peaks have already exceeded DWS with main breakthrough of trend in 2020.	Already above threshold.	25-75 (but with some younger 3-25).	46	Between 2031 and 2036.	Within model period.	Compare trend to Morestead porewater curve. Refine point source terms for Owslebury.	Even with 100% reduction no decrease below threshold until after 2032	Even with 100% reduction no decrease below DWS until after 2036 when trend starts to fall off.
Westergate	No (uncertainty in conceptual understanding).	Better understanding of difference between Eastergate and Westergate, but in the interim continue with actions based on Eastergate & Westergate combined as catchments overlap significantly.	DWS already exceeded by seasonal peak in concentration	Average value predicted forward is already at 37.5.	10-100.	48	Between 2033 and 2038.	Extrapolated.	Uncertainty in why Westergate concentrations are consistently 10 mg/l NO_3 above Eastergate when catchments overlap significantly.	Average value predicted forward is already at 37.5.	Seasonal peaks continue to exceed DWS to 2032, but likely to fall off after 2038 based on current leaching.
River Lavant	No (uncertainty in conceptual understanding).	Identify surface water inputs from BFI over non-Chalk parts of catchment.	Chichester harbour specific trigger value is un-achievable even with 100% reduction in nitrate leaching over the whole catchment.		0-100 and more.	51	Between 2036 and 2041.	Extrapolated.	Uncertainty as model does not include surface water input so fit to surface water quality is not good.	Trend model fit too poor to use for predictions.	Trend model fit too poor to use for predictions.

Sensitivity

The key factor affecting predictions of nitrate trends (i.e. rate of increase or decrease of nitrate concentrations over time) is the time of travel of water from the soil zone, through the unsaturated zone and saturated zone to the abstraction. In Chalk catchments, the time of travel in the saturated zone is usually very short compared with that in the unsaturated zone, and can be considered negligible (Rukin et al., 2010). The model parameters to which calculated time of travel in the unsaturated zone is most sensitive are:

- Depth to the water table (based on catchment area and low groundwater levels);
- Unsaturated zone porosity (moisture content used as a proxy for this parameter); and
- Rate of infiltration recharge (based on LTA modelled output per groundwater resource model cell).

The shape of the predicted trend in nitrate concentration at an abstraction also depends on the size and shape of the catchment, and hence the distribution of ages of water at the abstraction. The range of ages of water at the abstraction is determined by the distribution of ages of water at the water table, i.e. the range in unsaturated zone thickness. If parts of the catchment to the source are omitted from the model, or additional areas included, this will skew the age distribution and hence the assumed nitrate concentration in recharge at the water table.

The depth to water table is used to calculate the time of travel of recharge from the soil surface through the unsaturated zone as shown in Equation 1:

$$t = \frac{z.\theta}{R} \qquad \text{Equation (1)}$$

where *z* is the thickness of the unsaturated zone, θ is unsaturated zone porosity (moisture content) and *R* is rate of recharge. The calculated time of travel is therefore equally sensitive to each of these parameters (i.e. a change of *x*% in any one of them will result in a change of *x*% in calculated time of travel). Large unsaturated zone thickness (i.e. low water levels), high porosity or low recharge will increase times of travel, and *vice versa*.

The modelled long term trend is based on estimated times of travel under low water levels. Since low water levels usually coincide with low nitrate concentrations at the source, this long term trend represents a prediction of seasonal minimum nitrate concentrations. Seasonal variation in nitrate concentrations due to fluctuations in water levels is then added to the long term trend to produce the final prediction of nitrate concentrations.

The porosity of the Chalk, based on reported values of moisture content, is assumed to be 30%. However, in areas where the Chalk is greatly deformed, and more like a hardened limestone, for example along the fold structure in the Newmarket Valley, lower moisture content values are likely (Alexander, 1981). Decreasing the moisture content (and hence porosity) value will increase the rate at which nitrate in pore water travels through the unsaturated zone, decreasing the time of travel and producing a steeper gradient to the modelled nitrate curve.

A moisture content of 25% has been used for the Housedean abstraction as this is located at the junction between a fold axis and a normal fault so is in highly deformed Chalk with karstic characteristics. Reported values of moisture content for the Brighton Chalk at Patcham indicate a range of 20% to 30% (BGS, 2011). The effect of changing the value of the moisture content of the Chalk is illustrated in Plates 4.1 to 4.3. These show predicted long term nitrate trends at the Patcham source with assumed Chalk porosity of 30% (the "baseline" figure), 25% and 35%, respectively. The effect of decreased porosity is to reduce calculated travel times, such that higher nitrate water arrives at the source sooner, and predicted nitrate concentrations are higher than the baseline. Similarly, increased porosity increases calculated travel times and delays the arrival of high nitrate water, resulting in lower predicted nitrate concentrations.

Plate 4.1 Patcham Predicted Nitrate Trend with Chalk Porosity of 30%

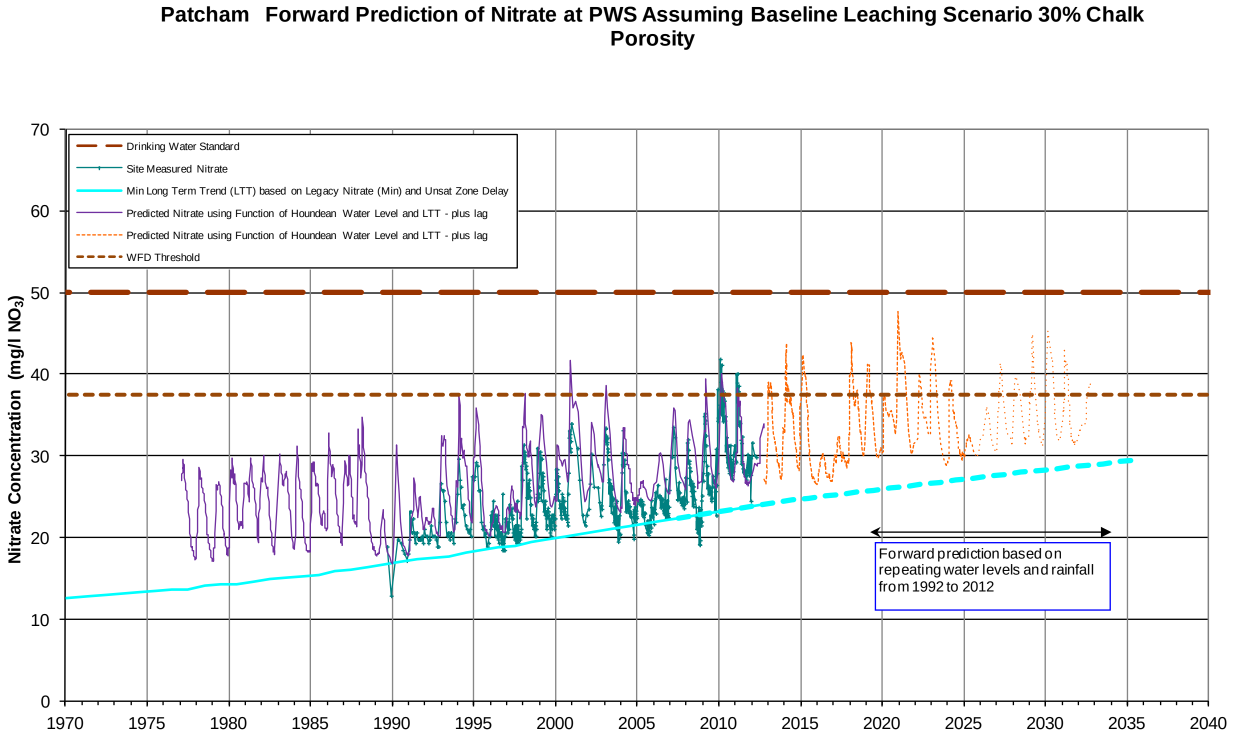


Plate 4.2 Patcham Predicted Nitrate Trend with Chalk Porosity of 25%

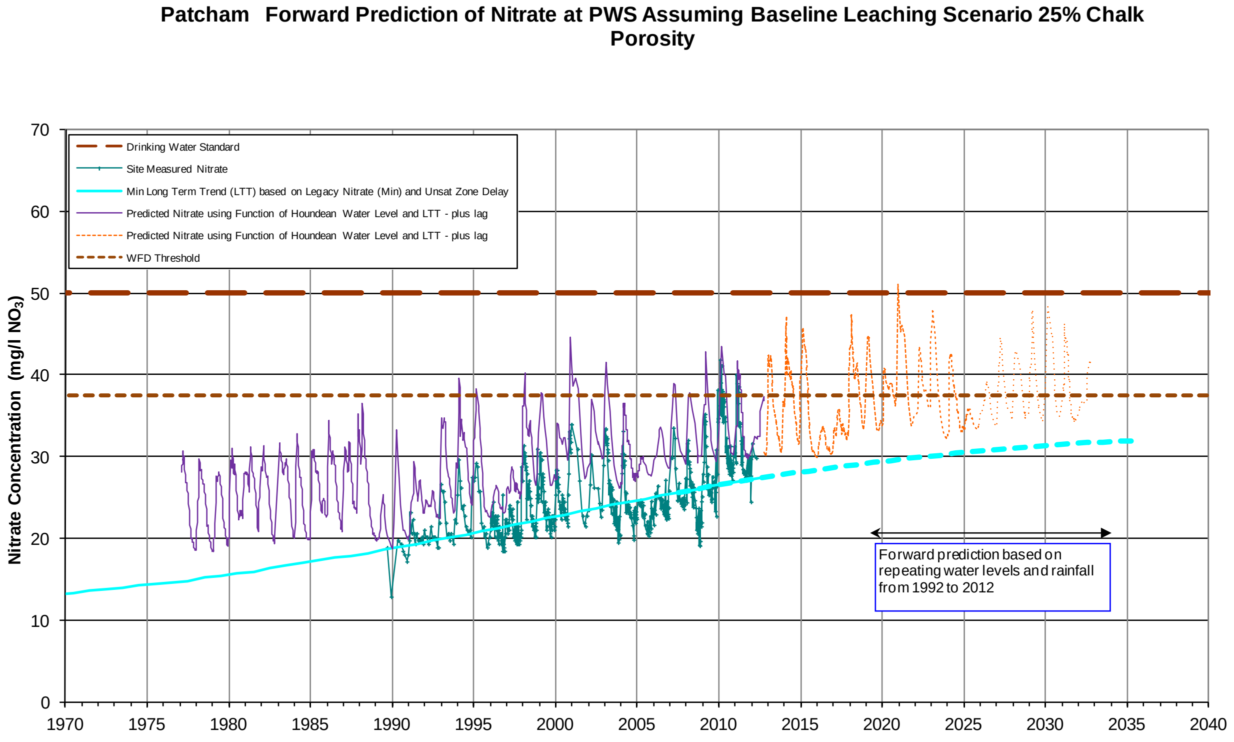
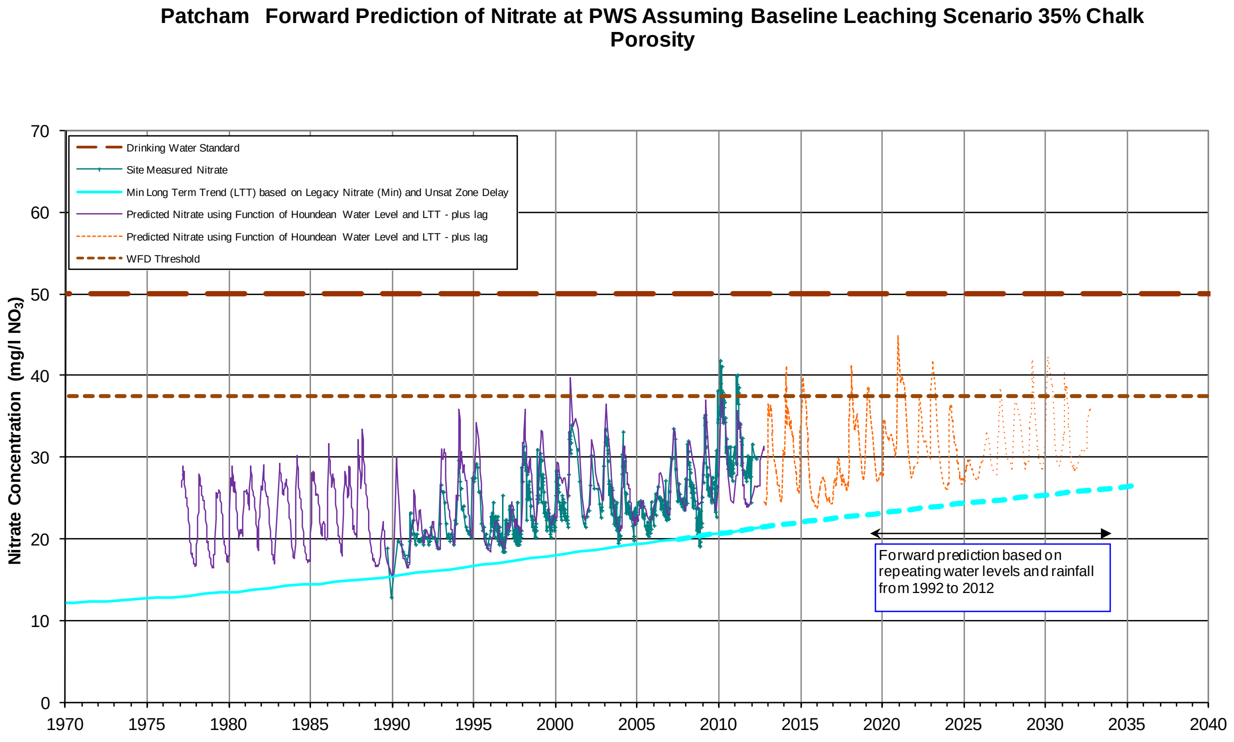


Plate 4.3 Patcham Predicted Nitrate Trend with Chalk Porosity of 35%



Infiltration recharge is calculated for each model grid square by the appropriate 4R (Rainfall, Runoff, Routing, Recharge) model. Predictions of infiltration recharge include runoff recharge where this is thought to occur (where areas of low permeability drift cover lead to significant runoff, which is routed through the catchment until it reaches a higher permeability formation such as outcrop Chalk).

Point sources are included in the model as a constant source term and sources with a high hydraulic loading (e.g. large landfill sites) will cause an increase in predicted nitrate concentration which does not vary over time, They will “move the curve up the nitrate concentration y-axis”, but they will not change the shape of the predicted trend. That is not to say of course that large point source loadings should not be further investigated where they are significant: for example landfills might be better represented as a declining source term.

4.3.2 Source Apportionment Models

The outcomes of the source apportionment modelling are summarised in Table 4.4. The main sources of nitrate identified in the catchments were agricultural, which is expected given the large proportions of the catchments made up of rural farmed land. The main crop types identified in each catchment were wheat, oil seed rape and cereals (barley, rye, oats and triticale). Improved grassland (cultivated grass which receives fertiliser inputs) also can provide a significant contribution to the nitrate budget, although the split between cut grass and permanent grazed grass is unknown and based on a best guess 50:50 split. Urban sources (run-off from allotments, sports grounds, gardens, leaking sewers and mains) provide relatively small contributions. Woodland areas can form very large parts of catchments where the only N input is from atmospheric deposition. The uptake by of N by trees is significant and the proportion of land-use area covered to leached N contribution for woodland is very low compared to other crops such as wheat and oil seed rape. For example in the Test and Itchen Chalk GWB woodland covers 15% of the catchment, and wheat covers 18%, but in terms of contribution woodland provides 1% of the nitrate budget whilst wheat provides 31%.

Table 4.4 shows the predicted nitrate from the source apportionment tools compared to the observed nitrate concentration for 2010 to 2013 at the abstraction point. The underestimation of the average observed nitrate is likely to be due to the delay in nitrate reaching the water table from the soil zone. The observed concentrations represent nitrate leaching concentrations for historical land management (with a delay for unsaturated zone travel), whilst the predicted values are based on likely current leaching rates for the same distribution of land uses in each catchment. This suggests that future nitrate in groundwater in each catchment could be lower than currently observed (apart from at Patcham), and below the DWS and below or at the WFD threshold (i.e. Twyford), ignoring any uncertainty in land-use for catchments such as Mossy Bottom discussed in below.

Uncertainty

For all catchments the main source of discrepancy between Land Cover Map and agricultural census data, apart from uncertainty due to small catchment areas, is likely to be areas of non-agricultural grassland such as sports pitches, amenity grassland (parks, golf courses etc.) These are likely to be included in Land Cover Map as improved grassland, but will not be included in agricultural census data (since they will not be associated with a County Parish Holding number). Other possible sources of discrepancies are allotments and infrastructure margins (e.g. road and railway embankments) which can be picked up as arable or grassland by the Land Cover maps (e.g. at Patcham).

Due to the small size of some of the catchments, in particular Mossy Bottom, Findon and Housedean, compared to the Agricultural Census data grid of 2 km^2 the accuracy of the data extracted will be greatly reduced. Where this is a problem (as identified by checking with aerial images from the same year) the modelled arable or grassland area can be a lot less than the arable area identified in the Land Cover Map 2007. Here, the area of arable land from the Land Cover Map 2007 is divided up based on the proportions of cropping from the Agricultural Census in 2010 e.g. at Findon. At Mossy Bottom and Housedean the Land Cover Map 2007 has been identified as incorrect in areas, when compared to aerial images (Google Earth) as a result of crop rotations between grass and arable crops or incorrect mapping of forestry land. Here the issue of both sets of information covering land use being in-accurate has been flagged, but no update to the dataset used in the source apportionment model has been made as no better information is available at the time of writing (i.e. no farm visit information was available).

The proportion of agricultural land in each catchment that has been modelled (i.e. the land covered by the Agricultural Census data) is shown as a percentage of the land identified as agricultural from Land Cover 2007 in Table 4.4. This additional “un-modelled” land area will affect the predicted nitrate concentration (based on total loading, area of catchment and recharge) by increasing the dilution of the predicted term. This will not affect the proportions of nitrate sources contributing to the overall nitrate budget. Improvements to the gaps between these two datasets can be made by collating catchment specific information and updating the source apportionment model where this is a significant issue, i.e. Burpham, Mossy Bottom and Patcham.

Table 4.4 Outcomes of Source Apportionment Modelling, Model Fit, Uncertainty and Modelled versus Actual Catchment Areas

Source Name	Nitrate (mg/l NO_3) Observed	Nitrate (mg/l NO_3) Predicted	Model Fit	Top Three Sources of Nitrate	Source Apportionment Model Uncertainty	Area Modelled	% Catchment Area Modelled
Burpham	37.3	30	Underestimates observed (uncertainty in land use change in catchment).	Wheat, grazed grass, cut grass.	OK - historic land use should not affect the snapshot of N leaching between 2007 and 2010.	289	65
Eastergate	32.7	19	Underestimates observed.	Wheat, woodland (covers 44% of catchment) grazed grass.	OK with uncertainty in landfill term reduced with site specific information.	3655	81
Findon	38.8	26	Underestimates observed.	wheat, grazed grass, cereal/Winter OSR.	Uncertainty in catchment size based on SPZ 2.	337	82
Housedean	40.0	28	Underestimates observed.	Wheat, grazed grass, cut grass.	Uncertainty in catchment size and need to check land-use with catchment walkover.	208	83
Lovedean	36.5	28	Underestimates observed.	Wheat , OSR, grazed grass.	Model ok.	1175	84
Mossy Bottom	34.0	28	Underestimates observed.	Wheat, grazed grass, cut grass.	Uncertainty in catchment size based on SPZ 2 and need better information on land-use in catchment.	102	53
Newmarket	33.9	30	Underestimates observed.	Wheat, Winter OSR, grazed grass.	Uncertainty in catchment size based on SPZ 2.	620	86
Patcham	31.6	30	Good fit.	Wheat, grazed grass, cut grass.	Landfill term needs to be refined.	582	65
River Lavant	n/a	12	Fits river water quality and underestimates GW nitrate.	Wheat, landfill, grassland.	Ok fit – uncertainty in surface water inputs.	6869	75
Twyford	41.5	37	Overestimates observed.	Wheat, OSR, cereal crops.	Refine point source terms for Owslebury.	2634	75
Westergate	42.2	22	Underestimates observed.	Wheat, woodland (44% of catchment is woodland) and grazed grass.	OK with uncertainty in landfill term reduced with site specific information.	3037	80

Sensitivity

As shown in Section 2 and Appendix C, the sensitivity of the source apportionment model is greatest for the landfill inputs. In these catchments the area of landfill is typically small along with the contribution. Sensitivity testing of fertiliser application rates and grassland management is discussed more fully in Section 2 at a large catchment scale.

As noted previously, the difference between the modelled catchment area and the actual modelled area as shown in Table 4.4 may increase dilution of the predicted nitrate concentration leaching to groundwater. However, changing the modelled catchment area in the calculation of this value to the actual catchment area makes no difference to the final predicted value.

4.3.3 Nitrate Leaching Simulation Conclusions

The outcomes of nitrate modelling are summarised in Table 4.6. The source apportionment modelling indicates that the current rates of nitrate leaching from the soil zone in all catchments may potentially be lower than currently observed at the water table, although there is some uncertainty in the land-use areas in some catchments. If the conceptual understanding of the trend models is correct then maintaining these modelled leaching rates through the period over which the impact of historic maximum nitrate application rates is seen should mean that **average** concentrations over the whole catchment will eventually reach or fall below the WFD threshold and the DWS. There will still be areas of the catchment where nitrate concentrations in water leaching to the underlying aquifer will be higher than the WFD threshold and DWS. These average current modelled leaching rates are based on N loading to crops in compliance with NVZ regulations (in place since 2006), or on farm information (which is also within the NVZ limits). This suggests that these existing restrictions alone should provide the necessary turn-around in nitrate trends for WFD compliance at abstractions at a point in the future. The main job for measures should therefore be to make sure that the current leaching situation is maintained and not made worse in the future, and to manage nitrate leaching concentrations in the interim period such that the frequency of exceedances of the DWS is minimised.

Conceptually the main control on observed nitrate at the water table is understood to be the time taken for matrix flow through the unsaturated zone. This suggests that the impact of any reductions in nitrate applied now will only be seen once historic nitrate already in the unsaturated zone has gone through the catchment and that nothing can be done to manage groundwater nitrate concentrations during this flushing through of historic porewater. Predicted DWS exceedances are controlled by seasonal **peak** concentrations (winter highs) and **spikes** in concentration (individual samples with unusually high concentrations of nitrate), which are linked to a combination of periods of heavy rainfall, the soil mineralised nitrate availability during recharge events, water table fluctuations and the depth profile of nitrate concentrations in matrix porewater.

The distribution of Chalk unsaturated zone porosity is not homogenous, i.e. pore space size ranges from matrix pores to large scale fissures. However, travel time through the unsaturated zone is based on an average value of porosity (moisture content), and this journey time will decrease with increased pore size, where fissure flow (through the largest “pores”) is fastest. Flow along fractures in the Chalk occurs when the unsaturated zone is close to saturation and during high recharge events (Adams et al., 2008, Price, 2000) and has been linked to isolated spikes or troughs and seasonal peaks in nitrate concentration (Rukin et al, 2010). Therefore a proportion of nitrate arriving at the water table will travel through faster flow paths than the majority of nitrate arriving through matrix porewater. The timing of this input should be during periods when the unsaturated zone is close to saturation i.e. during winter periods, however, Adams et al., (2008) identified that matric potentials were high all year round (i.e. close to saturation) at the Patcham BGS FLOOD study location i.e. fissure flow could happen during rainfall events outside of the wet winter period. The existence of these pathways is supported by bacterial contamination at some of the modelled abstractions. Typically proportions of water flowing modelled as by-pass flow (directly through the soil to produce a pressure change at the water table, so ignoring unsaturated zone effects) in the Test and Itchen Chalk groundwater model are 10%, whilst elsewhere a contribution of between 5 and 15% of water arriving at the water table is suggested as travelling through faster non-matrix porosity flow-paths (Mathias at al., 2005, Butler et al., 2012, Ireson and Butler, 2013).

Peak exceedances are of greatest concern to water companies where real time compliance with DWS is required. Peak concentrations linked to seasonal highs are predicted to exceed the DWS at all PWS abstraction catchments apart from Patcham. Isolated spikes in concentration have not been predicted, but could potentially occur. If measures can be applied to reduce the average concentration of nitrate arriving at the boreholes via faster flow-paths then this may provide the necessary dilution to bring seasonal peaks and any isolated spikes below the DWS.

4.3.4 Recommended Measures

The previous section concluded that measures to address nitrate pollution should ensure that catchment-wide nitrate leaching does not increase and should reduce the risk of nitrate peaks associated with soil nitrate loss following rainfall events and movement via fast flowpaths. The measures discussed in this section are aimed at reducing nitrate concentrations in the water which arrives at the water table and the abstraction through faster flow paths compared to matrix flow. The area over which measures focusing on faster flow-paths will be most effective is closer to the borehole where fissure flow to the abstraction is likely to be greatest. Focusing on the area surrounding the abstraction point will also minimise the socio-economic impact of the measures (discussed in Section 5).

In approaching the design and cost benefit/effectiveness assessment of measures to mitigate N leaching in any catchment it is important to understand: the level of reduction in nitrate concentrations needed; what the main sources of nitrate are; the measures already in place; the reduction in nitrate leaching produced by recommended measures; and the area over which the measures should/could feasibly be applied to achieve required reductions.

What Level of Reduction is Required to Retain Peak Concentrations Below the DWS?

The trend model predicted reductions needed to achieve the target concentration ranged between 30% at Newmarket, 60-70% at Lovedean and 100% at Findon for the whole catchment. These predictions are based on this level of reduction over the whole catchment, and measures needed to produce this are unlikely to achievable (economically or technically). At other catchments the trend model indicated that even 100% reduction would not achieve target concentrations within the model period. Instead the manually derived level of nitrate reduction needed to keep peak concentrations below the DWS catchments with a good model fit and the percentage reduction this represents (based on current observed rates of leaching) is shown in Table 4.5. At Patcham the current leaching rates should be maintained to keep peaks below the DWS. Table 4.5 shows the level of reduction required at each catchment, the timespan that the reduction is required over, and the percentage reduction from observed concentrations.

Table 4.5 Summary of Nitrate Reduction and Time-Span it is required for Per Catchment

Catchment	Nitrate Reduction to Keep Peaks Below DWS (mg/l NO_3)	Current Average Observed Value for 2010 to 2013 (mg/l NO_3)	Percentage Reduction in Peak Concentrations Required	Timescale for Measures (when Maximum Nitrate has gone through Unsaturated Zone)
Twyford[1]	12	41.0	29%	2036
Lovedean	8	36.0	22% (60-70% from trend model)	2044
Eastergate	10	32.7	31%	2036
Findon	15	38.8	39%	2030
Housedean	5	40.0	12%	2032
Newmarket	5	33.9	15% (30% from trend model)	2039
Westergate	20	42.2	47%	2038
Patcham	0	31.6	Maintain current leaching	

1 At Twyford the main trend will continue to exceed DWS until after 2032 and it is likely that treatment is required here. Catchment management measures could be used to shorten the timespan which treatment is required over to before 2036.

What Are the Main Sources of Nitrate?

For most catchments, the main sources of nitrate for the period 2007 to 2010, as identified in the source apportionment models, were agricultural (linked to crops particularly wheat and other cereals, and oil seed rape) and improved grassland (pasture and cropped grass receiving fertiliser inputs). Based on farm visit information, the majority of farms in the catchments are arable, or mixed farming with beef and sheep. Other source terms such as landfill, urban run-off, mains and sewer leakage do not contribute comparable proportions of the nitrate leaching to the water table.

What is Already Being Done to Reduce Nitrate Leaching?

NVZ regulations have covered all the catchments since 2006 (excluding the northern part of the Eastergate and Westergate catchment) and these comprehensively cover the management of livestock manures (Defra, 2013). For the modelled catchments, where soils are typically shallow over Chalk, the closed period for application of organic manures to cropped land with high readily available N can start on 1 August with the closed period for manufactured N and organic manures to grassland starting on 1 September. These periods end on 31 December for organic manures and 15 January for manufactured N. Where soils are heavier or more clayey these closed period dates will change. The maximum allowable N application rate (NMax) values for crops can be high, up to 220 kg N/ha for winter wheat, 250 kg N/ha for oil seed rape, and up to 370 kg N/ha for some horticultural crops. Where soils are thin a further 20 kgN/ha is allowed. Clearly the application of higher levels of N in areas of thin soils is contrary to the need to manage the amount of N leaching to groundwater. Soils are classified as “Shallow” over Chalk over the majority of the catchments, excluding the southern part of the Eastergate and Westergate catchment (Figure 4.6). Farm visit information suggests that this additional spreading quota is not taken up, and nitrate application rates are typically reported as being 170 kg N/ha on arable and grassland from solid or liquid fertiliser, animal slurry and manures, and sewage sludge. There is therefore potential for future increases in application rates.

At a more specific catchment level some of the catchments (e.g. Newmarket and Housedean) were in the South Downs **Environmentally Sensitive Area** scheme, for 10 years which came to and end in 2013. In part this involved paying farmers not to cultivate areas of land i.e. for set-aside land. The majority of farms in the catchments are in already in **environmental stewardship schemes** (which replaced the ESA scheme), although the benefits to groundwater from these are unknown.

The **Downs and Harbours Clean Water Partnership** (supported by Portsmouth Water, CSF and the Environment Agency) has been in operation since 2009, offering free and confidential services and support for farmers and other landowners. These services include free nutrient/manure/soil management plans as well as focussed workshops, 1:1 consultations and farm demonstrations of best management practices. The Partnership can also direct applicants to potential sources of grant funding, such as Environmental Stewardship or the Capital Grant Scheme, where appropriate. Some services, including specialist 1:1 visits, are also available to equestrian enterprises, which may be contributing a high level of nutrients to groundwater, rivers and harbours. This scheme covers the Lovedean and Eastergate and Westergate catchments.

The **Brighton Tenant Farmers project** (since 2012) covers the 4045 ha of farmland owned by Brighton and Hove City council, and looks to manage the land to deliver greater social and environmental benefits, partly through the Adur and Ouse Catchment Delivery Steering Group. Tenant farms were visited to check compliance with current legislation. Where required the delivery of capital grants to allow improvement of infrastructure has been supported through the scheme, with some subsidy of precision farming, mainly to control phosphate but with agreement to trial nitrate precision farming in the future. A spreader calibration workshop has been held with follow up visits at some farms. The focus has been on safeguard zone sites within the Brighton and Hove City Council land ownership as identified by Southern Water including Patcham, Newmarket and Housedean.

The **Test and Itchen Rivers Catchment** is priority catchment 29 under the capital grants scheme for CSF, and the Twyford catchment sits in the Upper Itchen Valley and Bow Lake target area, where grants are available for farmyard infrastructure improvements and soil management advice (plus other more surface water focused initiatives). The **Arun and Western Rother** is priority catchment 41 under the capital grants scheme and includes the Burpham catchment. The scheme focuses on sediment reduction in rivers and also at groundwater protection.

What Amount of Reduction Will Additional Measures Bring?

It is clear that measures for most catchments should focus on agricultural cropped land.

Where NVZ regulations already apply, these deal comprehensively with manure management, although additional voluntary measures could change timings of applications (e.g. extend the closed period to February), change to

NMax applications to certain crops and the improvement of farm-yard infrastructure with respect to clean/dirty water separation and slurry/manure storage. The extension of the closed period to February could involve an increase in manure/slurry storage capacity for the extra month, although this could be managed through clean water separation. The level of reduction from these additional NVZ based measures is unknown as there is no targeted monitoring, although visits are carried out ensure compliance. As previously noted the permitted additional spreading of 20 kg N/ha over thin soils (on top of the general allowance of 170 kg N/ha from animal manures and an overall limit of 250 kg N/ha) does not appear to be taken up from farm visit reports, although these are not comprehensive for the catchment areas. The uptake of this measure is likely to be low. Farm-yard drainage improvements, advice on manure heap management with point source pollution although source apportionment suggests agricultural point source contribution is likely to be small. However these measures will protect surface water and improve water efficiency. Advice on reducing/ceasing fertiliser applications in the location of swallow holes will potentially help reduce isolated peaks in concentration. The extension of the closed period appears to be the main measure which will have an impact, mainly on the winter/spring leaching of nitrate, and the impact could be significant over arable land (perhaps up to 30-40%).

The Diffuse Pollution Inventory (DPI) User Manual (Defra, 2010) identifies measures which can be used to mitigate diffuse pollution of air, land and water from emissions, and considers measures effectiveness based on farm typology, nitrate reduction and potential cost. For this study the measures applicable to cropped land and pasture which provide a reduction in N leaching of more than or equal to 5% have been selected. These have been reviewed to identify applicability to the study area by project board members. The identified measures and the reduction they provided are listed below. The project board also identified good practise measures to minimise run-off from farm-yards for all farms in a catchment.

Land Use Change:

- Arable or improved grassland to low intensity improved grassland, or pasture land receiving no fertiliser applications; and
- Arable land or improved grassland to woodland/forestry/biofuels (e.g. willow or miscanthus).

Reduction in soil nitrate leaching is between 90% and 85% where this type of measure is applied, but the cost of compensation, and loss of food production land means that the uptake of these measures is likely to be small, and very unlikely to be catchment wide. Forestry or biofuels such as willow may not be suitable for some areas with thin soils.

Manage How Much N is Applied:

- Precision farming (soil nutrient availability/crop requirement analysis to apply nitrate for the crops needs in the right locations);
- Fertiliser or manure spreader calibration; and
- Set-aside strips/Buffer strips to reduce cultivated area by a certain percentage depending on how many fields there are in the catchment, and can be included as part of other environmental schemes.

Reduction in nitrate soil leaching is between 10% and 5% where the measure is applied (i.e. will mainly apply to arable land rather than improved grassland), and the costs could be low (e.g. spreader calibration and advice). Impacts are probably greater in arable catchments (rather than from pasture land) so the overall reduction for the whole catchment will be reduced accordingly. This level of reduction is small relative to those required for catchments.

Manage Excess N Leaching After During Cropping and after Harvest:

- Cover crops in winter (with spring cropping);
- Soil management plan to manage excess nitrogen at the farm scale;
- Use of clover in place of fertiliser in pasture land;
- Extend closed period for spreading manure to areas of thin soils;
- Bailing and removing "straw" after oil seed rape to reduce the amount of N left on field for re-incorporation into soil;
- Cessation of high risk activities (stop slurry injection methods or ploughing in of grass, no application additional N at higher rates to thin soils);
- Cessation of application of manufactured or organic fertilisers to grazed land / permanent pasture (all year round); and
- Decrease stocking density of cattle.

Reduction in soil nitrate leaching is between 30% and 45% where measure is applied and can be relatively low cost. However, any reduction in application rate would need to be considered in light of any reduction in crop yield, for example, changing from winter wheat to a spring wheat rotation to accommodate cover crops will reduce the wheat quality (protein content) and hence its value. These measures appear to be more attractive in terms of the balance between reduction of N leaching and cost. The identified measures for each catchment are shown in Table 4.7.

What Area/Number of Farms Should Additional Measures be Applied to?

If the focus of reduction in nitrate is the zone over which fissure flow to the borehole is at its greatest then the 50 day travel time zone is the most relevant area over which to apply the greatest reductions from on land-use change. Similarly the extent of introduction of the use of cover crops will mean that the cash crop may drop in value, and this measure could be more palatable over a reduced area (or with compensation). For other measures which retain the current land-use but which focus on management of N applications and N after or during harvesting the reduction in N is less, but still can provide significant reduction, should be applied at the 400 day (SPZ 2) zone to the abstractions. For catchments delineated using a groundwater model, the SPZ 1 zone is based on a 50 day time of travel zone, whilst the "SPZ 2" area is based on the model cells which provide the greatest proportion of the abstraction, typically so contributing over 30 m^3/d at Eastergate and Westergate combined catchment, and Lovedean or 60 m^3/d at Twyford (Appendix E). Measures to address point sources from farm-yard drainage/manure heaps and advice on spreading around swallow holes, should be applied over the whole catchment as used for nitrate modelling as good practise. The delineated areas for measures to be applied over are shown in Figure 4.7. The number of farms with land in each area (including farms with land in more than one zone) is estimated from farm visit information and OS mapping, and is shown in Table 4.6.

Applying measures in this combination, however, means that reductions of over 30% in N leaching over the whole catchment are likely to be un-achievable, but focused reductions closer to the abstractions is likely to help in providing some improvement. The measures listed in Table 4.6 are modelled for the potential costs and benefits of application in the next Section of this report.

Table 4.6 Outcomes of Nitrate Modelling and Recommended Measures

Source Name	Summary of Model Outcomes	Actions Based on Model Outcomes	Measures in Place Already	Additional Measures	Area to Apply Measures and Number of Farms Per Area	Timescales to Apply Measures (for CBA based on Age of Waters Plot)
Burpham	Majority of nitrate from wheat/managed grassland, fissure flow important in catchment with interaction with surface water. Current leaching lower than observed at water table, so future reduction likely, probably by 2026. But historic land-use change and un-quantified input from river leads to uncertainty in trend model.	Refine historic landuse in catchment model, update catchment using Flowsource, and then review actions.	NVZ Arun and Rother CSF Priority Catchment	Point sources. Improve farmyard drainage, manage manure heaps, identify the location of solution features and the higher risk of nitrate leaching to land-owners.	Catchment scale.	Do not model
Eastergate	Nitrate source from wheat, woodland and grassland. 11% Contribution from woodland due to large extent (44%) of catchment. Predicted leaching lower than observed at the water table, so future reduction possible. Highest nitrate concentrations should go through unsaturated zone by 2036.	Apply measures to reduce spikes in concentration below DWS between now and 2040.	Downs and Harbours Clean Water Partnership including farm advice on soil management, spreader calibration etc. NVZ (partial)	Point sources. Improve farmyard drainage, manage manure heaps, identify the location of solution features and the higher risk of nitrate leaching to land-owners. Diffuse sources. Revert arable land to low input chalk grassland/pasture OR woodland/biomass. Fund precision farming. Fund manure/fertiliser spreader calibration. Do not spread additional N over shallow soils (against NVZ advice. Extend closed period into February (when crop starts to grow). Control the amount and timing of N application from grazing cattle. Control the amount and timing of manufactured N/organic N applications.	Point sources at catchment level. Diffuse sources. Inner Zone for land-use change. Farms -1 equestrian and 1 arable. Outer Zone (whole catchment) for measures to control N leaching/N application rates. 12 Landowners (10 likely to be farms with yards) At least 2 arable and 1 dairy (organic). Total catchment – Approximately 4 further landowners. Whole catchment around 18 land owners.	to 2040
Westergate	Poor model fit, use outcomes for Eastergate as catchments overlap.	Poor model fit, use outcomes for Eastergate as catchments overlap.	Downs and Harbours Clean Water Partnership including farm advice on soil management, spreader calibration etc. NVZ (partial)	Modelled with Eastergate.	Modelled with Eastergate.	Modelled with Eastergate
Findon	Nitrate sourced from wheat, cereals, winter oil seed rape and managed grassland. Future leaching predicted to be lower than current observed nitrate, therefore reduction in concentrations likely. Timescale for downturn in nitrate trend is by 2028, model predicts fall in average concentrations beneath DWS threshold by 2024 with no reduction. To reduce peak concentrations below DWS by 2035 requires 90-100% reduction over whole catchment.	Apply measures to reduce spikes in concentration below DWS between now and 2030.	NVZ	Point sources. Improve farmyard drainage, manage manure heaps, identify the location of solution features and the higher risk of nitrate leaching to land-owners. Diffuse sources. Revert arable land to low input chalk grassland/pasture OR woodland/biomass. Fund precision farming. Fund manure/fertiliser spreader calibration. Do not spread additional N over shallow soils (against NVZ advice). Extend closed period into February (when crop starts to grow). Control the amount and timing of N application from grazing cattle. Control the amount and timing of manufactured N/organic N applications.	Point sources at catchment level. Diffuse sources. SPZ 1 for land-use change. Farms -1 unknown. SPZ 2 (whole catchment) for measures to control N leaching/N application rates. 2-3 unknown farm types. Whole catchment around 3 farms.	to 2030
Housedean	Nitrate sourced from wheat and managed grassland, and predicted leaching is lower than current observed concentrations indicating future reduction. Timescale for downturn in nitrate trend is by 2032. To reduce peak concentrations below DWS by 2035 requires 90-100% reduction over whole catchment.	Update catchment area using Flowsource. Catchment walkover to confirm landuse and identify further information on landfill. Apply measures to reduce spikes in concentration below DWS between now and 2032. Maintain current leaching levels.	Was in an ESA (expired 2012) Brighton Tenant Farmers Project - payment for spreader calibration and advice on fertiliser rates (focused on P) NVZ.	Point sources. Improve farmyard drainage, manage manure heaps, identify the location of solution features and the higher risk of nitrate leaching to land-owners. Diffuse sources. Wait until model improves to inform diffuse pollution measures.	Catchment scale.	to 2032

Table 4.6 (continued) Outcomes of Nitrate Modelling

Source Name	Summary of Model Outcomes	Actions Based on Model Outcomes	Measures in Place Already	Additional Measures	Area to Apply Measures Over and Basis	Timescales to Apply Measures (for CBA based on Age of Waters Plot)
Lovedean	Nitrate sourced from wheat, winter oil seed rape and grazed grass, and predicted leaching is lower than current observed concentrations indicating future reduction. Timescale for downturn in nitrate trend is by 2044. To reduce average concentrations to 37.5% by 2024 requires 40-60% reduction. To reduce peak concentrations below DWS by 2024 requires 60-70% reduction over whole catchment	Apply measures to reduce spikes in concentration below DWS between now and 2044.	Downs and Harbours Clean Water Partnership including farm advice on soil management, spreader calibration etc. NVZ.	Point sources. Improve farmyard drainage, manage manure heaps, identify the location of solution features and the higher risk of nitrate leaching to land-owners. Diffuse sources. Revert arable land to low input chalk grassland/pasture OR woodland/biomass Fund precision farming. Fund manure/fertiliser spreader calibration. Do not spread additional N over shallow soils (against NVZ advice Extend closed period into February (when crop starts to grow). Control the amount and timing of N application from grazing cattle Control the amount and timing of manufactured N/organic N applications.	Point sources at catchment level. Diffuse sources. Inner Zone for land-use change. Farms -1 unknown. Outer Zone for measures to control N leaching/N application rates. 2 unknown farm types including one from SPZ 1. Whole catchment around 3 farms.	to 2044
Mossy Bottom	Nitrate sourced from wheat and managed grassland, and predicted leaching is lower than current observed concentrations indicating future reduction. Timescale for downturn in nitrate trend is by 2036.	Improve model fit, review catchment delineation, gain a better understanding of catchment area with abstraction rate, improve land-use information with walkover survey.	NVZ.	Point sources. Improve farmyard drainage, manage manure heaps, identify the location of solution features and the higher risk of nitrate leaching to land-owners. Diffuse sources. Wait until model improves to inform diffuse pollution measures.	Catchment scale.	Do not model
Newmarket	Nitrate sourced from wheat, winter oil seed rape and grazed grass, and predicted leaching is lower than current observed concentrations indicating future reduction. Timescale for downturn in nitrate trend is by 2039. To reduce average concentrations to 37.5% by 2035 requires 100% reduction. To reduce peak concentrations below DWS by 2032 requires 30% reduction over whole catchment.	Apply measures to maintain spikes below DWS between now and 2039.	Was in an ESA (expired 2012). Brighton Tenant Farmers Project - spreader calibration and advice on fertiliser rates (focused on P). NVZ.	Point sources. Improve farmyard drainage, manage manure heaps, identify the location of solution features and the higher risk of nitrate leaching to land-owners. Diffuse sources. Revert arable land to low input chalk grassland/pasture OR woodland/biomass. Fund precision farming. Fund manure/fertiliser spreader calibration. Do not spread additional N over shallow soils (against NVZ advice. Extend closed period into February (when crop starts to grow). Control the amount and timing of N application from grazing cattle. Control the amount and timing of manufactured N/organic N applications.	Point sources at catchment level. Diffuse sources. SPZ 1 for land-use change. Farms 2 arable and mixed beef. SPZ 2 (whole catchment) for measures to control N leaching/N application rates. 3 arable/arable mixed beef including one from SPZ 1. SPZ 2 farms.	to 2039
Patcham	Nitrate sourced from wheat and managed grass. Concentration predicted from current leaching is the same as observed suggesting that future concentrations will be at the same level. Catchment spread of age of waters is very wide.	Maintain nitrate leaching at current level.	NVZ. Brighton Tenant Farmers Project - payment for spreader calibration and advice on fertiliser rates (focused on P).	Point sources. Improve farmyard drainage, manage manure heaps, identify the location of solution features and the higher risk of nitrate leaching to land-owners. Diffuse sources - maintain nitrate at current levels.	SPZ 2/whole catchment.	to 2032
River Lavant			Downs and Harbours Clean Water Partnership including farm advice on soil management, spreader calibration etc. NVZ.	Point sources. Improve farmyard drainage, manage manure heaps, identify the location of solution features and the higher risk of nitrate leaching to land-owners. Diffuse sources. Revert arable land to low input chalk grassland/pasture OR woodland/biomass. Fund precision farming. Fund manure/fertiliser spreader calibration. Do not spread additional N over shallow soils. Extend closed period into February (when crop starts to grow).	Point sources at catchment level.	Do not model

Table 4.6 (continued) Outcomes of Nitrate Modelling

Source Name	Summary of Model Outcomes	Actions Based on Model Outcomes	Measures in Place Already	Additional Measures	Area to Apply Measures Over and Basis	Timescales to Apply Measures (for CBA based on Age of Waters Plot)
Twyford	Main sources of nitrate wheat, oil seed rape, cereal crops. Future predicted nitrate are lower than current observed (but above threshold), with trend decreasing by 2036, but exceedances of DWS likely to continue past this point to at least 2055.	Suggests that catchment management will not help to reduce nitrate in unsaturated zone, so treatment required, but catchment management should be implemented to ensure future reduction in trends.	NVZ. Test and Itchen Rivers – Priority Catchment for CSF.	Point sources. Improve farmyard drainage, manage manure heaps, identify the location of solution features and the higher risk of nitrate leaching to land-owners. Diffuse sources. Revert arable land to low input chalk grassland/pasture OR woodland/biomass. Fund precision farming. Fund manure/fertiliser spreader calibration. Do not spread additional N over shallow soils (against NVZ advice). Extend closed period into February (when crop starts to grow). Control the amount and timing of N application from grazing cattle/poultry manure. Control the amount and timing of manufactured N/organic N applications.	Point sources at catchment level. Diffuse sources. Inner Zone for land-use change. Farms -3 arable, 1 mixed. Outer Zone (whole catchment) for measures to control N leaching/N application rates. 4-5 farms unknown/equestrian including one from SPZ 1. Whole catchment around 4-5 farms. Total catchment around 12.	to 2060

5. Cost Benefit Analysis

In Section 4 a range of measures which aim to reduce the seasonal peak in nitrate concentrations below the DWS (Table 4.5) by tackling point and diffuse source nitrate pollution have been identified and proposed for consideration and uptake either through voluntary schemes or through compensated actions. This section assesses the proposed measures across different catchments in terms of financial costs, potential adverse environmental and social impacts as well as anticipated benefits from groundwater quality improvements.

The approach taken first considers financial costs associated with each of the measures identified in terms of one-off (capital) and operational and maintenance costs. The costs are then expressed as Equivalent Annual Costs (or annualized costs) to allow direct comparison of different measures. Information on the range of potential measures and associated costs is obtained from the Defra Diffuse Pollution Inventory (DPI) Manual (Defra, 2010) with costs inflated to 2014 prices (7% increase).

The adverse environmental and social impacts (e.g. carbon emissions) are also considered in qualitative terms and a summary of the financial costs, environmental and social impacts associated with each of the proposed measures in the affected catchments is provided in the form of a nitrate cost curve. Cost-curves can be misleading as they suggest that effects of measures are independent and that reductions in nitrate leaching are additive, neither of which may be the case (Defra, 2005). As the measures are applied over different (non-overlapping) areas the use of the cost-curve approach (which assumes that measures are not additive) should be appropriate. This method was used to calculate the cost of nitrate reduction so that the most cost effective measures could be identified. As previously noted the resolution/in-accuracy of the land-use/crop data means that there will be some uncertainty in the input values (e.g. at Housedean and Findon). Similarly, information about the number of farms with land in each area over which measures were applied was available from farm visit information for some catchments but had to be guessed elsewhere, based on OS mapping. With better information on these input values the confidence in the output values would be improved, but the outcomes provide a first estimate of potential costs of measures implementation to achieve nitrate reduction through reducing the average catchment N loading value (Table 5.1).

Benefits potentially resulting from implementation of the measures considered are identified and assessed in line with the draft “Groundwater Appraisal Guidance: Tool for estimating the costs and benefits of groundwater measures”. Anticipated benefits are described in described in qualitative manner, quantified and monetised where applicable.

Table 5.1 Nitrate Loading Reduction Required and Area of Measures Application

Catchment	Amount of Nitrate Reduction required (mg/l NO3)	Current Average Observed Value in Groundwater for 2010 to 2013 (mg/l NO3)	Percentage Reduction Required	Predicted Current Total Nitrate Loading in Catchment from Agricultural Sources (kg N/ha) note 1	Reduction in Loading Required (kg N/ha)	Area Whole Catchment (km^2)	Area Inner Zone (km^2)	Area Outer Zone (km^2)	No of Farms (total) Whole Catchment	No. of Farms (Cumulative) Inner Zone	No. of Farms (Cumulative) Outer Zone
Twyford	12	41.0	29%	148326	43015	34.98	1.3	8.6	12	4	8
Lovedean	8	36.0	22%	46614	10255	13.98	0.6	3.1	3	1	2
Eastergate	10	32.7	31%	109365	41559 note 2	45.27	0.4	7.2	6	1	4
Westergate	20	42.2	47%			37.94	0.1	8.1			
Findon	15	38.8	39%	13450	5246	4.1	1.2	4.1	4	1	3
Housedean	5	40.0	12%	7707	925	2.52	0.61	2.52	3	1	2
Newmarket	5	33.9	15%	21499	3225	3.63	1.35	3.63	3	2	3
Patcham	0	31.6	0%	23978	0	8.94	2.92	8.94	4	1	2

Note 1: nitrate loading calculated based on the land use data by land use type by SPZ areas. Note 2: 38% in the combined catchment

5.1 Identification of Measures, Unit Costs and Application Rates

5.1.1 Identification of Measures

Potential measures identified aiming to tackle point source and diffuse nitrate pollution in the modelled catchments are set out in Table 5.2 by farm type (according to the DPI manual and also including equestrian businesses). Measures resulting in increased nitrate pollution such as M54, M56 and M59 were not considered further in the analysis. The Burpham, Mossy Bottom and River Lavant catchments were not assessed further due to poor nitrate model fit and further investigations and improvements to model fit are recommended in Section 4 before further work on measures is carried out. Nitrate trends are not predicted to exceed the DWS at Patcham and, therefore, no measures aimed to address diffuse nitrate pollution were proposed for this catchment.

Table 5.2 Measures Proposed in the Modelled Catchments

Measure	Proportion Reduction in Nitrate	Dairy	Lowland Grazing (Mixed Beef and Sheep)	Combinable (Cereals)	Combinable (Roots)	Equestrian	Mixed (Beef or Sheep and Arable)
Method 1A – Convert arable land to unfertilised and ungrazed grass	0.9	x	x	M1a	M1a	x	M1a
Method 1B – Arable reversion to low fertiliser input extensive grazing	0.85	x	x	M1b	M1b	x	M1b
Method 2 – Convert arable/grassland to permanent woodlands	0.9	M2	M2	M2	M2	x	M2
Method 3 – Convert land to biomass cropping (i.e. willow, poplar, miscanthus)	0.5	M3	M3	M3	M3	x	M3
Method 4 – Establish cover crops in the autumn	0.45	x	x	x	M4	x	M4
Method 5 – Early harvesting and establishment of crops in the autumn	0.3	x	x	x	M5	x	M5
Method 6 – Cultivate land for crops in spring rather than autumn	0.35	x	x	M6	M6	x	M6
Method 7 – Adopt reduced cultivation systems	0.2	x	x	M7	M7	x	M7
Method 24 – Reduce manufactured fertiliser application rates	0.1	M24	M24	M24	M24	x	M24
Method 25 – Do not apply manufactured fertiliser to high risk areas	0.02	M25	M25	M25	M25	M25	M25
Method 28 – Use nitrification inhibitors	0.35	x	x	M28	M28	x	M28

Table 5.2 (continued) Measures Proposed in the Modelled Catchments

Method	Proportion Reduction in Nitrate	Dairy	Lowland Grazing (Mixed Beef and Sheep)	Combinable (Cereals)	Combinable (Roots)	Equestrian	Mixed (Beef or Sheep and Arable)
Method 31 – Use clover in place of fertiliser nitrogen	0.2	M31	M31	x	x	M31	M31
Method 33 – Reduce dietary N and P intakes	0.1	M33	M33	x	x	x	M33
Method 34 – Adopt phase feeding of livestock	0.05	M34	M34	x	x	x	M34
Method 35 – Reduce the length of the grazing day/grazing season	0.2	M35	M35	x	x	x	M35
Method 37 – Reduce field stocking rates when soils are wet	0.2	M37	M37	x	x	x	M37
Method 41 – Reduce overall stocking rates on livestock farms	0.2	M41	M41	x	x	x	M41
Method 54 – Install covers on slurry stores - to manage the volume of slurry through reduction of rainfall inputs	-0.05	M54	M54	x	x	x	M54
Method 56 – Anaerobic digestion of livestock manures	-0.05	M56	M56	x	x	x	M56
Method 59 – Compost solid manure	0	M59	M59	x	x	x	M59
Method 60 – Site solid manure field heaps away from watercourses/ field drains	0.01	M60	M60	M60	M60	M60	M60
Method 61 – Store solid manure heaps on an impermeable base and collect leachate	0.05	M61	M61	x	x	M61	M61

Table 5.2 (continued) Measures Proposed in the Modelled Catchments

Method	Proportion Reduction in Nitrate	Dairy	Lowland Grazing (Mixed Beef and Sheep)	Combinable (Cereals)	Combinable (Roots)	Equestrian	Mixed (Beef or Sheep and Arable)
Method 62 – Cover solid manure stores with sheeting	0.03	M62	M62	x	x	M62	M62
Method 63 – Use liquid/solid manure separation techniques	0.02	M63	M63	x	x	x	M63
Method 67 – Manure spreader calibration	0.05	M67	M67	M67	M67	x	M67
Method 68 – Do not apply manure to high risk areas	0.01	M68	M68	M68	M68	M68	M68
Method 74 – Transport manure to neighboring farms	0.1	M74	M74	x	x	x	M74
Method 79 – Farm track management	0.01	M79	M79	M79	M79	x	M79
Manure management plan (based on advice)	0.05	M_a	x	M_a	M_a	M_a	M_a
Fund precision farming for N	0.1	M_b	M_b	x	x	x	M_b
Improve yard drainage system (repairs and clean water / dirty water separation - diversion away from slurry stores)	0.01	M_d	x	x	x	x	M_d
Per farm advice cost of review of yard and drainage, track management etc.	0.01	M_e	M_e	M_e	M_e	x	M_e
Undersowing autumn sown crop with fast establishing catch crop (e.g. rye grass)	0.45	x	M_f	M_f	x	x	M_f

5.1.2 Unit Costs of Measures

Costs for each of the measures identified from the Defra DPI manual were also taken from this reference. The costs are based on the Nix (2008). Measures not included in the manual were sourced from the Capital Grants Scheme Farmer Handbook (Natural England, 2014) or supplied by the Downs and Harbours Clean Water Partnership project. The DPI costs are provided as estimates and will vary depending on the farm size and make up and the response of the farming system to the measure implementation. The annualised costs of measures are shown in Table 5.3. The equivalent annual costs, or annualised costs, reflect anticipated capital and annual operational and maintenance costs (or cost savings, for instance, in the case of reduced fertiliser use or additional revenue) of measures over its entire lifespan. Where measures have been independently costed the calculation of costs has been aimed to ensure that nitrate load reduction will depend on the assumed most likely choice of farmer's response. For instance, extension of a closed period into February may potentially result in a wide range of responses from farmers including extension of manure storage capacity, reduction of overall stocking rates (i.e. to ensure that the current storage capacity is sufficient for the extended storage time), transport the excess manure to neighbouring farms or employ alternative manure management techniques, such as composting, anaerobic digestion, incineration for energy recovery etc.

Details on the specific actions associated with the measures proposed and financial costs are set out in the table below. The cost-effectiveness model developed used a wide range of relevant unit costs, including costs per farm, per hectare, per tonne of solid manure or per cubic metre of slurry inflated to 2014 prices.

Table 5.3 Unit Costs of Measures Proposed in the Modelled Catchments

Measure	Unit Costs (DPI Manual or other information)	Units	Unit Costs (2013/2014 Prices)	Capital, £	Annual, £	Annualised Costs, £/year
Method 1A – Convert arable land to unfertilised and ungrazed grass	100	£/ha	113	0	113	113
Method 1B – Arable reversion to low fertiliser input extensive grazing	100	£/ha	113	not specified	not specified	113
Method 2 – Convert arable/grassland to permanent woodlands		£ per farm				Grazing: -396 Arable (cereals): -566 Mixed: -509
Method 3 – Convert land to biomass cropping (i.e. willow, poplar, miscanthus)		£ per farm				Grazing: -283 Arable (cereals): -453 Mixed: -453
Method 4 – Establish cover crops in the autumn	60	£/ha	68	0	68	68
Method 5 – Early harvesting and establishment of crops in the autumn	800	£/ha	905	0	905	905
Method 6 – Cultivate land for crops in spring rather than autumn	100	£/ha	113	0	113	113

Table 5.3 (continued) Unit Costs of Measures Proposed in the Modelled Catchments

Method	Unit Costs	Units	Unit Costs (2013/ 2014 Prices)	Capital, £	Annual, £	Annualised Costs, £/year
Method 7 – Adopt reduced cultivation systems	-40	£/ha	-45	not specified	not specified	-45
Method 24 – Reduce manufactured fertiliser application rates		£ per farm				Grazing: 1 245 Arable (cereals): -14 714 Mixed: 6 791
Method 25 – Do not apply manufactured fertiliser to high risk areas	5	£/ha	6	0	6	6
	1	£/ha	1	0	1	1
Method 28 – Use nitrification inhibitors	20	£/ha	23	0	23	23
Method 31 – Use clover in place of fertiliser nitrogen	0	£/ha; £ per farm	0	0	0	0
Method 33 – Reduce dietary N and P intakes	45	£/dairy cow	51	0	51	51
Method 34 – Adopt phase feeding of livestock	0.75	£/m3 of slurry	1	not specified	not specified	1
Method 35 – Reduce the length of the grazing day/grazing season	0.7	£/m3 of slurry	0.8	0	0.8	0.8
	1.8	£/m3 of slurry	2.0	0	2.0	2.0
Method 37 – Reduce field stocking rates when soils are wet	0.7	£/m3 of slurry	0.8	0	0.8	1
	1.8	£/m3 of slurry	2.0	0	2.0	2
Method 41 – Reduce overall stocking rates on livestock farms		£ per farm				Grazing: 5 659 Mixed: 6 791
Method 60 – Site solid manure field heaps away from watercourses/ field drains	1	£/ha	1.1	not specified	1.1	1.1
Method 61 – Store solid manure heaps on an impermeable base and collect leachate	1	£/tonne solid manure	1.1	not specified	0	1.1
Method 62 – Cover solid manure stores with sheeting	0.5	£/tonne solid manure	0.6	not specified	0.6	0.6
Method 63 – Use liquid/solid manure separation techniques	2.0	£ m3 slurry	2.3	not specified	0	2.3
	4.0	£ m3 slurry	4.5	not specified	0	4.5
Method 67 – Manure spreader calibration	200	£/farm	226.4	not specified	226.4	226.4
Method 68 – Do not apply manure to high risk areas	1	£/ha	1.1	0	1.1	1.1

Table 5.3 (continued) Unit Costs of Measures Proposed in the Modelled Catchments

Method	Unit Costs	Units	Unit Costs (2013/ 2014 Prices)	Capital, £	Annual, £	Annualised Costs, £/year
Method 74 – Transport manure to neighboring farms	5	£/m3 slurry	5.7	not specified	5.7	5.7
	4	£/t solid manure	4.5	not specified	4.5	4.5
Method 79 – Farm track management	1	£/ha	1.1	not specified	not specified	1.1
	3	£/ha	3.4	not specified	not specified	3.4
Manure management plan (based on advice)	700	£ per farm	700	700	0	267
Fund precision farming for N	8	£/ha	8	0	8	8
Improve yard drainage system (repairs and clean water / dirty water separation – diversion away from slurry stores)	2000	£ per farm	2000	2000	0	285
	5000	£ per farm	5000	5000	0	712
Per farm advice cost of review of yard and drainage, track management etc.	2000	£ per farm	2000	2000	0	285
	5000	£ per farm	5000	5000	0	712
Undersowing autumn sown crop with fast establishing catch crop (e.g. rye grass)	640	£/ ha	640	0	640	640

Measures in bold text were not sourced from the DPI Manual.

Application Areas and Rates of Measures

Aggregate costs of measures per catchment were estimated by multiplying unit costs of measures (Table 5.2) described in the previous sections with the relevant application rates (Table 5.3) (e.g. number of farms affected, area in ha affected etc.) over the lifetime of each measure.

Consideration of current practices is important to establishing potential application rates of each of the measures. For instance, in the Twyford catchment, three out of seven farms are not spreading manure in February, hence adoption of this measure would have zero net impact on these farms. One farm is equestrian and does not produce manure for arable land application. Farm visit data suggest that two out of three remaining farms do spread manure in February with no data collated on the third farm. Therefore, the potential application rate of this particular measure in Twyford catchment would be three (out of seven) farms.

Details on the potential application rates of each of the measures proposed in each of the catchments modelled, while having regard to the baseline application, are set out in Table 5.4 below.

Table 5.4 Application Rates of Measures Proposed in the Modelled Catchments

ID	Measure Description	Farm Type Code	Measure/ Farm Code	Applicability	Basis for Cost Calculation	Uptake	SPZ
M1A	Method 1A – Convert arable land to unfertilised and ungrazed grass	M	M1AM	50% of arable land in SPZ1	DPI, £/ha	0.5	SPZ1
M1B	Method 1B – Arable reversion to low fertiliser input extensive grazing	M	M1BM	50% of arable land	DPI, £/ha	0.5	SPZ1
M2	Method 2 – Convert arable/grassland to permanent woodlands	M	M2M	5% of farmland	DPI, £/farm	0.05	SPZ1
M3	Method 3 – Convert land to biomass cropping (i.e. willow, poplar, miscanthus)	M	M3M	25% of farmland in SPZ1	DPI, £/farm	0.25	SPZ1
M4	Method 4 – Establish cover crops in the autumn	M	M4M	70% of spring cropping area. Relative crops: spring oilseed rape, vegetables grown in the open; location assumed SPZ2	DPI, £/ha	0.7	SPZ2
M6	Method 6 – Cultivate land for crops in spring rather than autumn	M	M6M	25% in spring crops. Relative crops: spring oilseed rape, vegetables grown in the open; location assumed SPZ2	DPI, £/ha	0.25	SPZ2
M7	Method 7 – Adopt reduced cultivation systems	M	M7M	10% of arable land in SPZ1	DPI, £/ha	0.1	SPZ1
M24	Method 24 – Reduce manufactured fertiliser application rates	M	M24M	100% of arable land; 8% reduction in fertiliser	DPI, £/farm	1	SPZ1
M25	Method 25 – Do not apply manufactured fertiliser to high risk areas	M Gr Ar Eq	M25M M25Gr M25Ar M25Eq	1% of arable land in SPZ1 and SPZ2	DPI, £/ha	0.01	all farms
M28	Method 28 – Use nitrification inhibitors	M	M28M	75% of arable land in SPZ1 and SPZ2	DPI, £/ha	0.75	all farms
M31	Method 31 – Use clover in place of fertiliser nitrogen	M Eq	M31M M31Eq	90% of grassland land in SPZ1 and SPZ2	DPI, £/farm	0.9	all farms
M33	Method 33 – Reduce dietary N and P intakes	M	M33M	50% of dairy cows in SPZ2	DPI, £/cow	0.5	SPZ2
M34	Method 34 – Adopt phase feeding of livestock	M	M34M	50% of slurry produced in SPZ2	DPI, £/m3 of slurry	0.5	SPZ2
M35	Method 35 – Reduce the length of the grazing day/grazing season	M	M35M	20% of slurry produced in SPZ2 (to capture 20% reduction in grazing duration)	DPI, £/m3 of slurry (average)	0.2	SPZ2
M37	Method 37 – Reduce field stocking rates when soils are wet	M	M37M	20% of slurry produced in SPZ2 (to capture 20% reduction in grazing duration)	DPI, £/m3 of slurry (average)	0.2	SPZ2

Table 5.4 (continued) Application Rates of Measures Proposed in the Modelled Catchments

ID	Measure Description	Farm Type Code	Measure/ Farm Code	Applicability	Basis for Cost Calculation	Uptake	SPZ
M41	Method 41 – Reduce overall stocking rates on livestock farms	M	M41M	10% of farms in SPZ1; grassland only	DPI, £/farm	0.1	SPZ1
M60	Method 60 – Site solid manure field heaps away from watercourses/ field drains	M Gr Ar Eq	M60M M60Gr M60Ar M60Eq	100% of farms in SPZ1 and SPZ2	DPI, £/farm	1	all farms
M61	Method 61 – Store solid manure heaps on an impermeable base and collect leachate	M Gr Eq	M61M M61Gr M61Eq	100% of solid manure produced in SPZ1 and SPZ2	DPI, £/tonne of manure	1	all farms
M62	Method 62 – Cover solid manure stores with sheeting	M Gr Eq	M62M M62Gr M62Eq	100% of solid manure produced in SPZ1 and SPZ2	DPI, £/tonne of manure	1	all farms
M63	Method 63 – Use liquid/solid manure separation techniques	M Gr	M63M M63Gr	100% of farms in SPZ1 and SPZ2	DPI, £/farm	1	all farms
M67	Method 67 – Manure spreader calibration	M	M67M	100% of farms (arable and grassland) in SPZ1 and SPZ2	DPI, £/farm	1	all farms
M68	Method 68 – Do not apply manure to high risk areas	M Gr Ar Eq	M68M M68Gr M68Ar M68Eq	1% of farmland (arable and grassland) in SPZ1 and SPZ2	DPI, £/ha	0.01	all farms
M74	Method 74 – Transport manure to neighboring farms	M	M74M	100% of slurry produced in SPZ1	DPI, £/m3 of slurry (average)	1	SPZ1
M79	Method 79 – Farm track management	M Gr Ar	M79M M79Gr M79Ar	100% of farms in SPZ1 and SPZ2	DPI, £/farm	1	all farms
M_a	Manure management plan (based on advice)	M Ar	M_aM M_aAr	100% of arable land in SPZ1&SPZ2	£/farm	1	all farms
M_b	Fund precision farming for N	M	M_bM	100% of farmland (arable in SPZ2)	£/ha	1	SPZ2
M_d	Improve yard drainage system (repairs and clean water/dirty water separation - diversion away from slurry stores)	M	M_dM	100% of farms in SPZ1 &SPZ2	£/farm	1	all farms
M_e	Per farm advice cost of review of yard and drainage, track management etc.	M Gr Ar	M_eM M_eGr M_eAr	100% of farms in SPZ1 &SPZ2	£/farm	1	all farms
M_f	Undersowing autumn sown crop with fast establishing catch crop (e.g. rye grass)	M	M_fM	50% of arable land in SPZ2	£/ha	0.5	SPZ2

The measures applicable in each of the catchments were then ranked according to a single measure cost-effectiveness ratio. The single measure cost-effectiveness ratio is expressed as £ per kg of N load reduced without considering its potential interaction with other measures. The most cost-effective sequence of measures identified was then used to construct a cumulative cost curve where each of the subsequent measures consider the impact on the remaining nitrate load (based on current N loading from the source apportionment tool).

Where the annualized cost of the measure is negative, then this represents a saving or increased income. Two such measures which produce savings are land conversion to biomass production or woodland. These are costed over a period of **15 years of 75 years** respectively and include the value of the felled crop which can be significantly higher than an arable crop grown in rotation over the same period, and a lot less labour intensive. In the case of application of these measures the timescale for return and lack of annual cashflow should be considered, although a quality hard wood crop is potentially a very attractive investment.

Adverse Environmental and Social Impacts of Measures

Implementation of the measures proposed may be associated with temporary or permanent adverse environmental and social impacts. For instance, installation of a new manure storage facility may result in additional carbon impacts from temporary increase in traffic due to construction works and in a form of embodied carbon emissions associated with different construction materials used. Construction of manure storage could potentially cause odour related or visual nuisance to the neighbouring farms or recreational users, e.g. walkers. HGV movements potentially required to transport construction materials to the site may result in adverse air quality impacts.

To assess the total economic costs of proposed measures, potential environmental and social costs were also considered in a qualitative and semi-quantitative manner.

5.2 Results: Costs of Measures and Total Reduction Achieved

5.2.1 Patcham Catchment

No further load reduction is required in this catchment, but the measures applied cover the good practise of managing farmyard run-off, track maintenance and manure heaps. The cost curve capturing potential abatement measures was constructed by considering the range of measures applicable, the number of farms by SPZ areas and the current load attribution to different types of land use by SPZ. The results of the initial cost-effectiveness ranking are presented in Table 5.5 below. Data for the cumulative cost curve are presented in Table 5.6 and the cost-curve in Plate 5.1 which shows that there are opportunities present in the catchment to reduce loading by about 484kg of N per year (or 2% of the current load) at the annualized cost of less than £1,000.

In this particular catchment, the reduction could be achieved by implementing measures associated with small yield reductions (Measure 25), manpower required to implement the measures (Measure 60 and Measure 68), as well as capital and/or operational expenditures (Measure 61 (concrete pad construction) and Measure 62 (provision of sheeting). Some of the measures considered in other catchment are anticipated to be cost neutral. For instance, implementation of the Measure 31 appears to be cost neutral to farmers as according to the DPI manual the costs of establishing clover are offset by savings in manufactured fertilizer N use. Furthermore, some of the measures appear to be cost negative, i.e. to result in cost savings over the lifetime of the measure. Land use conversion measures are falling within this category including Measure 2 and Measure 3. While upfront costs and loss of yield, and, hence, revenues in the short-term are likely to be substantial in the long-term, i.e. over the whole lifetime, these measures appear to be cost negative.

Table 5.5 Cost-Effectiveness Ranking (Patcham)

Ref.	Measure Description	Overall Total Emission Reduction (kg)	Overall Total Annual Cost (£)	Single-Measure Cost-Effectiveness (£/kg)
M68Ar	Method 68 – Do not apply manure to high risk areas	2.8	2.4	0.8[1]
M_aAr	Manure management plan (based on advice)	471.3	533.5	1.1
M68Gr	Method 68 – Do not apply manure to high risk areas	1.5	2.2	1.5
M68M	Method 68 – Do not apply manure to high risk areas	2.8	4.3	1.5
M25Ar	Method 25 – Do not apply manufactured fertiliser to high risk areas	1.8	12.0	6.7
M62M	Method 62 – Cover solid manure stores with sheeting	1.2	33.6	28.6
M61M	Method 61 – Store solid manure heaps on an impermeable base and collect leachate	1.9	67.3	35.4
M60Gr	Method 60 – Site solid manure field heaps away from watercourses/ field drains	0.1	113.2	808.5
M60Ar	Method 60 – Site solid manure field heaps away from watercourses/ field drains	0.3	226.4	808.5
M60M	Method 60 – Site solid manure field heaps away from watercourses/ field drains	0.1	113.2	808.5
M79Gr	Method 79 – Farm track management	0.1	169.8	1 224.9
M79Ar	Method 79 – Farm track management	0.3	452.7	1 649.9
M79M	Method 79 – Farm track management	0.1	226.4	1 633.2
M_dM	Improve yard drainage system (repairs and clean water/dirty water separation - diversion away from slurry stores)	0.1	498.3	3 631.7
M_eGr	Per farm advice cost of review of yard and drainage, track management etc.	0.1	498.3	3 631.7
M_eAr	Per farm advice cost of review of yard and drainage, track management etc.	0.3	996.6	3 706.2
M_eM	Per farm advice cost of review of yard and drainage, track management etc.	0.1	498.3	3 668.4

Table 5.5 (continued) **Cost-Effectiveness Ranking (Patcham)**

Ref.	Measure Description	Overall Total Emission Reduction (kg)	Overall Total Annual Cost (£)	Single-Measure Cost-Effectiveness (£/kg)
M63Gr	Method 63 – Use liquid/solid manure separation techniques	0.4	2 942.8	7 221.1
M63M	Method 63 – Use liquid/solid manure separation techniques	0.4	2 942.8	7 294.0

[1] The cost-effectiveness ratio for the Measure M68Ar was derived by calculating the applicability of the measure in terms of the area (212ha) and baseline load (9.4t of N) available for reduction multiplied by the application rate of 1% and effectiveness of 3%. This results in potential emission reduction of 2.8 kg (9428 kg x 1% x 3%). The annualised costs of 2.4£/kg were then calculated by multiplying the application area of 2.1ha by 1.13£/ha unit cost. The cost-effectiveness ratio for this measures is calculated by dividing annualised costs by annual reduction, 2.4£ by 2.8kg to derive 0.8£/kg ratio.

Table 5.6 **Cumulative Cost Curve Data (Patcham)**

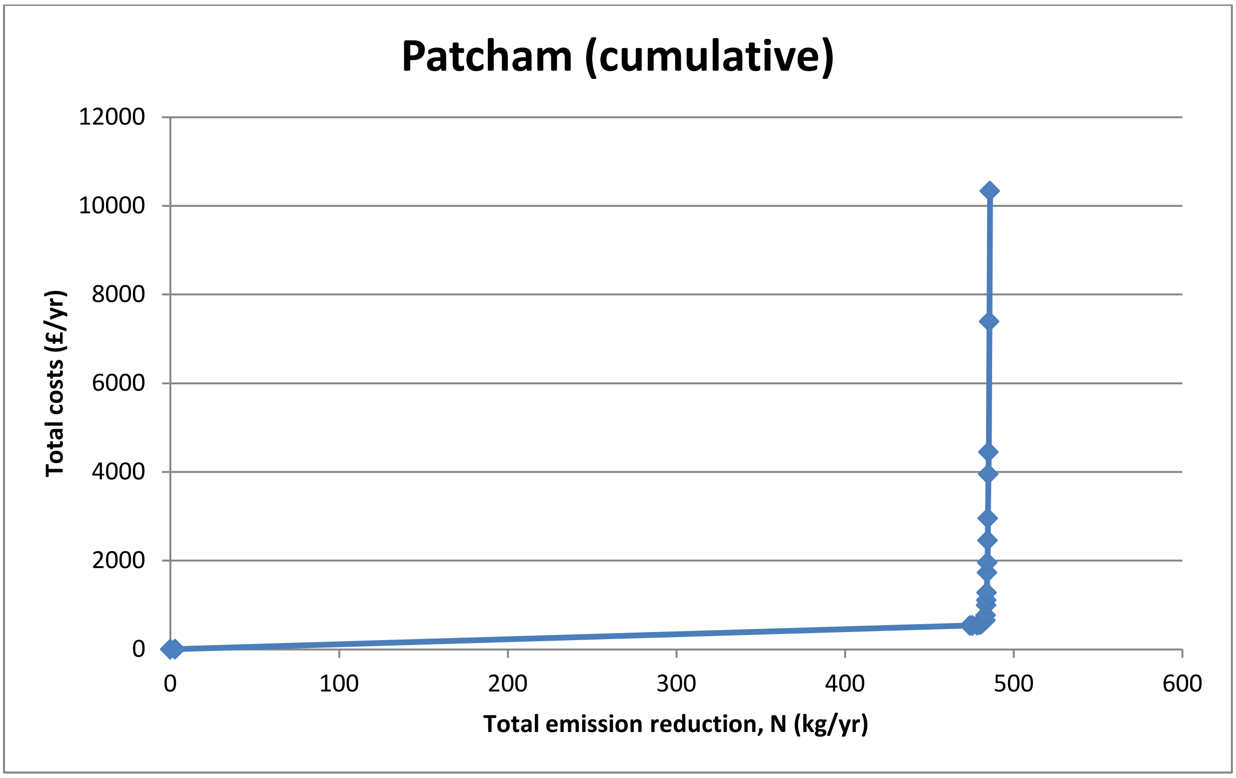
ID	Measure	Total Emission Reduction, Nkg/yr	Total Annualised Costs, £/yr
M68Ar	Method 68 – Do not apply manure to high risk areas	2.8	2.4[1]
M_aAr	Manure management plan (based on advice)	474	536
M68Gr	Method 68 – Do not apply manure to high risk areas	476	538
M68M	Method 68 – Do not apply manure to high risk areas	478	542
M25Ar	Method 25 – Do not apply manufactured fertiliser to high risk areas	480	554
M62M	Method 62 – Cover solid manure stores with sheeting	481	588
M61M	Method 61 – Store solid manure heaps on an impermeable base and collect leachate	483	655
M60Gr	Method 60 – Site solid manure field heaps away from watercourses/field drains	483	768
M60Ar	Method 60 – Site solid manure field heaps away from watercourses/field drains	484	995
M60M	Method 60 – Site solid manure field heaps away from watercourses/field drains	484	1 108
M79Gr	Method 79 – Farm track management	484	1 278
M79Ar	Method 79 – Farm track management	484	1 731
M79M	Method 79 – Farm track management	484	1 957
M_dM	Improve yard drainage system (repairs and clean water / dirty water seperation - diversion away from slurry stores)	485	2 455
M_eGr	Per farm advice cost of review of yard and drainage, track management etc.	485	2 954
M_eAr	Per farm advice cost of review of yard and drainage, track management etc.	485	3 950
M_eM	Per farm advice cost of review of yard and drainage, track management etc.	485	4 449

Table 5.6 (continued)   Cumulative Cost Curve Data (Patcham)

ID	Measure	Total Emission Reduction, Nkg/yr	Total Annualised Costs, £/yr
M63Gr	Method 63 – Use liquid/solid manure separation techniques	485	7 391
M63M	Method 63 – Use liquid/solid manure separation techniques	486	10 334

[1]. The cumulative cost curve takes into account anticipated interactions between different measures. According to the cost-effectiveness ranking, the measure M_aAr would take place after the implementation of the measure M69Ar and would also be applied to the arable land. The implementation of the first measure would, therefore, reduce the N load available for reduction from 471.4kg to 471.3kg. It will not, however, affect the costs in this instance, as implementation of the M68Ar on 1% of farmland will not reduce the land area available for the second measure. Overall, only land conversion measures reduce available land areas to apply subsequent measures.

Plate 5.1   Cost Curve – Patcham Catchment



5.2.2 Findon Catchment

A load reduction of 39% is estimated at Findon (Table 4.5) to keep nitrate peak concentrations below the DWS threshold. This is equivalent to about 5.2 tonnes of N (based on predicted loading at 9245 kg N/year). The catchment includes land at an estimated 4 likely mixed farms across SPZ1 and SPZ2 areas. The results of the initial cost-effectiveness ranking are presented in the Table 5.7, with data for the cumulative cost curve in Table 5.8

and the curve are presented in Plate 5.2. The results suggest that implementation of the first eleven measures M2M to M67M (Table 5.7) at the annual cost of £6k would achieve the required reduction in N load.

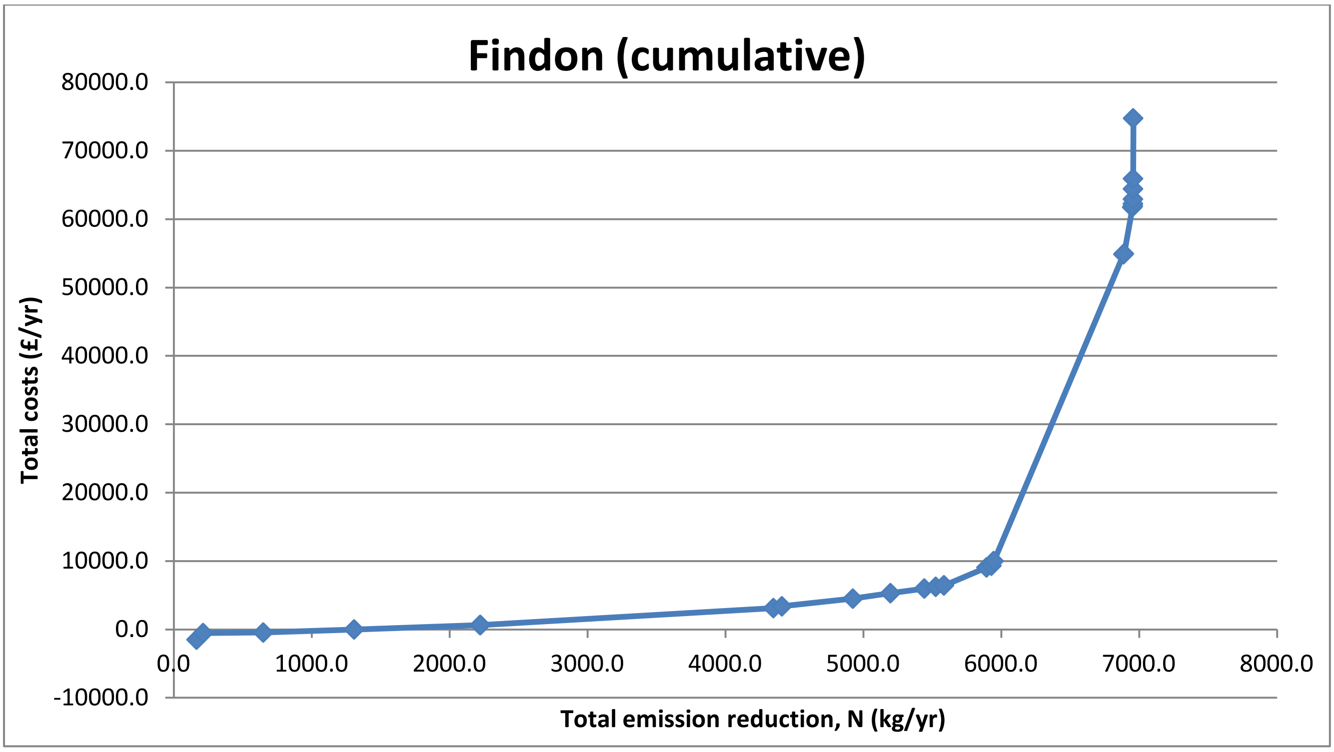
Table 5.7 Cost-Effectiveness Ranking (Findon)

Measure Description	Ref.	Overall Total Emission Reduction (kg)	Overall Total Annual Cost (£)	Single-Measure Cost-Effectiveness (£/kg)
Method 2 – Convert arable/grassland to permanent woodlands	M2M	166.6	-509.3	-3.1
Method 7 – Adopt reduced cultivation systems	M7M	47.3	-76.1	-1.6
Method 3 – Convert land to biomass cropping (i.e. willow, poplar, miscanthus)	M3M	436.2	-452.7	-1.0
Method 31 – Use clover in place of fertiliser nitrogen	M31M	658.8	0.0	0.0
Method 1A – Convert arable land to unfertilised and ungrazed grass	M1AM	913.1	641.8	0.7
Method 68 – Do not apply manure to high risk areas	M68M	3.3	3.6	1.1
Method 28 – Use nitrification inhibitors	M28M	2 124.2	2 476.5	1.2
Method 35 – Reduce the length of the grazing day/grazing season	M35M	61.6	261.6	1.4
Fund precision farming for N	M_bM	514.5	1121.6	2.2
Manure management plan (based on advice)	M_aM	272.7	800.2	2.9
Method 67 – Manure spreader calibration	M67M	245.4	679.1	2.8
Method 4 – Establish cover crops in the autumn	M4M	82.8	251.1	3.0
Method 37 – Reduce field stocking rates when soils are wet	M37M	59.2	209.3	3.5
Method 25 – Do not apply manufactured fertiliser to high risk areas	M25M	1.0	8.3	8.4
Method 74 – Transport manure to neighboring farms	M74M	308.2	2 615.6	8.5
Method 34 – Adopt phase feeding of livestock	M34M	35.5	251.1	7.1
Method 41 – Reduce overall stocking rates on livestock farms	M41M	16.3	679.1	41.7
Undersowing autumn sown crop with fast establishing catch crop (e.g. rye grass)	M_fM	941.3	44 864.0	47.7
Method 62 – Cover solid manure stores with sheeting	M62M	3.0	85.8	28.6
Method 24 – Reduce manufactured fertiliser application rates	M24M	60.6	6 791.0	112.0
Method 61 – Store solid manure heaps on an impermeable base and collect leachate	M61M	4.9	171.6	35.4
Method 60 – Site solid manure field heaps away from watercourses/ field drains	M60M	0.3	339.6	1 352.9
Method 79 – Farm track management	M79M	0.2	679.1	2 733.1
Improve yard drainage system (repairs and clean water / dirty water separation - diversion away from slurry stores)	M_dM	0.2	1 495.0	6 077.4
Per farm advice cost of review of yard and drainage, track management etc.	M_eM	0.2	1 495.0	6 138.8
Method 63 – Use liquid/solid manure separation techniques	M63M	0.7	8 828.4	12 206.1

Table 5.8 Cumulative Cost Curve Data (Findon)

ID	Measure	Total Emission Reduction, Nkg/yr	Total Annualised Costs, £/yr
M2M	Method 2 – Convert arable/grassland to permanent woodlands	166.6	-1 490.9
M7M	Method 7 – Adopt reduced cultivation systems	214.0	-528.8
M3M	Method 3 – Convert land to biomass cropping (i.e. willow, poplar, miscanthus)	650.1	-452.7
M31M	Method 31 – Use clover in place of fertiliser nitrogen	1 308.9	0.0
M1AM	Method 1A – Convert arable land to unfertilised and ungrazed grass	2 222.0	641.8
M68M	Method 68 – Do not apply manure to high risk areas	2 225.3	645.4
M28M	Method 28 – Use nitrification inhibitors	4 349.5	3 122.0
M35M	Method 35 – Reduce the length of the grazing day/grazing season	4 411.1	3 383.5
M_bM	Fund precision farming for N	4 925.7	4 505.1
M_aM	Manure management plan (based on advice)	5 198.3	5 305.3
M67M	**Method 67 – Manure spreader calibration**	**5 443.8**	**5 984.4**
M4M	Method 4 – Establish cover crops in the autumn	5 526.6	6 235.6
M37M	Method 37 – Reduce field stocking rates when soils are wet	5 585.8	6 444.8
M25M	Method 25 – Do not apply manufactured fertiliser to high risk areas	5 586.8	6 453.1
M74M	Method 74 – Transport manure to neighboring farms	5 895.0	9 068.7
M34M	Method 34 – Adopt phase feeding of livestock	5 930.5	9 319.8
M41M	Method 41 – Reduce overall stocking rates on livestock farms	5 946.8	9 998.9
M_fM	Undersowing autumn sown crop with fast establishing catch crop (e.g. rye grass)	6 888.1	54 862.9
M62M	Method 62 – Cover solid manure stores with sheeting	6 891.1	54 948.7
M24M	Method 24 – Reduce manufactured fertiliser application rates	6 951.7	61 739.7
M61M	Method 61 – Store solid manure heaps on an impermeable base and collect leachate	6 956.6	61 911.3
M60M	Method 60 – Site solid manure field heaps away from watercourses/field drains	6 956.8	62 250.8
M79M	Method 79 – Farm track management	6 957.1	62 929.9
M_dM	Improve yard drainage system (repairs and clean water/dirty water separation - diversion away from slurry stores)	6 957.3	64 424.9
M_eM	Per farm advice cost of review of yard and drainage, track management etc.	6 957.6	65 919.9
M63M	Method 63 – Use liquid/solid manure separation techniques	6 958.3	74 748.2

Plate 5.2 Cost Curve – Findon Catchment



5.2.3 Housedean Catchment

A load reduction of 12% is required in Housedean catchment (Table 4.5) equivalent to about 0.9 tonnes of N (based on 5 994 kg N/yr loading over the catchment). The catchment includes three mixed farms across SPZ1 and SPZ2 areas. The results of the initial cost-effectiveness ranking are presented in Table 5.9, with the ranked measures in Table 5.10 and the cost curve in Plate 5.3. The results suggest that implementation of the first four measures M2M to M31M at zero net annual cost would allow achievement of the required reduction in N loading (0.9 tonnes of N).

Table 5.9 Cost-effectiveness Ranking (Housedean)

Measure Description	Ref.	Overall Total Emission Reduction (kg)	Overall Total Annual Cost (£)	Single-Measure Cost-effectiveness (£/kg)
Method 2 – Convert arable/grassland to permanent woodlands	M2M	89.2	-509.3	-5.7
Method 7 – Adopt reduced cultivation systems	M7M	20.1	-94.2	-4.7
Method 3 – Convert land to biomass cropping (i.e. willow, poplar, miscanthus)	M3M	234.1	-452.7	-1.9
Method 31 – Use clover in place of fertiliser nitrogen	M31M	598.0	0.0	0.0
Method 68 – Do not apply manure to high risk areas	M68M	2.0	2.4	1.2

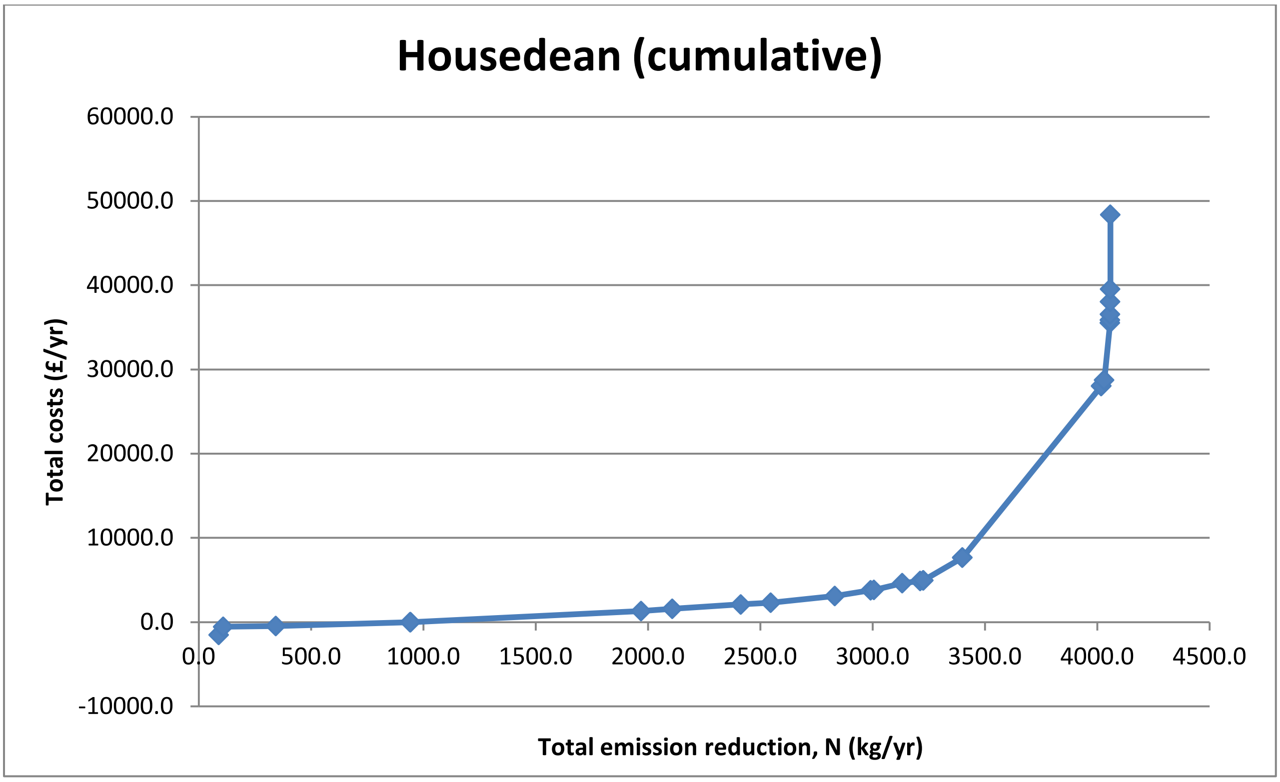
Table 5.9 (continued) Cost-effectiveness Ranking (Housedean)

Measure Description	Ref.	Overall Total Emission Reduction (kg)	Overall Total Annual Cost (£)	Single-Measure Cost-effectiveness (£/kg)
Method 28 – Use nitrification inhibitors	M28M	1026.3	1318.4	1.3
Method 35 – Reduce the length of the grazing day/grazing season	M35M	138.8	269.8	1.4
Fund precision farming for N	M_bM	305.0	508.9	1.7
Method 37 – Reduce field stocking rates when soils are wet	M37M	133.2	215.9	1.6
Method 1A – Convert arable land to unfertilised and ungrazed grass	M1AM	285.3	794.8	2.8
Method 67 – Manure spreader calibration	M67M	159.6	679.1	4.3
Method 4 – Establish cover crops in the autumn	M4M	14.6	45.8	3.1
Manure management plan (based on advice)	M_aM	126.0	800.2	6.4
Method 34 – Adopt phase feeding of livestock	M34M	79.9	259.0	3.2
Method 33 – Reduce dietary N and P intakes	M33M	13.5	67.9	5.0
Method 25 – Do not apply manufactured fertiliser to high risk areas	M25M	0.5	4.0	8.3
Method 74 – Transport manure to neighboring farms	M74M	173.5	2698.3	15.6
Method 62 – Cover solid manure stores with sheeting	M62M	0.5	15.6	28.6
Undersowing autumn sown crop with fast establishing catch crop (e.g. rye grass)	M_fM	617.6	20354.8	33.0
Method 61 – Store solid manure heaps on an impermeable base and collect leachate	M61M	0.9	31.3	35.4
Method 41 – Reduce overall stocking rates on livestock farms	M41M	12.4	679.1	54.8
Method 24 – Reduce manufactured fertiliser application rates	M24M	25.7	6791.0	264.2
Method 60 – Site solid manure field heaps away from watercourses/ field drains	M60M	0.3	339.6	1216.1
Method 79 – Farm track management	M79M	0.3	679.1	2456.8
Improve yard drainage system (repairs and clean water / dirty water separation - diversion away from slurry stores)	M_dM	0.3	1495.0	5462.9
Per farm advice cost of review of yard and drainage, track management etc.	M_eM	0.3	1495.0	5518.0
Method 63 – Use liquid/solid manure separation techniques	M63M	0.8	8828.4	10971.8

Table 5.10 Cumulative Cost Curve Data (Housedean)

ID	Measure	Total Emission Reduction, Nkg/yr	Total Annualised Costs, £/yr
M2M	Method 2 – Convert arable/grassland to permanent woodlands	89.2	-1 509.0
M7M	Method 7 – Adopt reduced cultivation systems	109.3	-546.9
M3M	Method 3 – Convert land to biomass cropping (i.e. willow, poplar, miscanthus)	343.4	-452.7
M31M	**Method 31 – Use clover in place of fertiliser nitrogen**	**941.3**	**0.0**
M68M	Method 68 – Do not apply manure to high risk areas	943.3	2.4
M28M	Method 28 – Use nitrification inhibitors	1 969.6	1 320.7
M35M	Method 35 – Reduce the length of the grazing day/grazing season	2 108.4	1 590.6
M_bM	Fund precision farming for N	2 413.4	2 099.4
M37M	Method 37 – Reduce field stocking rates when soils are wet	2 546.6	2 315.3
M1AM	Method 1A – Convert arable land to unfertilised and ungrazed grass	2 831.9	3 110.1
M67M	Method 67 – Manure spreader calibration	2 991.6	3 789.2
M4M	Method 4 – Establish cover crops in the autumn	3 006.1	3 835.0
M_aM	Manure management plan (based on advice)	3 132.1	4 635.3
M34M	Method 34 – Adopt phase feeding of livestock	3 212.1	4 894.3
M33M	Method 33 – Reduce dietary N and P intakes	3 225.5	4 962.2
M25M	Method 25 – Do not apply manufactured fertiliser to high risk areas	3 226.0	4 966.2
M74M	Method 74 – Transport manure to neighboring farms	3 399.5	7 664.5
M62M	Method 62 – Cover solid manure stores with sheeting	3 400.0	7 680.1
M_fM	Undersowing autumn sown crop with fast establishing catch crop (e.g. rye grass)	4 017.7	28 034.8
M61M	Method 61 – Store solid manure heaps on an impermeable base and collect leachate	4 018.5	28 066.1
M41M	Method 41 – Reduce overall stocking rates on livestock farms	4 030.9	28 745.2
M24M	Method 24 – Reduce manufactured fertiliser application rates	4 056.6	35 536.3
M60M	Method 60 – Site solid manure field heaps away from watercourses/ field drains	4 056.9	35 875.8
M79M	Method 79 – Farm track management	4 057.2	36 554.9
M_dM	Improve yard drainage system (repairs and clean water / dirty water separation - diversion away from slurry stores)	4 057.5	38 049.9
M_eM	Per farm advice cost of review of yard and drainage, track management etc.	4 057.7	39 544.9
M63M	Method 63 – Use liquid/solid manure separation techniques	4 058.5	48 373.2

Plate 5.3 Cost Curve – Housedean Catchment



5.2.4 Lovedean Catchment

A load reduction of 22% is required in Lovedean catchment (Table 4.5) equivalent to about 10.2 tonnes of N (based on a loading of around 33 500 kg N/yr). The catchment includes three mixed farms across SPZ1, SPZ2 and SPZ3 areas. The results of the initial cost-effectiveness ranking are presented in Table 5.11, with cost curve data in Table 5.12 and the plotted curve in Plate 5.4. The results suggest that implementation of the first eight measures M7M to M28M at the annual cost of £14.4k would achieve the required reduction in N load.

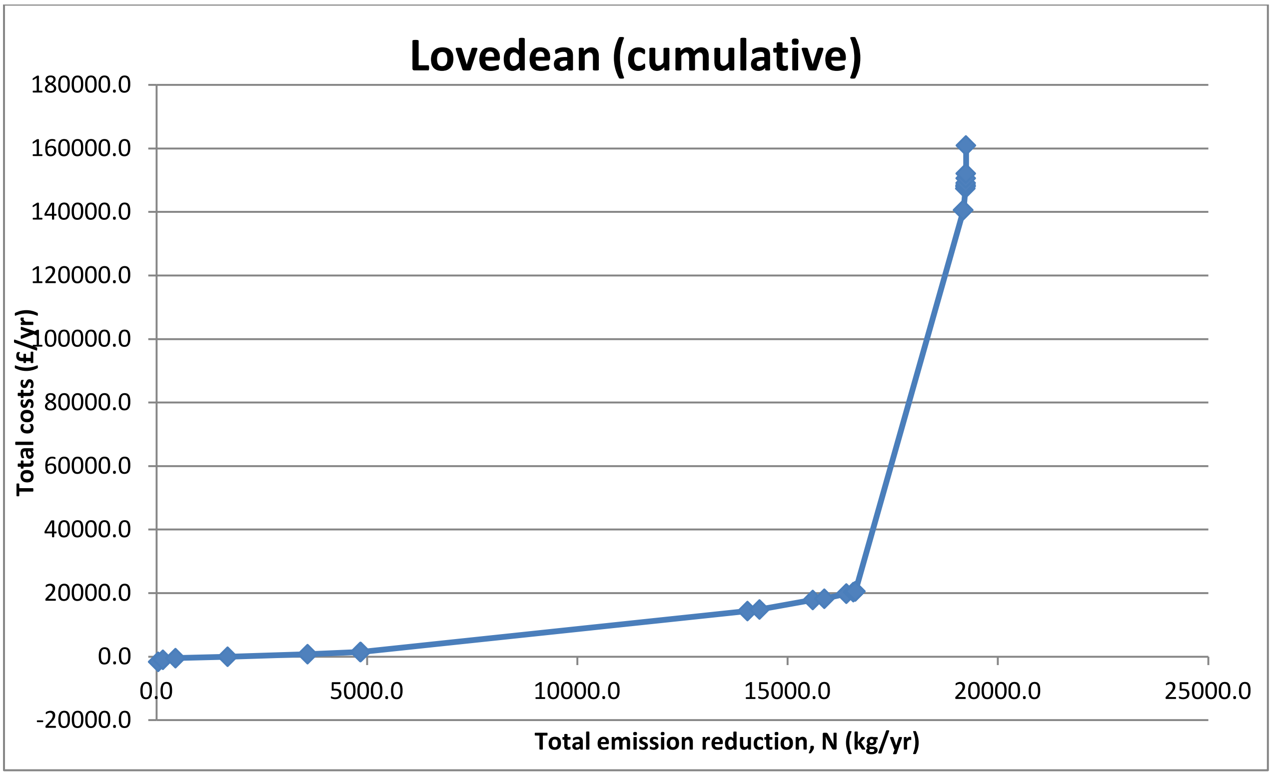
Table 5.11 Cost-effectiveness Ranking (Lovedean)

Measure Description	Ref.	Overall total Emission Reduction (kg)	Overall Total Annual Cost (£)	Single-Measure Cost-effectiveness (£/kg)
Method 7 – Adopt reduced cultivation systems	M7M	41.8	-190.1	-4.6
Method 2 – Convert arable/grassland to permanent woodlands	M2M	112.7	-509.3	-4.5
Method 3 – Convert land to biomass cropping (i.e. willow, poplar, miscanthus)	M3M	298.9	-452.7	-1.5
Method 31 – Use clover in place of fertiliser nitrogen	M31M	1 239.2	0.0	0.0
Manure management plan (based on advice)	M_aM	1 900.8	800.2	0.4
Method 67 – Manure spreader calibration	M67M	1 252.8	679.1	0.5
Method 68 – Do not apply manure to high risk areas	M68M	12.2	12.6	1.0
Method 28 – Use nitrification inhibitors	M28M	9 193.1	12 884.4	1.4
Method 35 – Reduce the length of the grazing day/grazing season	M35M	286.2	487.1	1.4
Fund precision farming for N	M_bM	1 266.3	3 000.0	2.4
Method 37 – Reduce field stocking rates when soils are wet	M37M	274.8	389.7	1.4
Method 1A – Convert arable land to unfertilised and ungrazed grass	M1AM	522.6	1 608.8	3.1
Method 4 – Establish cover crops in the autumn	M4M	2.0	6.0	3.0
Method 34 – Adopt phase feeding of livestock	M34M	164.9	467.6	2.8
Method 33 – Reduce dietary N and P intakes	M33M	42.1	212.2	5.0
Method 25 – Do not apply manufactured fertiliser to high risk areas	M25M	4.8	42.1	8.8
Method 62 – Cover solid manure stores with sheeting	M62M	0.2	6.9	28.6
Undersowing autumn sown crop with fast establishing catch crop (e.g. rye grass)	M_fM	2 563.7	120 000.0	46.8
Method 61 – Store solid manure heaps on an impermeable base and collect leachate	M61M	0.4	13.8	35.4
Method 24 – Reduce manufactured fertiliser application rates	M24M	51.1	6 791.0	132.9
Method 41 – Reduce overall stocking rates on livestock farms	M41M	6.1	679.1	111.6
Method 74 – Transport manure to neighboring farms	M74M	0.3	23.0	85.7
Method 60 – Site solid manure field heaps away from watercourses/ field drains	M60M	1.1	339.6	298.2
Method 79 – Farm track management	M79M	1.1	679.1	602.3
Improve yard drainage system (repairs and clean water/dirty water separation - diversion away from slurry stores)	M_dM	1.1	1 495.0	1 339.4
Per farm advice cost of review of yard and drainage, track management etc.	M_eM	1.1	1 495.0	1 352.9
Method 63 – Use liquid/solid manure separation techniques	M63M	3.3	8 828.4	2 690.1

Table 5.12 Cumulative Cost Curve Data (Lovedean)

ID	Measure	Total Emission Reduction, Nkg/yr	Total Annualised Costs, £/yr
M7M	Method 7 – Adopt reduced cultivation systems	41.8	-1604.9
M2M	Method 2 – Convert arable/grassland to permanent woodlands	154.4	-962.1
M3M	Method 3 – Convert land to biomass cropping (i.e. willow, poplar, miscanthus)	453.3	-452.7
M31M	Method 31 – Use clover in place of fertiliser nitrogen	1 692.5	0.0
M_aM	Manure management plan (based on advice)	3 593.3	800.2
M67M	Method 67 – Manure spreader calibration	4 846.1	1 479.3
M68M	Method 68 – Do not apply manure to high risk areas	4 858.2	1 492.0
M28M	**Method 28 – Use nitrification inhibitors**	**14 051.3**	**14 376.3**
M35M	Method 35 – Reduce the length of the grazing day/grazing season	14 337.5	14 863.4
M_bM	Fund precision farming for N	15 603.8	17 863.4
M37M	Method 37 – Reduce field stocking rates when soils are wet	15 878.5	18 253.0
M1AM	Method 1A – Convert arable land to unfertilised and ungrazed grass	16 401.2	19 861.9
M4M	Method 4 – Establish cover crops in the autumn	16 403.1	19 867.9
M34M	Method 34 – Adopt phase feeding of livestock	16 568.0	20 335.5
M33M	Method 33 – Reduce dietary N and P intakes	16 610.1	20 547.7
M25M	Method 25 – Do not apply manufactured fertiliser to high risk areas	16 614.9	20 589.8
M62M	Method 62 – Cover solid manure stores with sheeting	16 615.1	20 596.7
M_fM	Undersowing autumn sown crop with fast establishing catch crop (e.g. rye grass)	19 178.9	140 596.7
M61M	Method 61 – Store solid manure heaps on an impermeable base and collect leachate	19 179.3	140 610.5
M24M	Method 24 – Reduce manufactured fertiliser application rates	19 230.4	147 401.6
M41M	Method 41 – Reduce overall stocking rates on livestock farms	19 236.4	148 080.7
M74M	Method 74 – Transport manure to neighboring farms	19 236.7	148 103.7
M60M	Method 60 – Site solid manure field heaps away from watercourses/ field drains	19 237.8	148 443.2
M79M	Method 79 – Farm track management	19 239.0	149 122.3
M_dM	Improve yard drainage system (repairs and clean water / dirty water separation - diversion away from slurry stores)	19 240.1	150 617.3
M_eM	Per farm advice cost of review of yard and drainage, track management etc.	19 241.2	152 112.3
M63M	Method 63 – Use liquid/solid manure separation techniques	19 244.5	160 940.6

Plate 5.4 Cost Curve – Lovedean Catchment



5.2.5 Newmarket Catchment

A load reduction of 15% is required in Newmarket catchment (Table 4.5) equivalent to about 3.2 tonnes of N (based on a load of 19301 kg N/yr). The catchment includes three arable and mixed farms across SPZ1 and SPZ2 areas. The results of the initial cost-effectiveness ranking are presented in Table 5.13, with cost curve data in Table 5.14 and the plotted curve in Plate 5.5. The results suggest that implementation of the first five measures M7M to M67M at the annual cost of £0.5k would allow achieving the required reduction in N load.

Table 5.13 Cost-effectiveness Ranking (Newmarket)

Measure Description	Ref	Overall Total Emission Reduction (kg)	Overall Total Annual Cost (£)	Single-Measure Cost-effectiveness (£/kg)
Method 7 – Adopt reduced cultivation systems	M7M	50.6	-248.3	-4.9
Method 2 – Convert arable/grassland to permanent woodlands	M2M	189.2	-509.3	-2.7
Method 3 – Convert land to biomass cropping (i.e. willow, poplar, miscanthus)	M3M	501.9	-452.7	-0.9
Method 31 – Use clover in place of fertiliser nitrogen	M31M	2 130.0	0.0	0.0
Method 67 – Manure spreader calibration	M67M	551.5	452.7	0.8

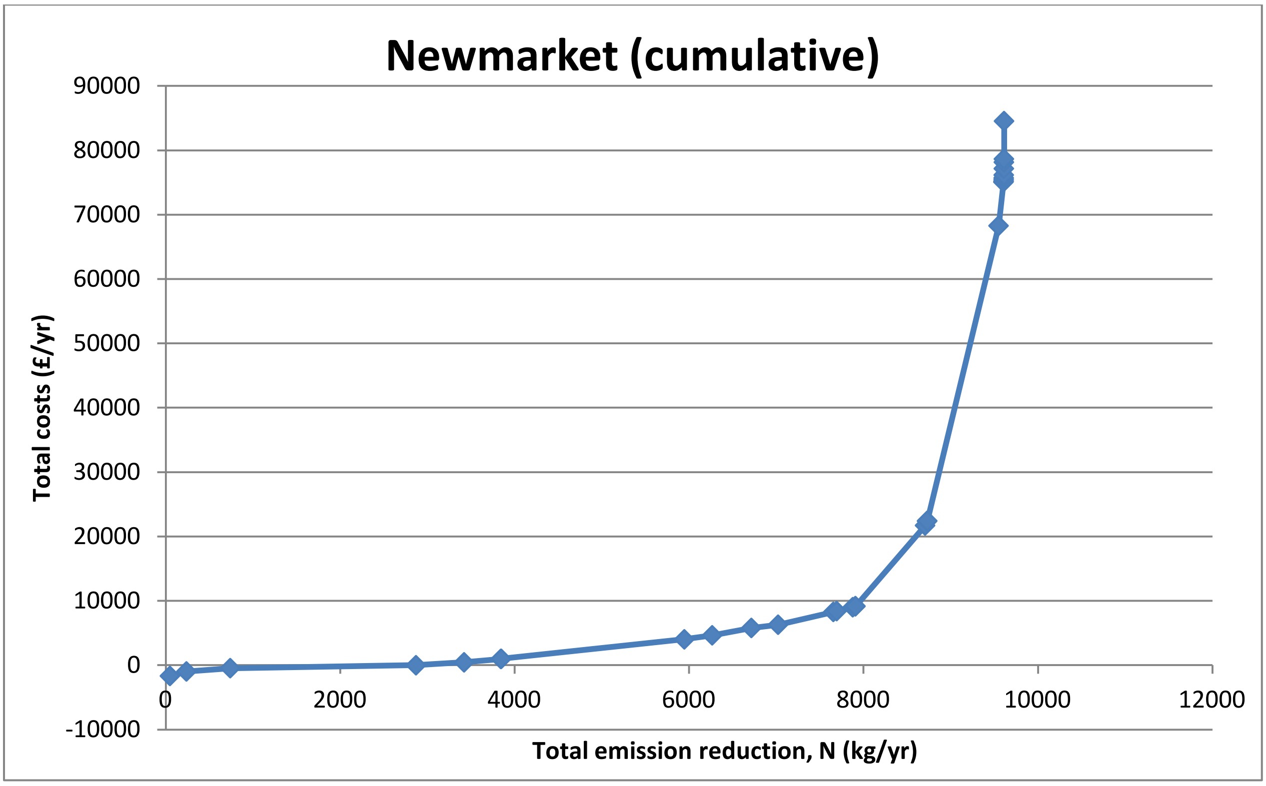
Table 5.13 (continued) Cost-effectiveness Ranking (Newmarket)

Measure Description	Ref	Overall Total Emission Reduction (kg)	Overall Total Annual Cost (£)	Single-Measure Cost-effectiveness (£/kg)
Manure management plan (based on advice)	M_aM	421.0	533.5	1.3
Method 68 – Do not apply manure to high risk areas	M68M	5.2	7.3	1.4
Method 28 – Use nitrification inhibitors	M28M	2 099.1	3 029.4	1.4
Method 35 – Reduce the length of the grazing day/grazing season	M35M	319.4	627.0	1.4
Fund precision farming for N	M_bM	449.0	1 146.1	2.6
Method 37 – Reduce field stocking rates when soils are wet	M37M	306.6	501.6	1.6
Method 1A – Convert arable land to unfertilised and ungrazed grass	M1AM	633.3	1 990.1	3.1
Method 4 – Establish cover crops in the autumn	M4M	38.5	125.8	3.3
Method 34 – Adopt phase feeding of livestock	M34M	184.0	601.9	3.3
Method 33 – Reduce dietary N and P intakes	M33M	30.3	152.8	5.0
Method 25 – Do not apply manufactured fertiliser to high risk areas	M25M	0.9	10.1	11.7
Method 74 – Transport manure to neighboring farms	M74M	798.4	12 539.7	15.7
Method 41 – Reduce overall stocking rates on livestock farms	M41M	22.9	679.1	29.6
Method 62 – Cover solid manure stores with sheeting	M62M	1.3	37.7	28.6
Undersowing autumn sown crop with fast establishing catch crop (e.g. rye grass)	M_fM	818.3	45 845.7	56.0
Method 24 – Reduce manufactured fertiliser application rates	M24M	55.7	6 791.0	121.9
Method 61 – Store solid manure heaps on an impermeable base and collect leachate	M61M	2.1	75.4	35.4
Method 60 – Site solid manure field heaps away from watercourses/ field drains	M60Ar	0.3	113.2	393.6
Method 60 – Site solid manure field heaps away from watercourses/ field drains	M60M	0.6	226.4	393.6
Method 79 – Farm track management	M79Ar	0.3	226.4	795.1
Method 79 – Farm track management	M79M	0.6	452.7	803.2
Per farm advice cost of review of yard and drainage, track management etc.	M_eM	0.9	996.6	1 170.7
Improve yard drainage system (repairs and clean water / dirty water separation - diversion away from slurry stores)	M_dM	0.5	996.6	1 861.6
Per farm advice cost of review of yard and drainage, track management etc.	M_eAr	0.3	498.3	1 768.0
Method 63 – Use liquid/solid manure separation techniques	M63M	1.6	5 885.6	3 739.3

Table 5.14 Cumulative Cost Curve Data (Newmarket)

ID	Measure	Total Emission Reduction, Nkg/yr	Total Annualised Costs, £/yr
M7M	Method 7 – Adopt reduced cultivation systems	51	-1663
M2M	Method 2 – Convert arable/grassland to permanent woodlands	240	-962
M3M	Method 3 – Convert land to biomass cropping (i.e. willow, poplar, miscanthus)	742	-453
M31M	Method 31 – Use clover in place of fertiliser nitrogen	2 872	0
M67M	**Method 67 – Manure spreader calibration**	**3 423**	**453**
M_aM	Manure management plan (based on advice)	3 844	986
M68M	Method 68 – Do not apply manure to high risk areas	3 849	994
M28M	Method 28 – Use nitrification inhibitors	5 949	4 023
M35M	Method 35 – Reduce the length of the grazing day/grazing season	6 268	4 650
M_bM	Fund precision farming for N	6 717	5 796
M37M	Method 37 – Reduce field stocking rates when soils are wet	7 023	6 298
M1AM	Method 1A – Convert arable land to unfertilised and ungrazed grass	7 657	8 288
M4M	Method 4 – Establish cover crops in the autumn	7 695	8 413
M34M	Method 34 – Adopt phase feeding of livestock	7 879	9 015
M33M	Method 33 – Reduce dietary N and P intakes	7 910	9 168
M25M	Method 25 – Do not apply manufactured fertiliser to high risk areas	7 910	9 178
M74M	Method 74 – Transport manure to neighboring farms	8 709	21 718
M41M	Method 41 – Reduce overall stocking rates on livestock farms	8 732	22 397
M62M	Method 62 – Cover solid manure stores with sheeting	8 733	22 435
M_fM	Undersowing autumn sown crop with fast establishing catch crop (e.g. rye grass)	9 551	68 280
M24M	Method 24 – Reduce manufactured fertiliser application rates	9 607	75 072
M61M	Method 61 – Store solid manure heaps on an impermeable base and collect leachate	9 609	75 147
M60Ar	Method 60 – Site solid manure field heaps away from watercourses/ field drains	9 609	75 260
M60M	Method 60 – Site solid manure field heaps away from watercourses/ field drains	9 610	75 486
M79Ar	Method 79 – Farm track management	9 610	75 713
M79M	Method 79 – Farm track management	9 611	76 166
M_eM	Per farm advice cost of review of yard and drainage, track management etc.	9 612	77 162
M_dM	Improve yard drainage system (repairs and clean water / dirty water separation - diversion away from slurry stores)	9 612	78 159
M_eAr	Per farm advice cost of review of yard and drainage, track management etc.	9 613	78 657
M63M	Method 63 – Use liquid/solid manure separation techniques	9 614	84 543

Plate 5.5 Cost Curve – Newmarket Catchment



5.2.6 Twyford Catchment

A load reduction of 29% is required in Newmarket catchment (Table 4.5) equivalent to about 43 tonnes of N. The catchment hosts 12 arable, equestrian and mixed farms across SPZ1, SPZ2 and SPZ3 areas. The results of the initial cost-effectiveness ranking are presented in the Table 5.15 below, with the cumulative cost curve data in Table 5.16 and plotted in Plate 5.6. The results suggest that implementation of the measures M2Ar to M_bM at the annual cost of £45.7k would allow achieving the required reduction in N load.

Table 5.15 Cost-effectiveness Ranking (Twyford)

Measure Description	Ref	Overall Total Emission Reduction (kg)	Overall Total Annual Cost (£)	Single-Measure Cost-effectiveness (£/kg)
Method 2 – Convert arable/grassland to permanent woodlands	M2Ar	187.4	-1 697.8	-9.1
Method 2 – Convert arable/grassland to permanent woodlands	M2M	94.1	-509.3	-5.4
Method 7 – Adopt reduced cultivation systems	M7Ar	79.5	-322.7	-4.1
Method 7 – Adopt reduced cultivation systems	M7M	26.5	-107.6	-4.1
Method 3 – Convert land to biomass cropping (i.e. willow, poplar, miscanthus)	M3Ar	487.1	-29 039.7	-59.6
Method 3 – Convert land to biomass cropping (i.e. willow, poplar, miscanthus)	M3M	246.3	-452.7	-1.8
Method 31 – Use clover in place of fertiliser nitrogen	M31Eq	264.4	0.0	0.0
Method 31 – Use clover in place of fertiliser nitrogen	M31M	3 016.4	0.0	0.0
Manure management plan (based on advice)	M_aM	5 549.9	2 133.9	0.4
Manure management plan (based on advice)	M_aEq	652.4	266.7	0.4
Method 67 – Manure spreader calibration	M67M	3 575.7	1 810.9	0.5
Method 68 – Do not apply manure to high risk areas	M68Ar	1.0	0.5	0.5
Method 68 – Do not apply manure to high risk areas	M68Eq	4.1	3.4	0.8
Method 68 – Do not apply manure to high risk areas	M68M	34.7	31.3	0.9
Method 28 – Use nitrification inhibitors	M28Ar	894.8	816.7	0.9
Method 28 – Use nitrification inhibitors	M28M	26 745.3	33 877.2	1.3
Method 35 – Reduce the length of the grazing day/grazing season	M35M	741.0	1 147.9	1.4
Fund precision farming for N	M_bM	2 659.3	5 641.7	2.1
Method 37 – Reduce field stocking rates when soils are wet	M37M	711.3	918.3	1.3
Method 1A – Convert arable land to unfertilised and ungrazed grass	M1AAr	1131.3	2 722.5	2.4
Method 1A – Convert arable land to unfertilised and ungrazed grass	M1AM	225.9	907.5	4.0
Method 4 – Establish cover crops in the autumn	M4M	161.1	438.1	2.7
Method 34 – Adopt phase feeding of livestock	M34M	426.8	1 102.0	2.6
Manure management plan (based on advice)	M_aAr	69.1	800.2	11.6
Method 33 – Reduce dietary N and P intakes	M33M	272.7	1 375.2	5.0
Method 25 – Do not apply manufactured fertiliser to high risk areas	M25Eq	2.5	13.3	5.4

Table 5.15 (continued) Cost-effectiveness Ranking (Twyford)

Measure Description	Ref	Overall Total Emission Reduction (kg)	Overall Total Annual Cost (£)	Single-Measure Cost-effectiveness (£/kg)
Method 25 – Do not apply manufactured fertiliser to high risk areas	M25Ar	0.3	1.4	5.2
Method 25 – Do not apply manufactured fertiliser to high risk areas	M25M	14.5	112.5	7.8
Method 67 – Manure spreader calibration	M67Ar	39.4	5 444.9	138.2
Method 74 – Transport manure to neighboring farms	M74M	617.5	7 652.6	12.4
Undersowing autumn sown crop with fast establishing catch crop (e.g. rye grass)	M_fM	5 384.0	225 668.7	41.9
Method 62 – Cover solid manure stores with sheeting	M62M	36.1	1 031.8	28.6
Method 61 – Store solid manure heaps on an impermeable base and collect leachate	M61M	58.4	2 063.5	35.4
Method 41 – Reduce overall stocking rates on livestock farms	M41M	9.3	679.1	72.6
Method 24 – Reduce manufactured fertiliser application rates	M24M	22.1	6 791.0	307.6
Method 24 – Reduce manufactured fertiliser application rates	M24Ar	101.9	44 141.8	433.1
Method 60 – Site solid manure field heaps away from watercourses/ field drains	M60Eq	0.2	113.2	578.1
Method 60 – Site solid manure field heaps away from watercourses/ field drains	M60M	1.6	905.5	578.1
Method 60 – Site solid manure field heaps away from watercourses/ field drains	M60Ar	0.6	339.6	578.1
Method 79 – Farm track management	M79M	1.4	1 810.9	1 256.7
Method 79 – Farm track management	M79Ar	0.6	679.1	1 191.9
Improve yard drainage system (repairs and clean water / dirty water separation - diversion away from slurry stores)	M_dM	1.3	3 986.6	3 006.9
Per farm advice cost of review of yard and drainage, track management etc.	M_eM	1.2	3 986.6	3 268.4
Per farm advice cost of review of yard and drainage, track management etc.	M_eAr	0.6	1 495.0	2 704.9
Method 63 – Use liquid/solid manure separation techniques	M63M	3.4	23 542.3	6 993.2

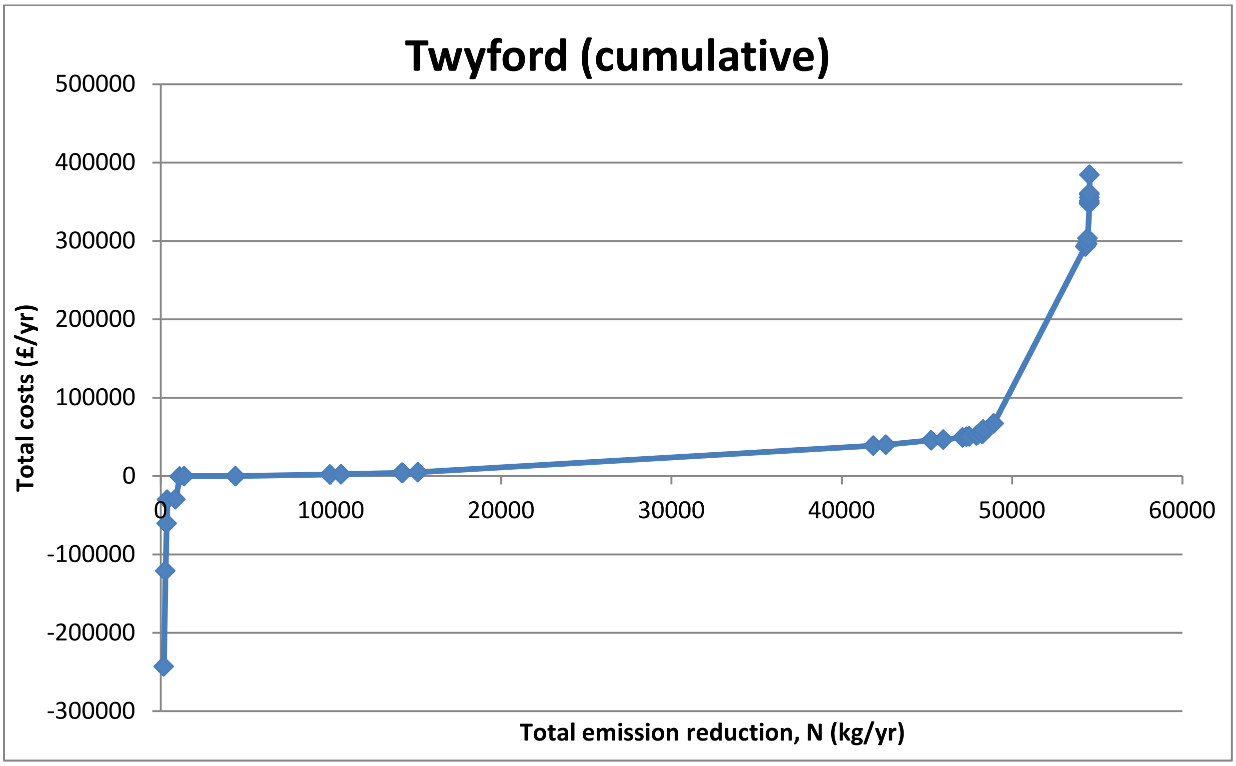
Table 5.16 Cumulative Cost Curve Data (Twyford)

ID	Measure	Total Emission Reduction, Nkg/yr	Total Annualised Costs, £/yr
M2Ar	Method 2 – Convert arable/grassland to permanent woodlands	187	-242 844
M2M	Method 2 – Convert arable/grassland to permanent woodlands	281	-120 828
M7Ar	Method 7 – Adopt reduced cultivation systems	361	-60 321
M7M	Method 7 – Adopt reduced cultivation systems	388	-30 053
M3Ar	Method 3 – Convert land to biomass cropping (i.e. willow, poplar, miscanthus)	875	-29 492
M3M	Method 3 – Convert land to biomass cropping (i.e. willow, poplar, miscanthus)	1 121	-453
M31Eq	Method 31 – Use clover in place of fertiliser nitrogen	1 385	0
M31M	Method 31 – Use clover in place of fertiliser nitrogen	4 402	0
M_aM	Manure management plan (based on advice)	9 952	2 134
M_aEq	Manure management plan (based on advice)	10 604	2 401
M67M	Method 67 – Manure spreader calibration	14 180	4 212
M68Ar	Method 68 – Do not apply manure to high risk areas	14 181	4 212
M68Eq	Method 68 – Do not apply manure to high risk areas	14 185	4 216
M68M	Method 68 – Do not apply manure to high risk areas	14 219	4 247
M28Ar	Method 28 – Use nitrification inhibitors	15 114	5 064
M28M	Method 28 – Use nitrification inhibitors	41 860	38 941
M35M	Method 35 – Reduce the length of the grazing day/grazing season	42 601	40 089
M_bM	**Fund precision farming for N**	**45 260**	**45 730**
M37M	Method 37 – Reduce field stocking rates when soils are wet	45 971	46 649
M1AAr	Method 1A – Convert arable land to unfertilised and ungrazed grass	47 103	49 371
M1AM	Method 1A – Convert arable land to unfertilised and ungrazed grass	47 328	50 279
M4M	Method 4 – Establish cover crops in the autumn	47 490	50 717
M34M	Method 34 – Adopt phase feeding of livestock	47 916	51 819
M_aAr	Manure management plan (based on advice)	47 985	52 619
M33M	Method 33 – Reduce dietary N and P intakes	48 258	53 994
M25Eq	Method 25 – Do not apply manufactured fertiliser to high risk areas	48 261	54 007
M25Ar	Method 25 – Do not apply manufactured fertiliser to high risk areas	48 261	54 009
M25M	Method 25 – Do not apply manufactured fertiliser to high risk areas	48 275	54 121
M67Ar	Method 67 – Manure spreader calibration	48 315	59 566
M74M	Method 74 – Transport manure to neighboring farms	48 932	67 219
M_fM	Undersowing autumn sown crop with fast establishing catch crop (e.g. rye grass)	54 316	292 888
M62M	Method 62 – Cover solid manure stores with sheeting	54 352	293 919
M61M	Method 61 – Store solid manure heaps on an impermeable base and collect leachate	54 411	295 983

Table 5.16 (continued) Cumulative Cost Curve Data (Twyford)

ID	Measure	Total Emission Reduction, Nkg/yr	Total Annualised Costs, £/yr
M41M	Method 41 – Reduce overall stocking rates on livestock farms	54 420	296 662
M24M	Method 24 – Reduce manufactured fertiliser application rates	54 442	303 453
M24Ar	Method 24 – Reduce manufactured fertiliser application rates	54 544	347 595
M60Eq	Method 60 – Site solid manure field heaps away from watercourses/ field drains	54 544	347 708
M60M	Method 60 – Site solid manure field heaps away from watercourses/ field drains	54 546	348 613
M60Ar	Method 60 – Site solid manure field heaps away from watercourses/ field drains	54 546	348 953
M79M	Method 79 – Farm track management	54 548	350 764
M79Ar	Method 79 – Farm track management	54 548	351 443
M_dM	Improve yard drainage system (repairs and clean water / dirty water separation - diversion away from slurry stores)	54 550	355 430
M_eM	Per farm advice cost of review of yard and drainage, track management etc.	54 551	359 416
M_eAr	Per farm advice cost of review of yard and drainage, track management etc.	54 551	360 911
M63M	Method 63 – Use liquid/solid manure separation techniques	54 555	384 453

Plate 5.6 Cost Curve – Twyford Catchment



5.2.7 Eastergate and Westergate Catchments

A load reduction of 38% is required in Newmarket catchment (Table 4.5) equivalent to about 42 tonnes of N. The catchment hosts 6 arable and mixed farms across SPZ1, SPZ2 and SPZ3 areas. The results of the initial cost-effectiveness ranking are presented in the Table 5.16 below. Data for the cumulative cost curve and the curve are presented below in Table 5.17 and the cost curve plotted in Plate 5.7. The results suggest that implementation of all the measures identified at the annual cost of £377k would result in a total N load reduction of 39 tonnes. Such reduction will be insufficient in achieving the targets set. However, increasing implementation rates of certain measures, such as land conversion to woodland or biomass cropping would offer additional potential for N load reduction.

Table 5.17 Cost-effectiveness Ranking (Eastergate and Westergate)

Measure Description	Ref	Overall Total Emission Reduction (kg)	Overall Total Annual Cost (£)	Single-Measure Cost-effectiveness (£/kg)
Method 7 – Adopt reduced cultivation systems	M7Ar	83.5	-448.2	-5.4
Method 2 – Convert arable/grassland to permanent woodlands	M2Ar	266.8	-565.9	-2.1
Method 3 – Convert land to biomass cropping (i.e. willow, poplar, miscanthus)	M3Ar	707.7	-452.7	-0.6
Method 31 – Use clover in place of fertiliser nitrogen	M31M	5 089.5	0.0	0.0
Method 67 – Manure spreader calibration	M67M	2 157.3	452.7	0.2
Manure management plan (based on advice)	M_aM	2 363.2	533.5	0.2
Manure management plan (based on advice)	M_aAr	818.3	533.5	0.7
Method 67 – Manure spreader calibration	M67Ar	661.6	452.7	0.7
Method 68 – Do not apply manure to high risk areas	M68Ar	6.4	7.4	1.1
Method 68 – Do not apply manure to high risk areas	M68M	20.2	27.4	1.4
Method 35 – Reduce the length of the grazing day/grazing season	M35M	743.2	1 371.6	1.4
Method 28 – Use nitrification inhibitors	M28Ar	3 957.6	6 288.2	1.6
Method 28 – Use nitrification inhibitors	M28M	11 782.8	19 610.8	1.7
Method 37 – Reduce field stocking rates when soils are wet	M37M	713.5	1 097.3	1.5
Fund precision farming for N	M_bM	1 785.7	4 984.8	2.8
Method 1A – Convert arable land to unfertilised and ungrazed grass	M1AAr	1 045.6	3 592.7	3.4
Method 4 – Establish cover crops in the autumn	M4Ar	140.9	504.1	3.6
Method 4 – Establish cover crops in the autumn	M4M	286.1	1 023.4	3.6

Table 5.17 (continued) Cost-effectiveness Ranking (Eastergate and Westergate)

Measure Description	Ref	Overall Total Emission Reduction (kg)	Overall Total Annual Cost (£)	Single-Measure Cost-effectiveness (£/kg)
Method 34 – Adopt phase feeding of livestock	M34M	428.1	1 316.8	3.1
Method 33 – Reduce dietary N and P intakes	M33M	247.5	1 247.9	5.0
Method 25 – Do not apply manufactured fertiliser to high risk areas	M25M	6.3	65.4	10.4
Method 25 – Do not apply manufactured fertiliser to high risk areas	M25Ar	2.0	19.2	9.5
Method 62 – Cover solid manure stores with sheeting	M62M	0.3	8.1	28.6
Undersowing autumn sown crop with fast establishing catch crop (e.g. rye grass)	M_fM	3 615.4	199 392.0	55.2
Undersowing autumn sown crop with fast establishing catch crop (e.g. rye grass)	M_fAr	1 978.6	98 208.0	49.6
Method 61 – Store solid manure heaps on an impermeable base and collect leachate	M61M	0.5	16.3	35.4
Method 24 – Reduce manufactured fertiliser application rates	M24Ar	102.2	14 713.9	144.0
Method 5 – Early harvesting and establishment of crops in the autumn - potatoes only	M5M	125.4	10 992.5	87.7
Method 60 – Site solid manure field heaps away from watercourses/ field drains	M60Ar	1.2	226.4	182.1
Method 60 – Site solid manure field heaps away from watercourses/ field drains	M60M	1.2	226.4	182.1
Method 79 – Farm track management	M79Ar	1.2	452.7	371.6
Method 79 – Farm track management	M79M	1.2	452.7	371.6
Improve yard drainage system (repairs and clean water/ dirty water separation - diversion away from slurry stores)	M_dM	1.2	996.6	834.7
Per farm advice cost of review of yard and drainage, track management etc.	M_eAr	1.2	996.6	834.7
Per farm advice cost of review of yard and drainage, track management etc.	M_eM	1.2	996.6	851.7
Method 63 – Use liquid/solid manure separation techniques	M63M	3.4	5885.6	1 710.8

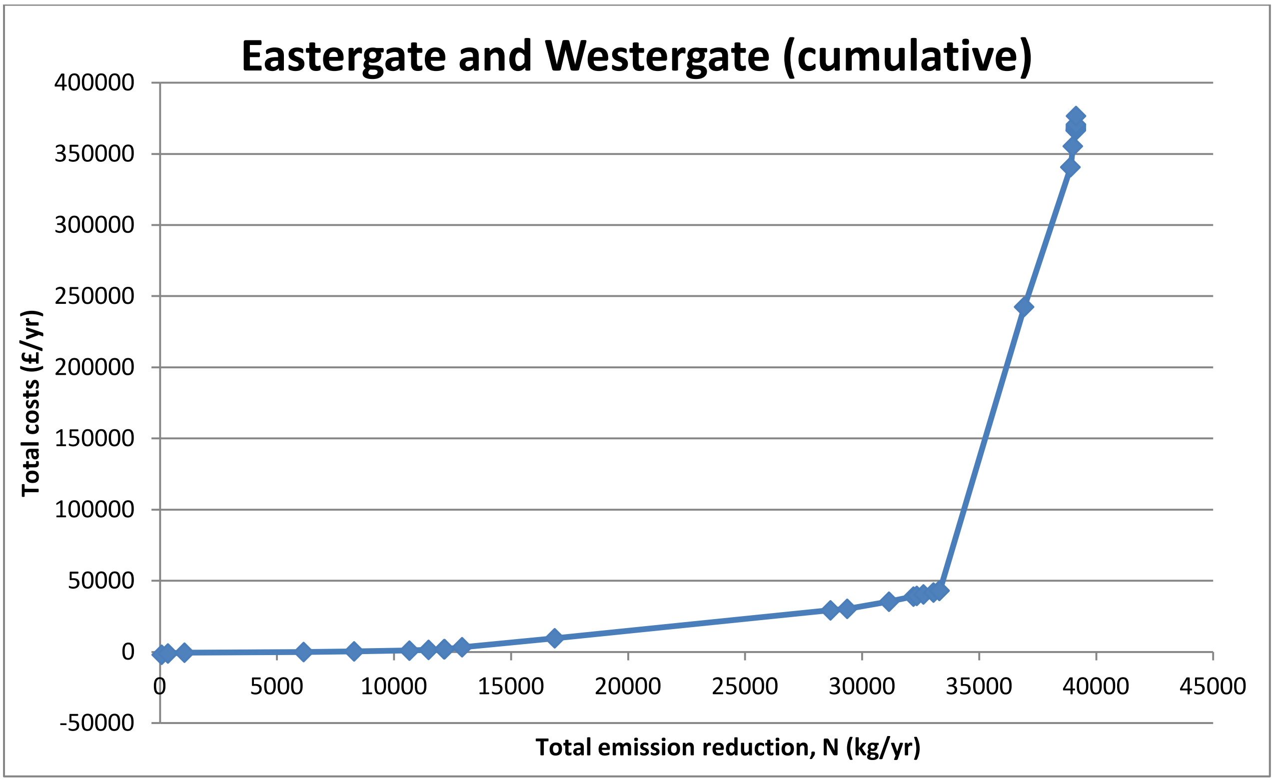
Table 5.18 Cumulative Cost Curve Data (Eastergate and Westergate)

ID	Measure	Total Emission Reduction, Nkg/yr	Total Annualised Costs, £/yr
M7Ar	Method 7 – Adopt reduced cultivation systems	84	-1 920
M2Ar	Method 2 – Convert arable/grassland to permanent woodlands	350	-1 019
M3Ar	Method 3 – Convert land to biomass cropping (i.e. willow, poplar, miscanthus)	1 058	-453
M31M	Method 31 – Use clover in place of fertiliser nitrogen	6 148	0
M67M	Method 67 – Manure spreader calibration	8 305	453
M_aM	Manure management plan (based on advice)	10 668	986
M_aAr	Manure management plan (based on advice)	11 486	1 520
M67Ar	Method 67 – Manure spreader calibration	12 148	1 972
M68Ar	Method 68 – Do not apply manure to high risk areas	12 154	1 980
M68M	Method 68 – Do not apply manure to high risk areas	12 175	2 007
M35M	Method 35 – Reduce the length of the grazing day/grazing season	12 918	3 379
M28Ar	Method 28 – Use nitrification inhibitors	16 875	9 667
M28M	Method 28 – Use nitrification inhibitors	28 658	29 278
M37M	Method 37 – Reduce field stocking rates when soils are wet	29 372	30 375
M_bM	Fund precision farming for N	31 157	35 360
M1AAr	Method 1A – Convert arable land to unfertilised and ungrazed grass	32 203	38 953
M4Ar	Method 4 – Establish cover crops in the autumn	32 344	39 457
M4M	Method 4 – Establish cover crops in the autumn	32 630	40 480
M34M	Method 34 – Adopt phase feeding of livestock	33 058	41 797
M33M	Method 33 – Reduce dietary N and P intakes	33 305	43 045
M25M	Method 25 – Do not apply manufactured fertiliser to high risk areas	33 312	43 110
M25Ar	Method 25 – Do not apply manufactured fertiliser to high risk areas	33 314	43 129
M62M	Method 62 – Cover solid manure stores with sheeting	33 314	43 137
M_fM	Undersowing autumn sown crop with fast establishing catch crop (e.g. rye grass)	36 929	242 529
M_fAr	Undersowing autumn sown crop with fast establishing catch crop (e.g. rye grass)	38 908	340 737
M61M	Method 61 – Store solid manure heaps on an impermeable base and collect leachate	38 908	340 754
M24Ar	Method 24 – Reduce manufactured fertiliser application rates	39 011	355 468
M5M	Method 5 – Early harvesting and establishment of crops in the autumn - potatoes only	39 136	366 460
M60Ar	Method 60 – Site solid manure field heaps away from watercourses/ field drains	39 137	366 686
M60M	Method 60 – Site solid manure field heaps away from watercourses/ field drains	39 138	366 913
M79Ar	Method 79 – Farm track management	39 140	367 366

Table 5.18 (continued) Cumulative Cost Curve Data (Eastergate and Westergate)

ID	Measure	Total Emission Reduction, Nkg/yr	Total Annualised Costs, £/yr
M79M	Method 79 – Farm track management	39 141	367 818
M_dM	Improve yard drainage system (repairs and clean water/dirty water separation - diversion away from slurry stores)	39 142	368 815
M_eAr	Per farm advice cost of review of yard and drainage, track management etc.	39 143	369 812
M_eM	Per farm advice cost of review of yard and drainage, track management etc.	39 144	370 808
M63M	Method 63 – Use liquid/solid manure separation techniques	39 148	376 694

Plate 5.7 Cost Curve – Eastergate and Westergate Catchments



5.2.8 Environmental and Social Costs

To assess the total economic costs of potential measures, environmental and social costs also need to be considered.

Carbon Impacts

The measures considered including land use changes and farm infrastructure development are likely to result in the relative changes in associated carbon emissions. Quantification and monetisation of such impacts has not been carried out due to the lack of detailed information on the anticipated change in the emissions.

Traffic Related Impacts

Some of the engineering options considered, e.g. construction of additional manure storage facilities, could be associated with Heavy Goods Vehicle (HGV) movements. These can potentially create issues with congestion, noise, increased risk of traffic accidents, disruptions of pedestrians and cyclists. While as a rule of thumb, congestion should not be a problem in rural areas, urban roads could be also affected as part of the trip leading to some economic costs of delays, e.g. due to queues as a result of lane closure.

Where an option results in significant levels of HGV movements, it may also give rise to local externalities[2], mainly related to air pollution. For rural roads, the "green" component of fuel excise in essence covers the economic value of the externalities, therefore the net additional costs are effectively zero.

While the proposed works will result in part of the site or the whole site being temporarily cordoned off, given that the area affected is very sparsely populated with very few households in the vicinity, the number of potentially affected pedestrians is likely to be very low. Furthermore, it can be assumed that suitable alternative routes/diversions would be put in place so that pedestrian and cyclists would not be unduly delayed by any works.

Landscape, Heritage and Archaeology Impacts

The measures considered could result in temporary and/or permanent impacts on the landscape, associated, for instance, with land use change or construction of manure storage facilities, although the impact of land-use change may be positive where it is implemented in line with the SDNP Landscape Character Assessment (State of the National Park, SDNP Authority, 2012). The social costs associated with alternative measures will depend on the original quality of the landscape, characteristics of the visual change and degree of the measure's intrusiveness and the number of the local residents and users affected (i.e. to whom the change in the landscape will potentially be visible).

[2] As defined in the EA (2003) "an externality is said to exist when the actions of one individual affect the well-being of other individuals, without any compensation taking place through the market". For example, a discharge of toxic substances in a water course used for drinking water abstraction would constitute a negative externality to abstractors to the extent that they would incur additional (and not compensated for) costs associated with additional treatment. In the case of air pollution, it can causes damage to public health, crops and buildings.

Property Disamenity Impacts

Property related disamenity impacts are associated with additional odour, noise and general nuisance. The Code of Good Agricultural Practice (Defra, 2006), among other documents, suggests adapting agricultural practices by considering the likely impacts on the neighbouring properties. Changes to landscape potentially affect drainage, increasing the risk of property or land flooding where this aspect is not considered. However, the measures considered here are more likely to benefit the landscape through increased water retention rather than encouraging run-off.

5.3 Benefits

5.3.1 Identification of Benefits

Identification of anticipated benefits associated with the reduced nitrogen load and improved groundwater status was carried out using the Environment Agency's draft "Groundwater Appraisal Guidance" (Environment Agency, 2013). The relevance and the impact of anticipated groundwater quality improvements on provisioning, regulatory, cultural and supporting ecosystem services was considered and presented in the table below.

Table 5.19 Ecosystem Services Benefits

Category	Impacts of N Load Reduction in South Downs NP	Applicability
Provisioning Services		
Fresh water	Increased availability or reduced costs	Yes
Food (e.g. crops, fruit, fish etc.)	Relevant if surface water quality or quantity improves	Uncertain (unless feeding transitional waters)
Fibre and fuel (e.g. timber, wool, etc.)	Relevant if GW required for growing biofuels and energy crops	Uncertain unless biofuels are grown as a measure
Genetic resources (used for crop/stock breeding and biotechnology)	No significant impacts expected	No
Biochemicals, natural medicines, pharmaceuticals	No significant impacts expected	No
Ornamental resources (e.g. shells, flowers, etc.)	No significant impacts expected	No
Water for non-consumptive use (energy harvesting)	No significant impacts expected	No
Regulatory Services		
Air Quality regulation	Relevant if positive changes occur to woodlands or other pollution absorbers	Yes
Climate regulation (local temperature/ precipitation, greenhouse gas sequestration)	Relevant if: Additional sink for CO_2, directly or from GW dependent surface waters (e.g. wetlands) Sink or source of geothermal energy	Yes
Water regulation (timing and scale of run-off, flooding, etc.)	Relevant if measures result in GW or surface water levels change leading to a reduced risk of flooding or droughts or reduced risk from GW flooding	Land-use change measures should encourage water retention and other measures will not affect drainage.

Table 5.19 (continued) Ecosystem Services Benefits

Category	Impacts of N Load Reduction in South Downs NP	Applicability
Natural hazard regulation (i.e. storm protection)	Relevant if results in reduction of risk of subsidence, earthquake etc.	No
Pest regulation	No significant impacts expected	No
Disease regulation	No significant impacts expected	No
Erosion regulation	No significant impacts expected	Uncertain (could apply where soil structure improvements are made)
Water purification and waste treatment	Improved ability of GW to dilute/ attenuate pollutants Reduction in materials and energy to build/run treatment works	Yes
Pollination	no significant impacts expected	No
Noise and Light regulation	no significant impacts expected	No
Cultural Services		
Cultural heritage	No significant impacts expected	No
Recreation and tourism	Relevant if surface water quality or quantity improves leading to improved informal (walking), in-stream (boating) or immersive (swimming) recreation and where measures include reversion to traditional landscapes of the South Downs.	Yes
Aesthetic value	Relevant if there is an impact on maintaining quality or flow of surface water	Yes where feed into transitional waters
Spiritual and religious value	No significant impacts expected	No
Intellectual and scientific, educational	No significant impacts expected	No
Inspiration of art, folklore, architecture, etc	No significant impacts expected (although where measures include reversion to traditional landscapes of the South Downs this could increase)	Uncertain
Social relations (e.g. fishing, grazing or cropping communities)	No impacts expected	No
Supporting Services		
Soil formation	No significant impacts expected	No
Primary production (in river)	No significant impacts expected	No
Nutrient cycling	Retention and dilution of pollutants (not to be assessed separately as double counting with water purification)	No
Water recycling	Retention of water, drainage etc. (not to be assessed separately as double counting with water regulation)	No
Photosynthesis (production of atmospheric oxygen)	No significant impacts expected	No
Provision of habitat	Improvements to GW dependent habitats and biodiversity (fish, animals, insects, plants)	Yes

5.3.2 Assessment of Benefits

A range of unit values are available to monetise benefits associated with relevant ecosystem services. Quantification and monetisation of these benefits require the ability to estimate the physical volume affected by the change in groundwater quality, such as volume of water affected, number of households or hectares per year (Table 5.20). Some of the benefits are measure specific and Table 5.21 provides a discussion on measure specific details.

Table 5.20 Ecosystem Services Benefits

Category		Unit Values (2013/2014 Prices)	Comments	Source
Fresh water	Water and wastewater treatment savings from direct abstraction	0.44	per m3. Long run MC for water companies	Vanner (2008)
	Water and wastewater treatment savings from direct abstraction, high	0.90	per m3. Marginal values from SG for abstraction and treatment of water for households	UK NES (2011)
	Water and wastewater treatment savings from direct abstraction, low	0.14	per m3. water replacement costs	Hardistry and Ozdemiroglu (2002)
	Savings to industry, high	0.51	per m3. direct industrial abstraction (market price of alternative supply)	Jacobs Gibb (2002)
Air Quality regulation	Nox	1 013	per tonne	ICGB/Defra 2011
	Sox	1 733	per tonne	ICGB/Defra 2012
	Ammonia	2 092	per tonne	ICGB/Defra 2013
	PM rural	15 959	per tonne	ICGB/Defra 2014
Climate regulation (local temperature/ precipitation, greenhouse gas sequestration)	Carbon price non-traded	60.48	per tonne CO2eq	DECC (2011)
Provision of habitat	Improvements to a GW dependent wetland: inland marsh	3 738	per ha per year. Caution combining with other values	Brander et al (2008)
	Improvements to a GW dependent wetland: peat bog	194	per ha per year. Caution combining with other values	Brander et al (2008)
	Improvements to a GW dependent wetland: salt marsh	5 191	per ha per year. Caution combining with other values	Brander et al (2008)
	Improvements to a GW dependent wetland: intertidal mudlflats	3 723	per ha per year. Caution combining with other values	Brander et al (2008)
	Avoid 10% decrease of up to 10 birds and plant species	28.97	per hh/year	Garrod et al (2001)
	Avoid 5% decrease of up to 10 birds and plant species	6.90	per hh/year	Garrod et al (2001)
	Avoid a small decrease in river flows	6.90	per hh/year	Garrod et al (2001)
	WTP to maintain or improve flow in 40 low flow rivers in England	21.12	per hh/year	Willis & Garrod (1995)

Table 5.21 Anticipated Benefits Per Measure

Method	Anticipated Benefits
Method 1A – Convert arable land to unfertilised and ungrazed grass	Improved soils as grassland should help to prevent erosion reducing sediment run-off to rivers. Carbon emissions reduction (with time there will be a reduction in use of vehicles). Reduction in residual N and other nutrients and better water retention with less run-off.
Method 1B – Arable reversion to low fertiliser input extensive grazing	Improved soils as grassland should help to prevent erosion reducing sediment run-off to rivers.
Method 2 – Convert arable/grassland to permanent woodlands	Reduced emissions through less vehicle use and uptake of carbon through tree respiration. Native tree planting – positive. Positive if links with SDNP landscape character assessment (LCA) (A way of classifying, mapping and describing the characteristics of a landscape – provides a framework within which imp elements of the landscape can be maintained, change can be managed and environmental benefits delivered.
Method 3 – Convert land to biomass cropping (i.e. willow, poplar, miscanthus)	Native tree planting – positive. But effectiveness likely to be affected by location. Willow / popular difficult to grown on thin chalk soils.
Method 4 – Establish cover crops in the autumn	Some evidence suggests benefits to birds, plants or invertebrates in response to reducing grazing intensity on permanent grassland (including seasonal removal of livestock).
Method 5 – Early harvesting and establishment of crops in the autumn	Some evidence suggests benefits to birds, plants or invertebrates in response to reducing grazing intensity on permanent grassland.
Method 6 – Cultivate land for crops in spring rather than autumn	Reduced risk of surface runoff/soil erosion/elevated river sediment yield.
Method 7 – Adopt reduced cultivation systems	Especially good for light soils. Reduces fuel consumption and soil compaction (which generates surface runoff production). More favourable for winter crops because seedbed quality is less important – i.e. winter oil seed rape, winter wheat which is dominant in many areas. Environmental benefit – inc in population of beneficial insects (beetles, wasps). Environmental impact – tendency for slug population to increase so potential for more pesticide use i.e. metaldehyde.
Method 24 – Reduce manufactured fertiliser application rates	Reduction in emissions – fewer deliveries of bagged fertiliser.
Method 28 – Use nitrification inhibitors	Reduce losses.
Method 31 – Use clover in place of fertiliser nitrogen	Benefits in crop rotation systems, in addition to furnishing nitrogen for succeeding crops, improves soil tilth, also creates root channels which benefit subsequent crops grown in rotation with clovers or clover/grass mixtures. Increase populations of beneficial predatory insects. Better forage quality, increased forage yield.
Method 61 – Store solid manure heaps on an impermeable base and collect leachate	Re-use of nutrients and reduction in diffuse losses.
Method 67 – Manure spreader calibration	Fewer inputs used; less nutrient loss.
Method 74 – Transport manure to neighboring farms	Spread of nutrients to areas of need; increase soil organic material [with associated benefits].

In particular land-use change measures M1A, M1B and M2 can bring about additional benefits linked to habitats provision as well as significant reductions in nitrate loading.

Chalk Grassland vs Arable Cropping (Method 1A)

Chalk grassland (both upland and lowland) are priority UK BAP habitats that typically support a diverse range of flowering plants and associated insect species that are often not found in other habitats. There is around 41 000ha of lowland chalk grassland and 21 000 ha of upland chalk grassland in Britain. Both habitats have suffered as a result of agricultural intensification. Chalk grassland is typically managed by sheep grazing, with no artificial fertilizer inputs and brings many benefits to a wide range of receptors when compared to arable cropping (with or without fertilizer inputs). Key benefits can be summarized as follows:

- Nature conservation – significant biodiversity value, BAP habitat and associated plant and insect species, many of which are only found within this habitat. By comparison arable has a very low biodiversity value;
- Aesthetic/landscape value – chalk grassland is rich in flowering plants and has significant aesthetic/landscape value in publicly accessible areas. By comparison arable has a low aesthetic/landscape value;
- Rainfall and sediment run-off – chalk grassland typically occurs on dry valley slopes. Retention of grassland habitat in these situations will slow the rate of rainfall run-off, and also limit/prevent sediment mobilization, relative to that likely from areas used for arable cropping;
- Climate change mitigation – data relating to the carbon storage potential of chalk grassland are limited but AMEC (2014)[3] suggests that, on average, chalk grassland stores more carbon per hectare than arable, and hence makes a greater contribution to climate change mitigation than arable cropping.

Improved Pasture/Grassland vs Arable Land (Method 1B)

Pasture can encompass a wide range of grassland types, from almost mono-culture improved[4] grassland to semi-improved[5] or even unimproved[6] areas of grassland. However, it has been assumed here that managed pasture comprises either improved or semi-improved grassland (i.e. receiving fertiliser applications). It is considered that the benefits of managed pasture relative to arable land are similar to those outlined above for chalk grassland relative to arable land although they would typically not be as significant. The benefits of managed pasture relative to arable cropping can be summarized as follows:

- Nature conservation – managed pasture would be expected to support a wider range of plant and animal species, and hence have greater biodiversity value, than arable land, although the difference between the two will depend on the character of the grassland under consideration;
- Aesthetic/landscape value – managed pasture, which will typically be grazed by cows/sheep and/or cut for silage/hay is considered to likely have greater aesthetic/landscape value that arable cropped land in publicly accessible areas. However, as indicated above, the relative benefit will depend on the character of the grassland under consideration;

[3] AMEC (2014). Spatial Prioritisation of Land Management for Carbon. Report for Natural England.

[4] Agriculturally improved as a result of a combination of application of fertiliser, slurry, intensive grazing, herbicides or drainage.

[5] Some agricultural improvement, leading to reduced species diversity.

[6] No agricultural improvement.

- Rainfall and sediment run-off – managed pasture will slow the rate of rainfall run-off, and also limit/prevent sediment mobilization, relative to that likely from areas used for arable cropping;

- Climate change mitigation – data relating to the carbon storage potential of grasslands are limited but AMEC (2014)[7] suggests that, on average, grassland/pasture stores more carbon per hectare than arable, and hence makes a greater contribution to climate change mitigation than arable cropping.

Low Cultivation Methods (Tilling vs No Tilling) (Method 7)

Tilling is the agricultural preparation of soil by mechanical agitation of various types, such as digging and ploughing. Growing crops without tilling the soil is reported to have a number of benefits for the environment relative to growing crops including the use of tilling. The key benefits of correct application of a no-tilling approach relative to a tilling approach can be summarised as follows:

- Nature conservation – a no-till approach can lead to an increase in the biodiversity of the area as a result of improved cover, reduced traffic and the reduced chance of destroying ground nesting birds and animals;

- Soil structure - a no-till approach leaves the soil intact and crop residue on the field. Therefore, soil layers, and in turn soil biota, are conserved in their natural state. It is considered that field under a no-till regime have more beneficial insects and worms, a higher microbial content, and a greater amount of soil organic material;

- Rainfall and sediment run-off – fields under a no-till approach typically hold more water than tilled fields, resulting in a positive effect on plant growth rates but also in the reduction of run-off rates through improved infiltration. Additionally, there is less sediment mobilized from no-tilled fields during rainfall events that is the case for tilled land;

- Climate change mitigation – fields under a no-till approach can be expected to store more carbon than fields that are tilled. When fields are tilled (ploughed) the soil layers are turned over, air mixes in, and soil microbial activity increases relative to non-tilled soils. The result of tilling is that soil organic matter is broken down much more rapidly, and carbon is lost from the soil into the atmosphere. This, in addition to the emissions from the farm equipment used for the tilling process, increases carbon dioxide levels in the atmosphere.

5.4 Summary

5.4.1 Costs

The cost curves developed suggest that implementation of the measures considered would allow achievement of the required reduction in all the catchments with the exception of the Eastergate and Westergate catchment. The required reduction is to keep nitrate concentrations below the DWS between the current day and the point at which the maximum historic nitrate concentrations have passed through the unsaturated zone. This assessment is based on the assumption that the reduction will be achieved through faster flowpaths feeding the abstraction (i.e. that historic matrix porewater can be diluted through fissure flow to some extent.

[7] AMEC (2014). Spatial Prioritisation of Land Management for Carbon. Report for Natural England.

The results of the cost-effectiveness assessment are presented in Table 5.22 below.

Table 5.22 Results of the Cost-Effectiveness Assessment

Catchment	Overall Total Annualised Cost of all the measures identified (£)	Overall Total Emission Reduction available (t/yr)	Required Emission Reduction (per cent)	Required Emission Reduction (N t/yr)	Annualised costs of Achieving required Reduction
Patcham	£10 334	0.5	0%	0	n/a*
Findon	£74 748	7.0	39%	5.4	£5 984
Housedean	£48 373	4.0	12%	0.9	£0
Lovedean	£160 941	19.2	22%	10.2	£14 376
Newmarket	£84 543	9.6	15%	3.2	£453
Twyford	£384 453	54.6	29%	43	£45 730
Eastergate and Westergate	£376 694	39.1	38%	42	Measures identified at the annualized costs of £377k insufficient to reach the required reduction

*Not applicable as measures are not required at Patcham to manage nitrate concentrations.

In all the catchments (with the exception of the Patcham catchment where no reduction is required) land use change related measures such as conversion of arable land or grassland to permanent woodlands or biomass cropping appear to be among the most cost-effective measures. Other cost-effective measures include adoption of the reduced cultivation systems, use of clover in place of fertilizer nitrogen, development of manure management plan and avoidance of application of manure or fertilizer to high risk areas (assumed to be 1% of arable land (fertilizer) or arable and grassland (manure)). Measures aimed at improving manure application efficiency, such as manure spreader calibration and practicing precision farming also appear to have a high cost-effectiveness ratio.

5.4.2 Benefits

The qualitative assessment suggests that improvements in the groundwater quality as a result of N load reduction are likely to result in benefits associated with provisioning, regulatory, cultural and supporting ecosystem services and, in particular, in benefits to fresh water, air quality regulation and climate regulation as well as to provision of habitats. For instance, improvements in source water quality would result in financial savings to water companies and private abstractors due to reduced water treatment needs and can be quantified and monetised by assessing the abstraction volume affected. The beneficial impact on climate regulation could be estimated based on the carbon value of £60.48 per tonne of CO_2eq. However, this would require quantitative estimates of the tonnes of carbon saved. Similarly, monetary assessment of the benefits to habitat provision would require a detailed and quantitative understanding of anticipated changes to relevant and dependent habitats that could not be provided.

Abstraction related benefits associated with the reduced nitrate loading are presented in Table 5.23 below. These are based on typical abstraction rates and unit values of benefits to water companies of 0.44 m^3 and 0.16 m^3 (low estimate). Clearly the potential costs to water companies through raw water treatment to remove nitrate outweighs the potential measures which could be compensated to achieve reductions with time.

Table 5.23 Abstraction Related Benefits to Water Companies

Source Name	Abstraction Rates (ML/d)*	Abstraction Rates (m3/year)*	Annual Savings to Water Companies, £	Annual Savings to Water Companies, Low, £
Eastergate and Westergate combined	15.5	5 661 375	2 491 005	323 831
Findon	7	2 556 750	1 124 970	146 246
Housedean	5	1 826 250	803 550	104 462
Lovedean	4	1 461 000	642 840	83 569
Newmarket	12	4 383 000	1 928 520	250 708
Patcham	9	3 287 250	1 446 390	188 031
Twyford	20	7 305 000	3 214 200	417 846

6. Summary

The aim of this study was to produce compelling evidence in support of existing or new initiatives which will deliver groundwater quality improvements through sustainable land management in the South Downs Way Ahead NIA. The initiatives include catchment management schemes (e.g. through CSF partnerships or water company funded actions), environmental stewardship schemes, voluntary changes to land-management and enforcement by the Environment Agency. The investigation used nitrate source apportionment, risk mapping and trend modelling at different scales of catchment to build up a set of potential actions which could be implemented to improve groundwater quality. The potential actions or measures identified for individual PWS abstractions have also been assessed economically to produce nitrate cost-curves which identify the most cost-effective measure per abstraction.

Catchment Scale Source Apportionment

Source apportionment of nitrate over 17 GWBs linked to the South Downs National Park NIA and contained within the South East River Basin District indicates the following:

- Nitrate contributions are mainly sourced from agricultural land and for most catchments wheat, winter oil seed rape, cereals and grassland (grazed, cut and temporary receiving fertiliser inputs) make up the bulk of the nitrate budget. Mains water and sewer leakage can also provide significant proportions of nitrate where the population density is high, although most of these areas are close to the coast and groundwater from these areas will potentially discharge to the sea;

- The uncertainty in the inputs from landfill can be high, and the source apportionment tool is sensitive to this input (due to the high loading term). The Brighton Chalk, A&WS Lower Greensand, East Hants Secondary, Test and Itchen Secondary and the New Forest Secondary GWBs all have a >10% contribution from Landfill. The landfill term for these catchments should be refined further to reduce the uncertainty in the source apportionment outputs before actions based on the outputs are finalised;

- Denitrification is likely to occur in the C&PL Lower Greensand and Adur and Ouse Lower Greensand, and is confirmed in the C&L Secondary, A&O Secondary, A&WS Secondary, Test and Itchen Secondary and the IOW Lower Greensand. The occurrence of the phenomena is likely to depend on the presence of impermeable strata and so will be variable. However, the attenuation of groundwater nitrate concentrations produced by denitrification suggests that further management of nitrate leaching should not be the greatest priority for water quality in these catchments;

- Predicted concentrations leaving the soil zone at the current day exceed the WFD threshold in the Brighton Chalk, C&PL Lower Greensand, Adur and Ouse Lower Greensand, A&WS Lower Greensand, East Hants Secondary and Test and Itchen Secondary GWBs. Denitrification in the Secondary and Lower Greensand GWBs will mean that these predicted values are likely to over-estimate the actual future average nitrate concentration. The Brighton Chalk GWB should be given the greatest priority for actions to reduce nitrate concentrations;

- Where a GWB has a baseflow index greater than 50% i.e. the Chalk and the Adur and Ouse Secondary GWBs may contribute significantly to nitrate in transitional waters where nitrate is the rate limiting nutrient for eutrophication.

Nitrate Risk Mapping

Nitrate risk maps were developed to enable end-users to identify at the GWB or larger catchment scale the areas of high risk of nitrate leaching based on depth to water table (for the Chalk), N loading, solution features mapping and drift cover type. This mapping combined with the source apportionment outputs suggests that the main focus of actions should be areas of aquifer with no superficial cover, high N loading from agricultural cropping (wheat, oil seed rape and grassland receiving fertiliser inputs) and where there are high concentrations of solution features. In particular advice on more efficient use of N through precision farming, or a simpler approach of soil/ nutrient management planning and fertiliser calibration, with advice on the location of solution features could help to reduce nitrate loading. In the Test and Itchen Chalk GWBs, the whole area is at high risk due to the aquifer being at outcrop with intensive arable farming (although source apportionment predicted values are around the same as observed) and it would be difficult to see what effective (in terms of uptake) catchment scale actions could be put in place where arable farming is such a large part of the economy.

Groundwater Safeguard Zone and River Lavant Nitrate Trend Modelling and Source Apportionment

Nitrate source apportionment and trend modelling has been carried out for 10 Safeguard Zone catchments to PWS abstractions and for the River Lavant (Sussex). Catchments were delineated to the Twyford, Lovedean, Westergate and Eastergate sources using the regional groundwater models and the Flowsource programme. The Findon, Burpham, Patcham, Newmarket, Housedean and Mossy Bottom catchments were based on SPZ2 to the sources as a complete Brighton and Worthing groundwater model was not available at the time of modelling. The catchment to the River Lavant was based on the WFD catchment to this water body.

Source apportionment identified the main sources of nitrate contributing to the groundwater abstractions and baseflow to the Lavant were wheat, improved grazed and cut grassland, oil seed rape, woodland (at Eastergate and Westergate where this covers 44% of the catchment) and landfill (River Lavant). There is some uncertainty in the land-use inputs for smaller catchments such as Mossy Bottom, Housedean and Findon where the catchment area is close to the gird square of the agricultural census data, or where Land Cover 2007 mapping appears to differ from aerial photos from 2007. Predicted average nitrate concentrations currently leaving the soil zone over the modelled catchment area are typically close to (e.g. Newmarket and Patcham) or less than the current observed average nitrate at the abstraction points for 2010-2013. The predicted values are expected to be different to the observed concentrations, as there will be a travel time between the soil zone and abstraction point. These values suggest that if the land use and assumed application rates (based on farm records) are maintained then future concentrations at most abstractions will reduce below the DWS and the WFD threshold value. However, uncertainty in land-use mapping and agricultural census data means that these values should be treated with caution for smaller catchments.

Nitrate trend models were produced for the ten Safeguard Zones and the River Lavant, with a good model fit produced at most catchments. Adjustments for Chalk moisture content, re-mapping of land-use based on aerial photos of catchments and additional dilution from river water at Burpham were made. Poor model fit was achieved at Mossy Bottom, the River Lavant and Burpham and further assessment of these sites was not made. At Housedean a better model fit was made based on land-use adjustment, but this adjustment should be confirmed by a catchment walkover, and further assessment at this site is less certain than at other abstractions.

One of the aims of the nitrate trend modelling exercise was to predict any future exceedance of the WFD threshold value for nitrate (37.5 mg/l NO_3) and of the DWS. Based on observed and predicted concentrations the WFD threshold is already achieved at Eastergate, Westergate and Patcham, whilst at Twyford, Findon and Housedean even a theoretical 100% reduction in leaching would not achieve the threshold value prior to 2032, although it could at Newmarket. A 40-60% reduction nitrate leaching over the Lovedean catchment is predicted to reduce concentrations below the threshold value by 2032.

Seasonal peaks in nitrate concentration which exceed the DWS could be controlled at Lovedean with a 60-70% reduction over the whole catchment. At other abstractions even a theoretical 100% reduction in nitrate leaching would not bring predicted peak concentrations below the DWS. The timing and likely magnitude of future exceedances for all catchments has been identified from the average age of water in the unsaturated zone and the historic maximum in nitrate application rates (arable land 1985 and improved grassland 1990). As whole catchment scale reductions at the level required from trend models will be un-achievable (due to lack of uptake and technical infeasbility of 100% reduction) measures development focused on the timing of the impact of maximum nitrate concentrations to be seen and the likely magnitude of exceedances (as a required reduction). The assumption being that implementing measures closer to the abstraction points will help to manage nitrate sourced from faster flow-paths (i.e. fissure flow and/or non-matric flow). Assuming that future leaching does not change from the current day, for most catchments maximum nitrate concentrations will be seen over a five year period between 2023 and 2044, with the frequency of DWS exceedance greatest in this period.

Safeguard Zone Recommended Measures and Cost Benefit Assessment

Measures to improve address the nitrate concentrations at each of the modelled catchments with a good fit have been identified as follows:

Point Sources - It is suggested that point sources are dealt with in all catchments as part of good agricultural practise including improving farmyard drainage, manage manure heap to minimise N leaching, identify the location of solution features and the higher risk of nitrate leaching to land with thin soils to land-owners.

Diffuse Sources – As application of measures to address diffuse pollution will be unfeasible over the whole catchment, measures have been designed and assessed further in a staggered approach, with high impact measures applied closer to the abstraction points, and lower impact but less disruptive measures located in areas of the catchment where contribution to the abstraction is still significant. At most sources this is SPZ1 and SPZ2, for the Flowsource modelled catchments these zones have been defined based on a 50 day travel time (Inner Zone), a zone of significant contribution (Outer Zone) and the total catchment. Inner zone measures include arable land reversion to low input chalk grassland/pasture or woodland/biomass, whilst outer zone measures include: controlling how much N is applied through precision farming, manure/fertiliser spreader calibration, not spreading additional N over shallow soils (against NVZ advice, although farm records suggest this is not being taken up anyway); and controlling when N is available to leach through extending closed periods into February (when crop starts to grow); control the amount and timing of N application from grazing cattle; controlling the amount and timing of manufactured N/organic N applications.

The costs of each measure has been calculated based on costs from the Defra DPI Manual (Defra 2010) with costs inflated to 2014 prices and from other sources where not directly linked to a measure in the Manual. The application of measures over the catchment has been costed in £ per Kg N/ha reduction and is presented as a cost-curve which allows the identification of the most cost-effective measures. The benefits of each measure (social and economic) have also been assessed qualitatively and quantitatively where possible. The outcomes of this assessment suggest that:

- The most cost-effective measures appear to be related to land-use conversion from agricultural land to permanent woodland or biomass cropping. Reduced cultivation systems, use of clover in place of nitrogen in pasture, manure management plans, using precision farming techniques and spreader calibration also have high cost – effectiveness ratios.;

- The benefits of proposed measures include the provisioning of: clean water, habitats (terrestrial and transitional waters), air quality improvements, climate regulation, water retention, recreation and tourism and aesthetic value;

- In the assessed catchments the cost savings of implementing measures for water companies appear to be very significant, however, the achievable reductions and the time scale for achieving these is dependent on the mechanisms controlling rapid flow through the unsaturated and saturated zones.

The costs of each measure and the area of application required to retain nitrate below the DWS are uncertain, due to the resolution of data sets, the uncertainty in farm extents and actual application rates. Any implementation of measures should be carried out with a programme of review of effectiveness through uptake and monitoring of the impact on groundwater at the abstraction, and potentially upstream beneath fields (using porous pot data or precision farming results) or coring of the unsaturated zone to monitor the impact of measures.

Further Model Improvements

In carrying out this investigation further improvements to the model inputs could help to refine the model outputs and increase confidence in the actions based on the models. The recommended improvements include:

- Refinement of the landfill term for GWBs, although this should not stop implementation of measures where the landfill term is less significant or better understood;

- Catchment walkovers and farm visit information to improve model outputs and to form part of a baseline monitoring programme for use during the following measures assessment period.

7. References *(to be completed for final version)*

AMEC, 2010. Cumulative Nitrate and Phosphorous Loadings to Groundwater, AMEC Report (27510rr32i3)) to the Scottish Environment Protection Agency, the Environment Agency of England and Wales and the Northern Ireland Environment Agency.

Anthony S, Quinn P, Lord E, 1996. Catchment scale modelling of nitrate leaching. Aspects of Applied Biology, 46, 23-32.

Defra, 2010. Diffuse Pollution Inventory (DPI) User Manual.

Defra, 2010. Fertiliser Manual RB209.

Environment Agency, 2009. South East River Basin Management Plan

Marsh T J and Hannaford J, (Eds), 2008. UK Hydrometric Register. Hydrological data UK series. Centre for Ecology & Hydrology. 210 pp.

Rodda H J E, Scholefield D, Webb B W and Walling D E, 1995. Management model for predicting nitrate leaching from grassland catchments in the United Kingdom: 1. Model development. Hydrological Sciences, 40, 4, 433-451.

References for Solution Features in Risk Mapping

Robins N S, Buckley D, Darling W G, Dance L, Dumpleton S, Evans D J, Hargreaves R L, Jones H K, McCann L, Mathias S A, 2001. 3-D Conceptualisation of the Central South Downs Aquifer (Commissioned Report No. CR/01/154). British Geological Survey.

University of Brighton FLOOD1 project - Patcham_Map2.jpg

Appendix A
N&P Source Apportionment Spreadsheet

Non-agricultural Sources and Agricultural Point Sources

The calculation of nitrate loadings from non-agricultural sources is based on assumed nitrate concentrations in recharge or loadings from each source, which are based on the findings of the literature review undertaken during the original 2010 project. Recharge volumes are based on catchment hydrological data or estimated on the basis of, for example, catchment population. In some cases, it is assumed that some attenuation of nitrate will occur in the unsaturated zone, and this is based on the literature review. The relevant spreadsheet parameters are summarised in Table A.1. If more detailed data are available for a particular catchment, the spreadsheets may be refined by changing the relevant model parameters. In most cases, however, it is anticipated that these default values will be used in the calculations.

Table A.1 Calculation of Nitrate Loading from Non-agricultural Sources

Source	Recharge Volume	Nitrate Concentration or Loading
Sewage discharges to ground (sewage treatment works)	Based on sewered catchment population and average water usage per person.	20 mg-N/l
Sewage discharges to ground (package treatment works)	Based on sewered catchment population and average water usage per person.	20 mg-N/l
Sewage discharges to ground (septic tanks)	Based on sewered catchment population and average water usage per person.	50 mg-N/l
Sewer leakage	Based on sewered catchment population and average water usage per person, with 2% leakage rate.	45 mg-N/l
Mains water leakage	Based on catchment population, average water usage per person and 22% leakage rate.	8.5 mg-N/l
Graveyards	Calculated catchment HER.	1.35 kg-N/burial/year
Landfill (non-hazardous)	Based on area of landfill sites and assumed infiltration rate through base of site.	723 mg-N/l
Landfill (inert)	Based on area of landfill sites and assumed infiltration rate through base of site.	27 mg-N/l
Surface runoff from roads & paved areas	Based on rainfall and assumed percentage area draining to ground.	3.5 mg-N/l
Urban diffuse sources (gardens, allotments, sports grounds etc.)	Based on area covered by source and catchment HER.	Assumed loading per unit area (range 5-25 kg-N/ha)
Animal burials	Catchment HER.	Based on number and mass of buried animals, and release rate of 4.5 kg-N/tonne

Nitrate loadings from agricultural point sources such as slurry stores, farmyard runoff and constructed wetlands are estimated based on assumed area covered by each source and rates of runoff or infiltration, and values of nitrate concentration of 4 000 mg-N/l (slurry stores), 17 mg-N/l (farmyard runoff) and 9 mg-N/l (wetlands).

Diffuse Agricultural Sources

The calculation of nitrate loadings from diffuse agricultural sources uses existing models. Leaching from arable land is calculated using a soil N budget approach and a leaching algorithm taken from the NEAP-N model (Anthony et al., 1996). Leaching from agricultural grassland is estimated from assumed fertiliser inputs and results from the N-CYCLE model (Rodda et al., 1995).

Nitrate Leaching from Arable Land

Nitrate leaching from arable land is calculated using a soil N budget approach to estimate the residual soil mineral nitrogen (SMN) post-crop harvest, and the NEAP-N leaching algorithm to predict the proportion of this residual SMN which is leached during subsequent winter drainage. The residual SMN is calculated as the sum of nitrogen inputs to the soil, minus the sum of nitrogen removed from the soil, as shown in the following equation:

$$N_{residual} = N_{fertiliser} + N_{organic\ waste} - N_{crop\ offtake} + N_{atmospheric} + N_{mineralisation} - N_{denitrification} - N_{vol}$$

The terms in this equation are summarised in Table A.2.

Table A.2 Soil Nitrogen Budget Terms

Budget Term	Description
$N_{fertiliser}$	Inorganic fertiliser application taken.
$N_{organic\ waste}$	Calculated based on number of livestock and composition.
$N_{crop\ offtake}$	Calculated based on statistics for crop yield and N content of crop.
$N_{atmospheric}$	Atmospheric (wet and dry) deposition.
N_{vol}	Volatisation loss dependent on soil type.
$N_{mineralisation}$	Nitrogen released by mineralisation. For this initial assessment this has been assumed to be zero assuming that there is no net gain or loss of N from the soil organic matter.
$N_{denitrification}$	Denitrification loss dependent on soil type.

Guidance is included in the spreadsheet on suitable values for these parameters, which will depend on the areas of major crops and livestock numbers present in each catchment. Cropping and livestock information are available from Agricultural Census data, and the preliminary models have been populated using 2010 census data.

The proportion of residual SMN that is leached in winter soil drainage is calculated as a function of HER and soil field capacity using the NEAP-N algorithm:

$$\varepsilon = h/\varphi$$

$$P = 1.111\varepsilon - 0.203\varepsilon^3 \quad \text{where } \varepsilon \le 1.35$$

$$P = 1.0 \quad \text{where } \varepsilon > 1.35$$

Here, h is cumulative soil drainage, φ the soil field capacity and P the proportion of available nitrate leached.

Nitrate Leaching from Agricultural Grassland

Nitrate leaching from agricultural grassland is a complex function of soil N cycling, and cannot easily be calculated using a simple soil N budget approach. Instead, the existing N-CYCLE model has been run for various sets of input parameters, and the output included in the source apportionment spreadsheets as lookup tables.

The main sensitivity of grassland leaching rates is to climate, soil drainage condition and fertiliser input. Two tables of model output are provided, for grazed dairy systems and for cut swards. Each table provides model predictions of leaching rate as a function of soil drainage condition (good, moderate, poor), climate zone and fertiliser application rate. Guidance on parameter selection is included in the source apportionment spreadsheets.

Appendix B
Uncertainty and Sensitivity Assessment

Dataset	Format	Information Extracted	Source of Uncertainty	Impact on Calculations	Level of Uncertainty	Outputs Affected	Sensitivity of Model - Based on A&O Chalk and NF Secondary
Agricultural census data 2010	2 km gridded dataset based on farm level returns to the UK Agricultural Census for the year 2010	Crop areas.	Clipping of catchment boundary with 2 km gridded catchment means that actual areas of cropped land can be underestimated - leading to a difference in total area of the catchment and the modelled area.	The areas of land-use types are used to calculate the weighted loading from individual sources of N. The total catchment area is used to predict the concentration of N in groundwater. For individual crop loading rates the modelled area is used. If the catchment area is larger than the modelled area on which leachate concentrations are based then the predicted value will be more dilute.	High to moderate, can be between 15% and 35% difference in total catchment and modelled catchment areas.	N from crop types Predicted N in groundwater term (dilution).	35% change in area of catchment has negligible impact on the predicted nitrate in groundwater due to averaging in the spreadsheet.
		Crop type.	Grouping of crop types together for input to SA spreadsheet under the following types: Grazed grass - = 50% of grass over 5 years old Cut grass= 50% of grass over 5 years old Temporary Grass = grass under 5 years old Cereal Crops = winter barley, spring barley, oats, rye, triticale and mixed grain Other Arable = total arable –(specified crops + temporary grass+bare fallow) Bare Fallow = uncroppped arable land Ploughed out long term grass = set to zero unless other available Uncertainty from the assumptions made when grouping crops with the same residual N.	Overestimate in residual N for other arable category.	Low as likely to apply to relatively small areas of catchment.	Other arable residual N.	Not assessed.
		Livestock numbers - to calculate slurry for spreading represented by the organic fertilser rate, farm-yard run-off (point sources) and engineered slurry store areas.	Clipping of catchment boundary with 2 km gridded catchment, where values are area weighted to represent partial grid squares and data is averaged over the 2 km grid. Total livestock numbers are likely to be inaccurate. Grouping of types of livestock is sometimes unclear as cattle and sheep are represented in several different classes (e.g. dairy, beef, calves, adults etc).	Impact on organic fertiliser application rates to grass and tilled land. Assume that all slurry in catchment is spread to land - although poultry litter could be incinerated. The largest inputs area from cattle and pigs - so the more uncertainty in these figures the bigger the impact.	As for land areas as the same calculation is used 15%-35%.	Over-estimate in organic fertiliser application, increased N leaching from arable land.	35% change in livestock head produces a 1% change in arable/ grassland contributions, so assumed negligible.
Land-use 2007	Polygon dataset at for 23 habitats/land-use types based on digital cartography and satellite imagery for the year 2007 at the 25 m vector scale	Woodland areas.	Low uncertainty - due to accuracy of input data.	Calculation of N loading from woodland.	Low.	Woodland N loading.	Not assessed.
		Division of urban land run-off - OS datasets?	Uncertainty in allocation of urban run-off from gardens, allotments, paved areas draining to ground and sports fields.	Division of allocation is based on default values, as are loading rates. Input is typically low (highest rate is from allotments).	Low (low input source).	Urban run-off loading.	Not assessed
Area of roads outside of urban areas	Extracted from OS Master Map Polyline dataset with a standard road width of 10 m applied	Based on OS master map.	Application of 10 m road width.	Overestimate area of roads and run-off - but suspect this should balance out.	Low	Roads outside urban areas.	Not assessed.
Population Census data	Polygon file containing parish boundaries and population in 2011 census	Population number for mains water.	Clipping parish boundaries to catchment boundaries - where an overlap exists in polygon shapes an area weighted proportion of the parish population is calculated. The final summed number can be affected by the location of towns in a parish which overlaps the catchment, but where the town is located outside of the catchment boundary. Manual checks for thinner catchments (Lower Greensand outcrop) have been made - but other catchments are likely to be affected.	Affects mains water and sewer leakage values. Indirectly affects septic tank/package treatment works values.	Moderate - up to 30%.	Mains water and sewer leakage values. Indirectly affects septic tank/package treatment works values.	30% increase/decrease in population leads to 0.5-1% change in mains water/sewer leakage, therefore assumed negligible.

Dataset	Format	Information Extracted	Source of Uncertainty	Impact on Calculations	Level of Uncertainty	Outputs Affected	Sensitivity of Model - Based on A&O Chalk and NF Secondary
Sewerage network	Polygon file containing extent of Southern Water Sewerage network, treatment works each network supplies and resident population served.	Mains sewer population for mains leakage and calculation of population on private sewerage undertakings.	As for population parish data, sewerage network polygons overlap catchment boundaries. Again manual checks of the actual location of population centres has been made.	Affects mains water and sewer leakage values. Indirectly affects septic tank/package treatment works values.	Moderate - up to 30%.	Mains water and sewer leakage values. Indirectly affects septic tank/package treatment works values.	30% increase/decrease in population leads to 0.5-1% change in mains water/sewer leakage, therefore assumed negligible.
Discharge consents	Point dataset showing location of consented discharges.	Septic tank/cesspit/package treatment works population.	Equal split between package treatment works and septic tanks. Package treatment works usually have a lower loading to groundwater. Cesspits will exist in catchments but are not represented as they should provide no loading to groundwater (even though they are known to leak - no data is available to represent this term).	Affects septic tank / package treatment works values as package treatment works tend to discharge to surface water and also have a lower N loading (as the effluent is treated).	Private sewerage treatment could be mainly package treatment works in surface water dominated catchments. Split could be more like 20:80 depending on catchment.		80% of privately sewered population on septic tanks leads to a 1% increase in contribution from treated sewage effluent. The same increase to Package treatment works population produces no discernible increase in contribution. Overall model sensitivity is assumed negligible.
Landfill - Authorised Current	Polygon file showing extent of authorised landfills with waste type and licence issue date.	**Age of waste** to identify reduction in leachate concentration due flushing**.**	Age of waste allows allocation of a flushing reduction based on how long the waste has been exposed to infiltration from rainfall, based on the following values from AMEC, 2010. Where no age is available assume a 1970 date: **2010 4%** **2000 8.5%** **1990 16.2%** **1980 18%** **1970 21%** **1960 27%** **1950 32%** **1940 37%** **1930 42%** **1920 48%** **1910 58.7%**	Change in landfill leachate concentration.	Moderate as the extent of flushing rate can change the leachate concentration by 14% (assuming 1980 start date could reduce to 2010 for latest inputs of waste).	Landfill contribution.	Decrease age of waste from 1980 to 2010 and reduction in flushing term-by leads to minimal reduction in landfill term. Assume that impact is negligible on model outputs.
		Age of waste to identify presence of engineered liner assumed for landfill begun after 1990 (date of Landfill Regulations update).	Assumption that all landfill prior to 1990 Landfill Regulations has no engineered liner, and all landfill post 1990 has some protection against infiltration rainfall and leachate leakage.	Change in landfill leakage rate.	High to Moderate impact of liner/ cap presence as can change the leakage rate by 100 times the modelled rate.. Landfill loading could be significantly high if there is no liner or cap increasing the 30mm/a assumed leakage rate to the catchment infiltration rate (can be over 100 times greater).	Landfill contribution.	For authorised landfills which are assumed to be lined increasing infiltration to the catchment infiltration recharge value leads to a 10-25% increase in the landfill term. Model is sensitive to this input.
		Type of waste to identify leachate starting concentration.	Assumption that waste leachate starting concentration is 723 mg/l N for non-hazardous waste and 27 mg/l N for inert waste. Starting leachate concentration is too low (although this is based on national statistics).	Change in landfill leachate concentration.	Low - Leachate concentrations are based on national datasets reported in AMEC, 2010. This information could be improved with site specific information.	Landfill contribution.	Not assessed.

Dataset	Format	Information Extracted	Source of Uncertainty	Impact on Calculations	Level of Uncertainty	Outputs Affected	Sensitivity of Model - Based on A&O Chalk and NF Secondary
Landfill - Historic	Polygon file showing extent of historic closed landfills with inert waste flagged and licence issue/surrender, first/last input date.	Leachate concentration.	Age of waste for flushing reduction is the same as last input date (or where not available, any latest other date, or 1970 default) (see previous row for flushing reductions v age).	The age of waste will affect the reduction for flushing factor.	Moderate as the extent of flushing rate can change the leachate concentration by 10-40% (assuming 1970 reducing to 2000 age or increasing from 1970 to 1910).	Landfill contribution.	Where no date for the waste is available decreased flushing to 40% with negligible impact on landfill contribution.
		Leakage rate from historic landfill.	Assumption that landfill started prior to 1990 will have no cap of liner.	Where no liner is present assume there is no protection for the underlying aquifer.	If a liner is present the leakage rate will decrease over 100 times (depending on catchment IR).	Landfill contribution.	Where no date available - increasing infiltration rate to catchment IR - to reflect no liner produces 10% increase in contribution. Significant impact on landfill term.
		Leachate concentration.	Assumption that waste leachate starting concentration is 723 mg/l N for non-hazardous waste and 27 mg/l N for inert waste.	Landfill loading/leachate concentrations could be higher/ lower.	Low - values based on national datasets.	Landfill contribution.	Not assessed
		Leakage rate from historic landfill.	Where no engineered liner or cap is assumed the leakage rate is set to the infiltration rate - this doesn't account for compacted waste so the leakage rate could be reduced.	Leakage rate could be reduced, especially where waste has been compacted, reducing waste permeability.	Low - IR value could be decreased slightly to take this factor into account.	Landfill contribution.	Not assessed.
Soils	1km grid dataset showing simplified soil types.	Soils simplified description field is extracted and predominant soil description is used to designate as sand, clay or loam.	1 km grid mapping. Based on soil descriptions. But the 'dominant' soil type per grid square can represent <50% of each I km square. One than one soil type could be appropriate for a catchment.	Soil type is used to calculate the proportion of N leached from the soil. Clay soil reduces leaching from arable land compared to sand and loam soils.	Low.	Agricultural leaching rates.	Not assessed.
Rainfall	LTA (1971-2000) for hydrometric areas 41, 42 and 101, as reported in the UK Hydrometric Register (Marsh and Hannaford, 2008).	Used to calculate run-off from paved areas and HER (HER is used to calculate N loading from crop types and catchment soil N loss).	Averaging over the study area will bring in uncertainty in the calculated HER values for individual catchments.	Increase or decrease in dilution rate from HER to agricultural crops.	Low -+ 46 mm/a (around 5%).	Calculation of leaching rates.	Not assessed.
Infiltration Recharge	Grid of model data clipped to catchment boundary or LTA value supplied by Environment Agency for IOW and non-GW resource model catchments.	From 4R model or from Catchmod model.	Used to calculate leachate concentrations - and predicted concentration in groundwater.	Increase or decrease in dilution rate from HER to agricultural crops.	Low -+ 46 mm/a (around 5%).		Not assessed.
Input to groundwater (BFI)	Estimated proportion of HER that arrives at the water table (i.e. not going to surface water as baseflow).	Estimated - 60% for sandstone or 80% for Chalk.	Used to calculate HER, PE and proportion of N entering groundwater, based on assumption that in Chalk aquifers there will be a high proportion of recharge ending up as groundwater, whilst in sandstone / mudstone catchments surface run-off or shallow interflow to surface water is greater.	Increase or decrease the N loading to groundwater.	Low.		Not assessed.
Attenuation rates	Applied reduction in N leaching to groundwater due to attenuation of nitrate in the unsaturated zone.		Attenuation rate based on aquifer material type and groundwater quality data indication of nitrate attenuation. Rates are taken from SA report.	Lower or higher rates will affect the contribution from sources, and the predicted nitrate concentration in groundwater.	Moderate - although confident for the Chalk aquifer. In mudstone / sandstone aquifers the rate of attenuation could vary up to 50% (between 40 and 90% quoted in SA report).	Nitrate in groundwater and source contributions.	Increasing attenuation rates from 20% for non-agricultural sources to 40% and decreasing from 20% to 0% for agricultural sources leads to an overall shift in contributions but with 1-2% for most sources.
Observed average nitrate concentrations in groundwater	Nitrate data for the period 2010 to 2013 for groundwater quality locations.	Nitrate concentrations for each groundwater quality monitoring point within each catchment for the period 2010 to 2013 (or earlier if not enough recent data is available).	Is the data representative of the whole aquifer? The location of water quality monitoring points may be biased towards more productive parts of the catchment, or the number of monitoring points is low and a true average is not calculated.	Predicted nitrate concentrations under or over estimate N leaching to groundwater.	Low – moderate.	Comparison with predicted nitrate concentration.	Not assessed.

Dataset	Format	Information Extracted	Source of Uncertainty	Impact on Calculations	Level of Uncertainty	Outputs Affected	Sensitivity of Model - Based on A&O Chalk and NF Secondary
Fertiliser application rates	Defra Manual RB209.	Assumes that farmers follow good practise and recommended rates. This could include potentially higher rates in catchments with poor thin soils (e.g. over Chalk).	Rates of spreading of inorganic fertiliser to different crop types..	Underestimation/underestimation of N applied to cropped land and leached N loading/concentration in groundwater.	Low- moderate as rates are based on best available information at this scale of catchment.	Not assessed.	

Appendix C
Source Apportionment Models for the South East River Basin District

Source apportionment spreadsheets for the following catchments are supplied on the accompanying DVD.

1. Seaford and Eastbourne Chalk;
2. Cuckmere and Pevensey Levels Secondary;
3. Cuckmere and Pevensey Levels Lower Sand;
4. Brighton Chalk;
5. Adur and Ouse Lower Greensand;
6. Adur and Ouse Secondary;
7. Arun & Western Streams Chalk;
8. Arun & Western Streams Lower Greensand;
9. Arun & Western Streams Secondary;
10. East Hants Chalk;
11. East Hants Secondary;
12. Test & Itchen Chalk;
13. Test & Itchen Secondary;
14. Isle of Wight Lower Greensand;
15. Isle of Wight Chalk;
16. Isle of Wight Secondary;
17. New Forest Secondary.

Appendix D
Nitrate Trend Modelling Spreadsheet

Introduction

The nitrate model used in this work represents some minor development of models developed for previous projects (AMEC 2008, 2009, 2010). The original models are also described in some detail in AMEC reports 20953rr120i1 to Wessex Water Ltd and 21464rr060i3 to UKWIR, and this text is based on those reports.

The conceptual understanding of nitrate transport in the Hampshire Chalk, Portsdown Chalk, Worthing Chalk and Brighton Chalk is set out in detail in the main text of the report (Section 4). This appendix describes how the Nitrate Trend model workbooks are developed such that this conceptual model is represented.

Model Data Requirements

The necessary spatial data are collated in a GIS project, converted to a gridded dataset, which can then be "cookie-cut" or clipped to the defined catchment to the source and exported as a table, for import to the calculation workbooks. The workbooks use time series of predicted nitrate concentrations in soil drainage from arable land and grassland, and water level data from a reference observation borehole. In addition the nitrate model requires the following input data for each grid cell in the catchment to the source being modelled:

- Land use in the catchment to the location (arable, managed grass, rough grazing/semi-natural vegetation, woodland, urban);
- Ground level and water levels at low water level conditions (to calculate the thickness of the unsaturated zone and travel times);
- The location of the centre of each model cell (to calculate the distance to the abstraction and hence the saturated zone travel time);
- Long term average total effective rainfall and infiltration recharge to the Chalk at outcrop;
- Soil and aquifer type (to determine leaching rates and moisture content); and
- Water quality data for model calibration.

The modelling work carried out here used depth to water table, recharge information and solid and drift geology information from the Brighton and Worthing, Test and Itchen and East Hants and Chichester Chalk groundwater MODFLOW and recharge 4R models. Land-use information was taken from the Land Cover Map 2007 spatial mapping produced by CEH (CEH, 2011). Soils mapping from the Soils Tool Kit (NAT MAP) and water quality data were both supplied by the Environment Agency.

Nitrate Concentrations in Soil Drainage

The modelled concentration of nitrate in soil drainage arriving at the water table depends on land use and, for grassland and arable land, the age of water (time of travel through the unsaturated zone). The long term trends in concentrations of nitrate from arable land and grassland are shown in Figure D.1. These trends are based on national fertiliser use statistics with calibration to groundwater concentrations in the Wessex area. For arable land, the concentration of nitrate in soil drainage is derived based on an assumed effective rainfall of 510 mm/yr (based on the average effective rainfall in the Wessex Basin). The concentration value applied in the models is scaled to account for the actual (modelled) effective rainfall in the catchment, according to equation E.1, in which C_0 is the reference concentration for arable land for the appropriate year (mg-N/l), HER is the modelled hydrologically effective rainfall in the arable model cell (mm/yr) and C_{Arable} is the concentration for arable land applied in the nitrate models (mg-N/l). No such scaling is applied to concentrations from improved grassland or other land uses.

$$C_{Arable} = C_0 \times \frac{510}{HER} \qquad \text{(E.1)}$$

This scaling was applied on the advice of ADAS consultants following modelling work in the WAgriCo project. It allows for the possibility of source exhaustion on arable land, whereby, once the majority of nitrate available to be leached has been lost from the soil, further soil drainage results in dilution, and the total nitrate load lost from the soil does not further increase. On grassland, by contrast, the much slower mineralisation of organic matter results in a steady source of nitrate which is less likely to be exhausted. The nitrate load lost from grassland is therefore assumed to increase with increasing soil drainage.

Concentrations from other land uses are assumed to be constant in time and are as given in Table E1. The “urban” values are consistent with predictions of nitrate losses from urban areas from the NEAP-N model, provided by the Environment Agency. Note that, for water younger than about 60 years old, assumed nitrate concentrations in drainage from arable land and grassland are significantly greater than those from other land uses.

Historic nitrate leaching from arable land in the period approximately 70-110 years ago is assumed to be somewhat higher than that in the 40-70 years ago. This might appear counter-intuitive. Although inorganic fertiliser use only really started after WWII, County agricultural returns for neighbouring Dorset and Hampshire suggest a significant decline in animal numbers from 1900 to 1930-40 most likely due to the depression between the two world wars. This trend is likely to be reflected in the study area. The long term soil nitrate leaching trend in 1900 for arable is about the same as that in 1960. There is limited or no historical nitrate data available to further constrain these estimates.

Table D.1 Nitrate Concentration in Soil Drainage for Each Land Use (non agricultural land)

Land Use	Nitrate Concentration (mg-N/l)
Semi-natural vegetation/rough grazing	2.0
Forest and Woodland	0.5
Urban	3.0

Recharge

Based on the conceptual understanding of recharge in the three groundwater model areas (AMEC, 2011), recharge occurs as:

- **Infiltration recharge:** recharge which occurs as matrix flow through the unsaturated zone to the water table in areas where the aquifer is not confined;

- **Runoff recharge**: recharge which occurs where runoff from lower permeability deposits runs-off and recharges adjacent permeable material;
- **Bypass recharge:** rapid recharge through macropores or fissures in the unsaturated zone.

Bypass recharge is not simulated in this model.

Time of Travel Through the Unsaturated and Saturated Zone

The rate of movement of infiltration recharge through the matrix of the unsaturated zone is calculated assuming piston flow, the equation for which is given in Box D.1. In this way, the distribution of ages of water reaching the water table in a given year can be calculated, and hence, for arable land and grassland, the associated nitrate concentrations determined.

Box D.1 Equation for Plug Flow through the Unsaturated Zone

$$T_u = z \,.\, \theta \,/\, R_I$$

Where:

T_u	=	the travel time (years) of a water particle or conservative ion (such as chloride and nitrate);
z	=	the thickness (m) of the unsaturated zone (or depth to the water table below the soil zone);
θ	=	the moisture content (fraction) of the strata in the unsaturated zone;
R_I	=	the infiltration recharge (m/yr) leaving the base of the soil zone.

In previous investigations in the Wessex and Lincolnshire Chalk the travel time through the saturated zone to the abstraction point is not significant compared to the unsaturated zone travel time and was ignored for these investigations. In the South Downs study the saturated zone travel time is also not included but the method of calculation if shown in Box D.2 for completeness.

Box D.2 Equation for Movement through the Saturated Zone

$$V_s = k \,.\, i \,/\, n$$

Where

V_s	=	the rate of movement (m/day) of a water particle or conservative ion (such as chloride and nitrate);
k	=	the saturated hydraulic conductivity (m/day) of the aquifer
i	=	the hydraulic gradient;
n	=	the effective porosity of the aquifer

Note: This equation is an approximation based on Darcy's Law and for unconfined strata more accurately should be related to Dupuits' Law.

Finally, the combination of ages of water and associated nitrate concentrations within the catchment are combined to give an average concentration at the study location, according to the equation in Box D.3.

Box D.3 Equation for NO_3 Concentration in Combined Recharge

$$C_{Average} = \sum (C_{age} \times P_{age})_{Arable} + \sum (C_{age} \times P_{age})_{Improved\_Grassland} + \sum (C_{age} \times P_{age})_{Urban} + ...$$

Where:
$C_{Average}$ = the average nitrate concentration for the combined recharge at the water table;
C_{age} = the nitrate concentration for water of a given age for that land use;
P_{age} = the proportion of recharge in the catchment (for which there are data) of a given age and land use ;
The land uses are arable, improved grassland, rough grassland, woodland and forestry, and urban.

Land Use Data

Land use data were taken from the simplified Land Cover Map 2007 (CEH, 2011) data. The nitrate trend spreadsheet requires land-uses defined as arable, managed grassland, semi-natural vegetation, urban and woodland. The division of the Land Use 2007 designations between these categories is shown in Table D.2.

Table D.2 Division of Land-Use 2007 Types between Nitrate Trend Model Input Categories

LCM 2007 Class	Nitrate Trend Model Class
Broadleaved woodland	Woodland
'Coniferous Woodland'	Woodland
'Arable and Horticulture'	Arable
Improved Grassland'	Managed grassland
Rough Grassland	Rough grazing
'Neutral Grassland'	Rough grazing
'Calcareous Grassland'	Rough grazing
Acid Grassland	Rough grazing
'Fen, Marsh and Swamp'	Rough grazing
Heather	Rough grazing
Heather grassland	Rough grazing
'Bog'	Rough grazing
'Montane Habitats'	Rough grazing
Inland Rock'	Rough grazing
Salt water	Not Modelled
Freshwater	Not Modelled
'Supra-littoral Rock'	Not Modelled
'Supra-littoral Sediment'	Not Modelled
'Littoral Rock'	Not Modelled
Littoral sediment	Not Modelled
Saltmarsh	Not Modelled
Urban	Urban
Suburban	Urban

Catchment Definition

Catchments to abstraction boreholes have been defined either through use of the Flowsource (© Groundwater Science) tool and the East Hants and Chichester Chalk (EHCC) and Test & Itchen MODFLOW models, or, for those sites in the Brighton and Worthing Chalk, the existing SPZ 2, modified to consider groundwater level gradients and to include an area consistent with the known abstraction rate from the source and predicted recharge in the catchment area. Numerical modelling of catchments was not required as part of the project brief.

Water Quality Data

For model calibration, it is desirable that historic nitrate concentration data are available. This enables empirical estimation of model parameters to improve the predicted fit to seasonal and transient variations, and assessment to be made of the ability of each model to capture observed historical trends in water quality.

Water Level Data

Seasonal variations in nitrate concentrations at modelled locations are empirically related to seasonal fluctuations in water levels. This is simulated in the nitrate models through consideration of observed water levels at a reference borehole.

Previous projects for Wessex Water and WAgriCo used data from boreholes at Woodyates and Ashton Farm. These sites were chosen because of the length of the data record (Woodyates) and the frequency and continuity of data (Ashton Farm), but also because of their reasonable proximity to the Chalk sources for which nitrate models were being constructed, which were mainly around Dorchester. For this work, water level data from Environment Agency observation boreholes local to the sources has been used, since it will be more representative of water levels in the aquifers from which the sources take water.

Previous work in the Wessex Chalk has shown evidence of short term "spikes" in nitrate concentrations, which it was hypothesised are due to rapid bypass recharge flowing through fissures in the Chalk. This bypass recharge was simulated by the recharge model, and included in the nitrate trend models. Examination of nitrate trends at sources in the South Downs does not show conclusive evidence of such spikes, and the simulation of bypass recharge and associated spikes has not been included in these models.

Point Sources

Where point sources such as discharges to ground or leachate from landfill sites are located in the catchments to modelled locations, they are included in the nitrate models as additional loadings in the appropriate model cells. Calculations of the estimated loadings from such sources were carried out "off-line" and assembled into a GIS layer for export to the nitrate trend workbooks.

Conceptual Model for Predictive Workbooks

Overview

The conceptual model for nitrate trend prediction is illustrated on Figure 4.1a and b of the main report. Component parts of the conceptual model are discussed in the following subsections.

In summary, nitrate historically leached from the soil at a concentration depending on land use and local infiltration recharge is driven down through the unsaturated zone to the water table. The time taken for soil drainage to reach the water table depends on the depth to the water table, the moisture content of the unsaturated zone and the infiltration recharge at each point in the catchment. The time taken for that same water to travel to the abstraction point through the saturated aquifer from the point of entry at the water table depends on the distance to travel, the aquifer effective porosity and hydraulic gradient (i.e. Darcy's Law).

Each catchment therefore has different proportions of different ages of water leached from different land uses. By combining these different recharge waters an average nitrate concentration is produced which changes each year. On top of the long term trend, seasonal variations in nitrate concentration are simulated by visual correlation to changes in groundwater level.

Long Term Annual Average Trends

The long term annual average nitrate concentration (for water arriving at the water table) is predicted through the following steps:

i) The catchment to the PWS source is defined either by use of the Flowsource tool and a regional groundwater model, or through consideration of the existing Environment Agency Source Protection Zone (SPZ).

ii) The digitised catchment is subdivided into 200 m × 200 m sized (ArcGIS v 9.1) GIS grid cells. Groundwater models (East Hants and Chichester Chalk, Test & Itchen, Brighton & Worthing Chalk) provide land use (e.g. arable, improved grassland), depth to water table, total recharge for each grid cell and distance of the centre of each model cell from the abstraction point.

iii) The concentration of historically leached nitrate depends on the land use, but also takes into account the diluting effect of each catchment's average infiltration recharge direct to the aquifer (or effective rainfall).

iv) Historically leached nitrate moves downwards through the unsaturated zone under piston flow. In each grid cell of the catchment, the historically leached nitrate arrives at the water table in a time dependent on the thickness (z) (at low water levels) and the moisture content (θ) of the unsaturated zone and the annual average infiltration recharge (R_I) (see equation in Box D.1).

v) Cells with lower infiltration recharge (e.g. in areas with alluvium) contribute less water and so less flux of nitrate to the water table than cells with higher recharge. The proportions of water of different age and land use making up the recharge at a catchment's water table therefore also depends on the recharge in each cell.

vi) Movement of recharge and its nitrate from the point of arrival at the water table has previously been modelled using the equation in Box D.2. This delay in arrival at the abstraction point is added to the age of water at the water table to provide a total age of water. For this work, transport to the abstraction through the saturated zone is assumed to occur at a very rapid rate compared with transport through the unsaturated zone, and saturated time of travel has been neglected.

vii) The average concentration of nitrate arriving each year at the catchment's water table is the sum of the proportion (based on recharge) of waters of the same age (calculated in ArcGIS v9.1) multiplied in Microsoft Excel by the historically leached nitrate concentration for that age for each land use (see equation in Box D.3). Land use is assumed to be unchanged over the age of the water.

The models presented in this report have been based on the greatest depth to water table i.e. low water table.

Seasonal Trends

Increases in water level lead not only to younger waters at the water table, but also to a narrower range of water ages. To model the effect of water table rises mechanistically would require the long term trend calculation to be repeated with different grids of water level (and so travel time) and this was not done due to data and time limitations as well as computational effort (file size).

Seasonal variations have, instead, been simulated using an empirical relationship with groundwater levels at local Chalk boreholes.

The empirical relationship between water level and nitrate concentration has been determined by visual inspection for each source evaluated. Parameters modified are:

- The constant (k_1) relating nitrate concentration change to water level difference from the historical minimum value for that borehole, i.e.

$$NO_3 \text{ change} = k_1 \times \text{water level change}$$

  - This empirically sets the amplitude of any seasonal nitrate variations. k1 varies between boreholes due to different amplitudes of water level variation;

- A lag on the date of the water level measurement to more closely match the falls and rises in nitrate. This empirically corrects the timing of any seasonal change in nitrate. The lag of nitrate behind water levels (typically 1-6 months) is likely to reflect a delay between hydraulic response of the water table to recharge and that recharge arriving at the pumped source or spring.

It is noted that the constant (k_1) in the empirical relationship would be expected to change over the years (see Box D.4).

Box D.4 Discussion of Change in Seasonal Variability over Time

If at some date in the future, all nitrate in the unsaturated zone attains the same concentration, then increases in water level would be expected to produce no change in nitrate concentration.

Conversely, significant seasonal variations in nitrate are expected where (a) there are large variations in water level and (b) the water in the overlying unsaturated zone is of a much higher or lower nitrate concentration.

Indeed, in future where nitrate concentrations from the most recent recharge has lower nitrate than that historically, then higher water levels are predicted to bring lower nitrate concentrations and the seasonal pattern should switch to being lower in winter and higher in summer.

Key Uncertainties in Input Parameters

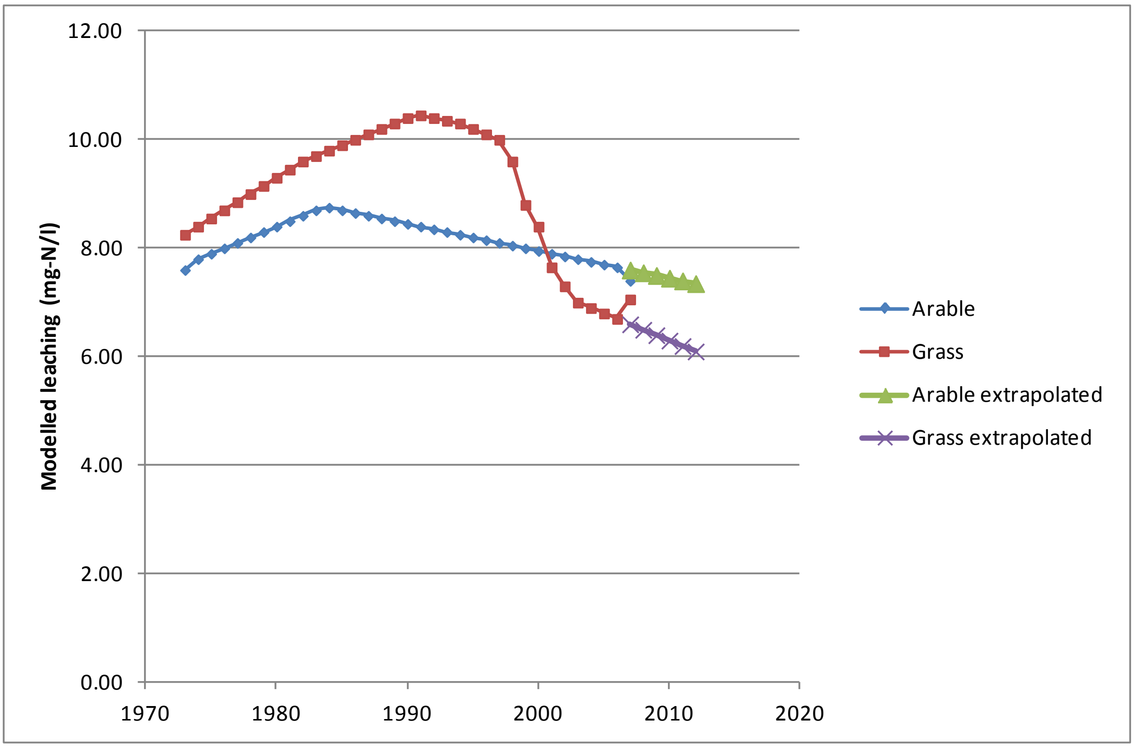
For the reasons set out in Table D.2, the main uncertainty in input parameters is likely to be in the historically leached nitrate.

Table D.2 Key Uncertainties in Input Parameters

Input	Basis	Uncertainty
Historically leached nitrate	National average fertiliser use records for arable and improved grassland.	Well constrained nationally, but assumes application in catchments is the same as the national average. Greater uncertainty for older application rates.
	Ploughing up of grassland	Date and effect poorly constrained.
	Leaching factors	Significant uncertainty (range of 20% to 60%?).
	Observation borehole nitrate (based on calibration to Chalk sites)*	Significant variability and therefore uncertainty.
	Iteration to give good model fit	Makes this variable non independent plus the predictions are insensitive to leaching in the last 5-10 years.
Catchment	Groundwater model plus Flowsource, or existing SPZ2	Minor – likely to be more significant for sites based on SPZ 2 due to basis of SPZ delineation (400 day time of travel at fully licensed abstraction rate).
Land Use	Simplified Year 2007 land cover	Moderate – land use may have changed significantly over the previous 50-100 years so arable land use may be being assumed when area was grassland.
Recharge	4R Recharge Model outputs and MOSES data	Minor - model was calibrated with a water balance and by consideration of hydrographs and so the outputs are as well constrained as possible for this project. Long periods of above or below average infiltration recharge would affect predictions.
Unsaturated zone thickness	Based on topography and modelled groundwater levels.	Minor uncertainties likely for topography associated with model grid using lowest 50 m grid elevation in 250m nitrate trend model grid.
Unsaturated zone moisture content	Conservative literature values. 30% assumed.	Moderate – possible variation from 30% where the Chalk is structurally deformed.

* Nitrate leaching trend was originally developed for Chalk sites in Wessex, based on national fertiliser statistics and comparison with Chalk porewater concentrations, and calibration against Chalk groundwater quality. It is assumed that the same trend will be applicable in the neighbouring Chalk aquifers as the trend does not reflect the aquifer properties.

Figure D.1 Modelled Nitrate Concentrations in Drainage from Arable Land and Grassland to 2013



Appendix E
Individual Catchment Reports

The following catchments are included in this Appendix, covering abstraction and catchment characterisation, nitrate trends model outputs, nitrate source apportionment, recommended measures assessment and simple cost benefit assessment:

- Twyford;
- Lovedean;
- Westergate;
- Eastergate;
- Findon;
- Burpham;
- Patcham;
- Mossy Bottom;
- Newmarket;
- Housedean;
- River Lavant.

Appendix F
Delineation of Zones for Measures Application

As described in Section 4.3.4 of the report, catchment wide reductions are thought to be un-achievable due to low uptake of measures providing high levels of reduction but at a high cost (e.g. land-use change). The timescale for historic nitrate to travel through the unsaturated zone is also a factor in low uptake, although measures closer to the borehole are likely to help reduce nitrate concentrations travelling along more rapid pathways. Measures have been applied in areas where they are most cost effective based on an inner zone for land-use change and an outer zone for measures controlling N application and leaching.

At Findon, Housedean, Newmarket and Patcham, SPZ1 is used as the inner zone and SPZ2 as the outer zone.

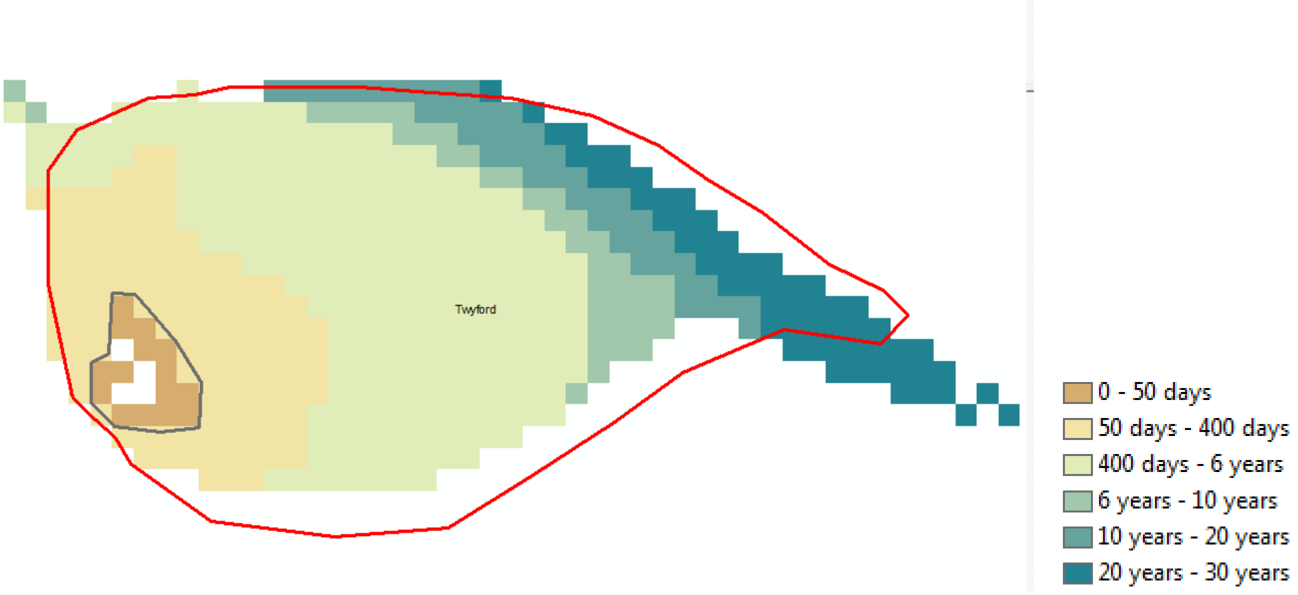
For Twyford, Eastergate and Wetsergate and Lovedean there is an opportunity to use the Flowsource output to refine the inner and outer zone further. In keeping with the definition of SPZ 1 as a zone of protection for rapid transport of pollutants to the abstraction the inner zone has been based on the 50 day travel time zone. For the outer zone the volume from output has been used to identify the area over which X % of water at the abstractions comes from. The outputs and methodology used to define these zones are described below.

For whole catchment scale measures (to address farm-yard and manure heap management) the defined total catchment for each abstraction has been used.

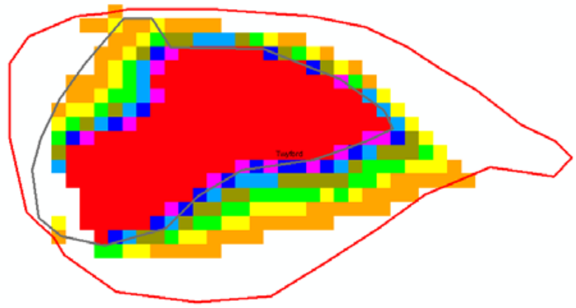
Twyford

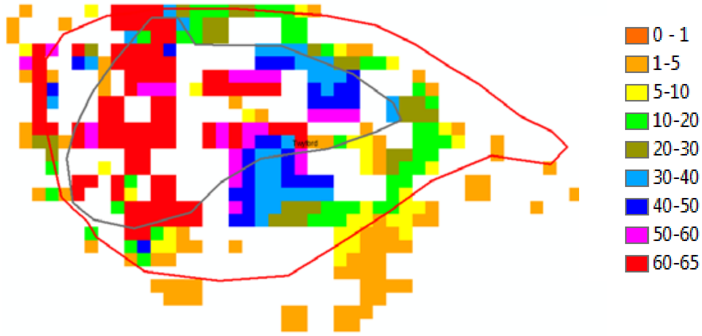
Modelled abstraction rate is 20 ML/d.

Inner Zone (grey line) – based on the saturated zone time of travel to the abstraction being within a 50day period.



Outer Zone (grey line) based on volume from (m^3/d) the area covered includes cells with 60 m^3/d contribution from the dry and wet stress periods. The area delineated is 14 749 246 m^2, which covers 235 model cells. At a volume from rate of 60 m^3/d over this number of cells equates to 14 159 m^3/d which is close to 70% of the abstraction (albeit it from different stress periods).

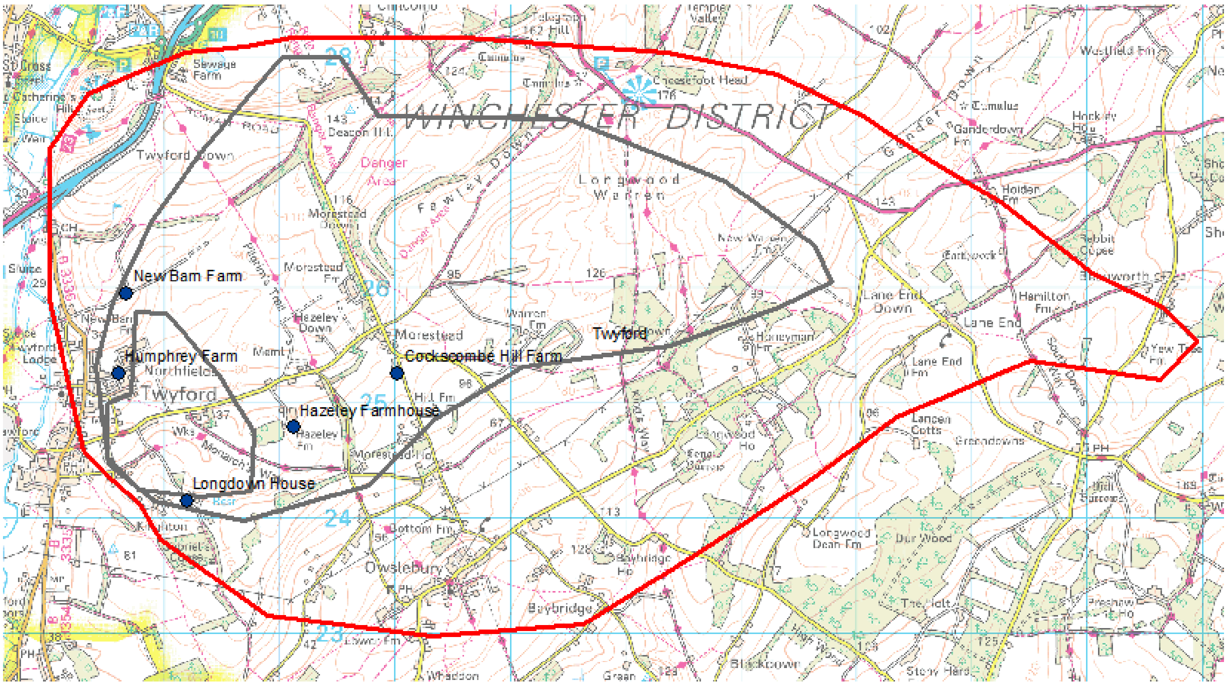




Wet stress period volume from m^3/d

Dry stress period volume from m^3/d

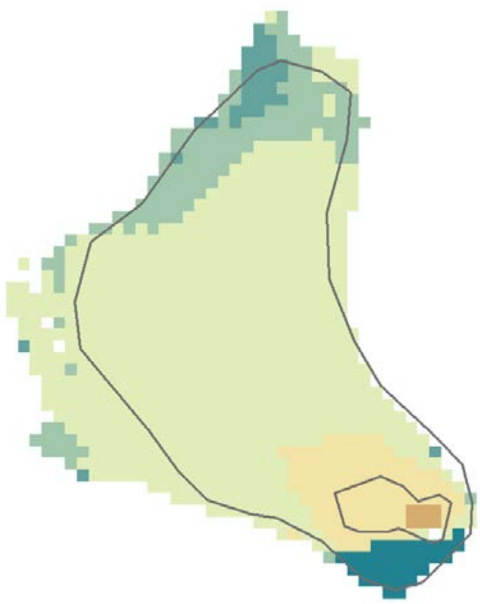
Final Twyford zones for measures application with farm visit locations, red line is whole catchment.



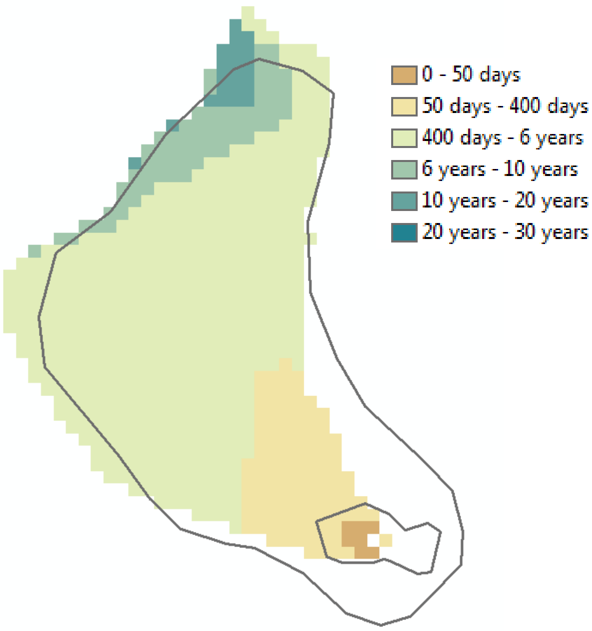
Eastergate and Westergate Combined

These sites are combined due to the overlapping catchments. Modelled abstraction rate is 9.3 Ml/d at Eastergate and 6.2 Ml/d at Westergate.

Inner Zone (grey line) – based on the saturated zone time of travel to the abstraction being within a 50 day period.

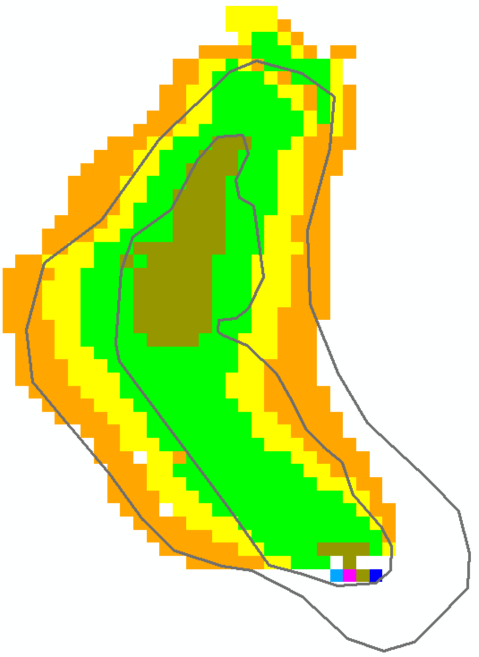


Eastergate Time of Travel and Inner Zone

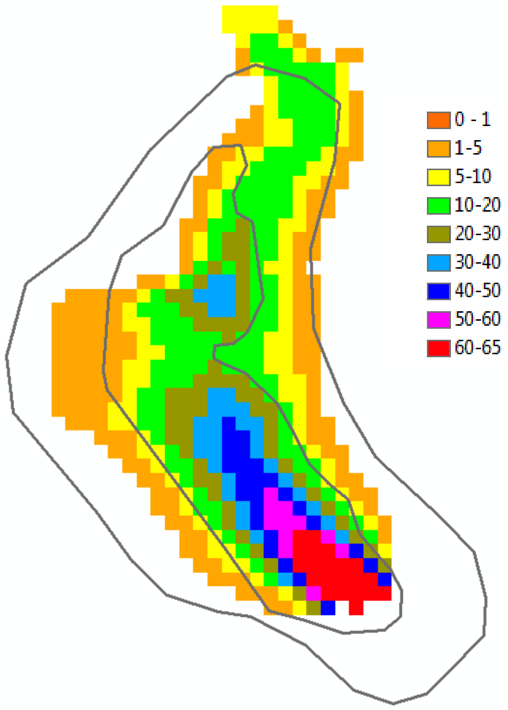


Westergate Time of Travel and Inner Zone

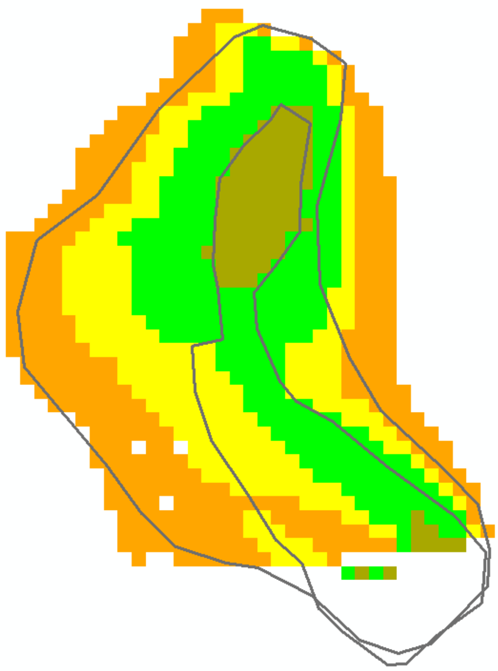
Outer Zone (grey line) based on volume from (m^3/d) the area covered includes cells with >30 m^3/d contribution from the dry and wet stress periods. The final combined area delineated is 27 043 581 m^2, which covers 643 model cells. At a volume from rate of 30 m^3/d over this number of cells equates to 19 305 m^3/d which exceeds the total combined abstraction but this is because of the double counting of model cells and adding in the bottom part of the catchment under drift cover. The selected area should provide coverage of a significant proportion of catchment where water travels from to end up at the abstraction.



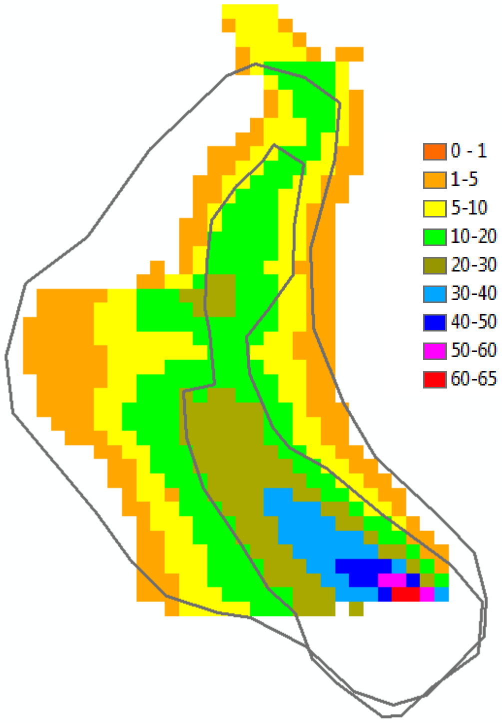
Westergate Volume from dry stress period



Volume from Wet Stress period

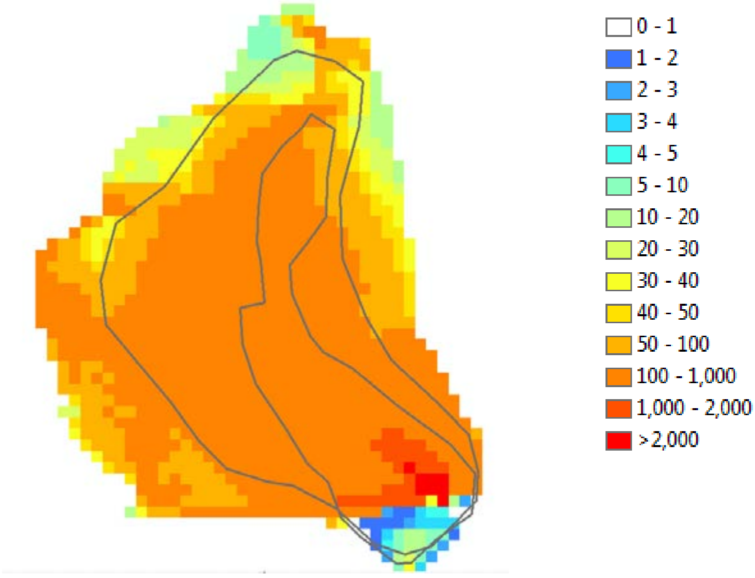


Eastergate Volume from dry stress period



Volume from Wet Stress period

Eastergate volume through LTA m^3/d – reason for retaining area beneath drift cover.

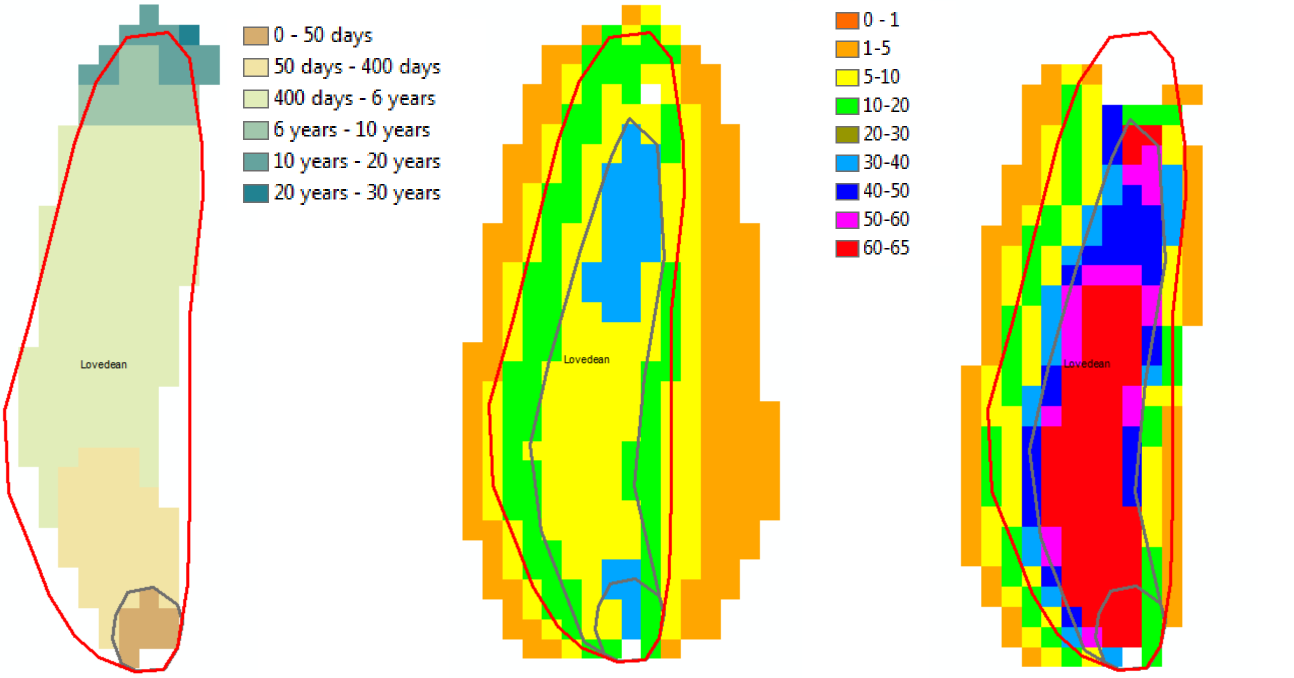


Final Zones combined including farm visit sites, dairy farms and equestrian businesses (red triangles).

Lovedean

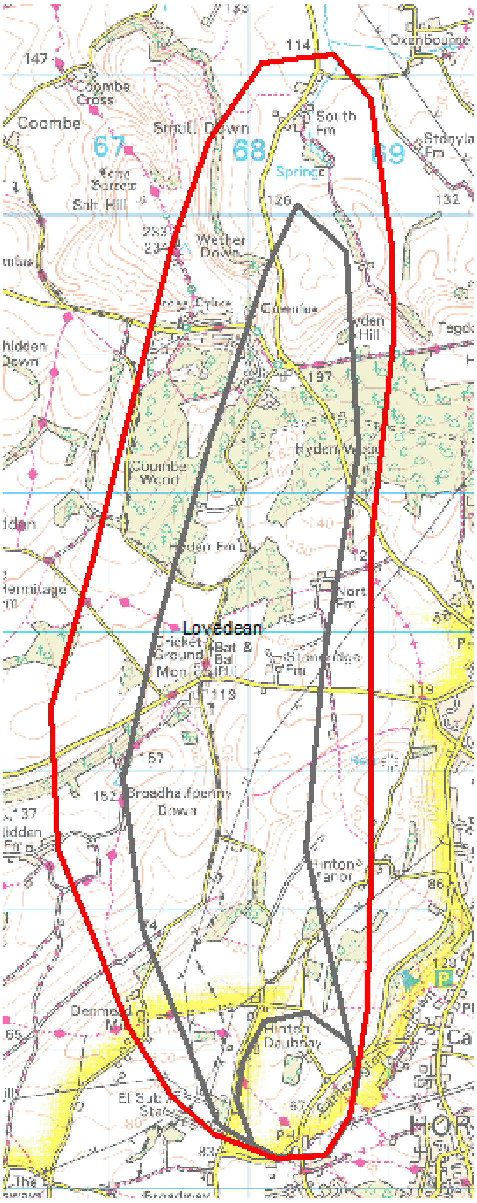
Modelled abstraction rate is 5.3 Ml/d.

Inner Zone (grey line) – based on the saturated zone time of travel to the abstraction within a 50 day period.



Time of travel 50 days	Volume from dry stress period	Volume from wet stress period

Outer Zone based on volume from exceeding 30 m^3/d in the wet stress period and incorporating >30 m^3/d from dry stress period. Area covered equates to 222 model cells, which at a volume from rate of 30 m^3/d equates to 3 565 m^3/d or around 70% of the abstraction.



Final Inner, Outer and total capture zone at Lovedean.