

**Scottish Environment
Protection Agency,
the Environment
Agency, the
Environment
Protection Agency
and Northern Ireland
Environment Agency**

**Cumulative Nitrogen
and Phosphorus
Loadings to
Groundwater**

Final Report

22 November 2010

Entec UK Limited

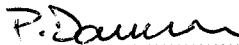
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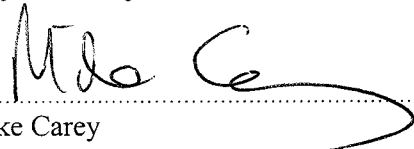
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Scottish Environment Protection Agency, the Environment Agency, the Environment Protection Agency and Northern Ireland Environment Agency

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Final Report

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Entec UK Limited



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Document Revisions

No.	Details	Date
1	Draft Report	2 August 2010
2	Draft Report	22 October 2010
3	Final Report	22 November 2010

Executive Summary

Purpose of this Report

This report has been produced for the purpose of assessing cumulative loadings of nitrogen and phosphorus to groundwater. A literature review has been undertaken to provide information on loadings from both agricultural and urban sources of nitrate and phosphorus. Sources considered include:

- Landfill;
- Graveyards;
- Sewage effluent discharges;
- Mains water and sewer leakage;
- Agricultural point sources (e.g. leakage from slurry stores);
- Agricultural diffuse sources (infiltration from arable and grassland);
- Urban diffuse sources.

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

This information has been used to estimate typical loadings from each source to allow a comparative assessment of their significance in terms of cumulative loading to groundwater.

Two Excel tools have been developed to estimate nitrogen and phosphorus loadings to urban and rural catchments. These spreadsheets provide an initial rapid assessment tool to look at catchment nitrogen and phosphorus balances and to identify main contributions and thereby identify where measures should be targeted or if further investigation of a source is required.

These tools have been applied to two urban and six rural catchments. In rural areas the main inputs of nitrogen are predicted to be organic and inorganic fertilisers, and the main losses to groundwater are from diffuse agricultural sources. For urban areas the main losses are associated with park and gardens, leaking water mains and sewers. The majority of phosphorus inputs to groundwater are predicted to be from sewage effluent discharges, sewer and mains leakage, particularly in urban areas.

The review has identified a number of gaps in the available information and in particular quantitative data on attenuation in the subsoil/ unsaturated zone, especially of phosphorus.

Phosphorus loadings to soil can be high but the focus of modelling work to date has been on losses to surface water rather than groundwater, as leaching rates from the soil are typically low compared to phosphorus inputs. However, only relatively low losses (few Kg P/ha/year) are required to exceed water quality standards and therefore uncertainties in loading calculation and attenuation will be significant.

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1. Introduction

1.1 Background

The Scottish Environment Protection Agency (SEPA), the Environment Agency (EA), the Environment Protection Agency (EPA) and Northern Ireland Environment Agency (NIEA) have published their first River Basin Management Plans (RBMP) which include the results of the classification of groundwater and surface water bodies and outlines the programme of measures that will be implemented to improve the status of water bodies and to reverse deteriorating trends.

As part of their RBMPs, these Agencies have set objectives for failing water bodies (i.e. achieve good chemical status by 2015 and where this is not possible, and subject to the criteria set out in the Directive, aim to achieve good status by 2027) and are looking to put in place measures to reverse significant and upward trends.

For the next RBMP cycle the Agencies have identified that there is a need to undertake more detailed analysis of the pressures that pose a risk to groundwater bodies including those that give rise to nitrogen (N) and phosphorus (P) loading to groundwater. For the first RBMP cycle the loading of N and P from diffuse and point sources was largely considered separately and in the next cycle the cumulative loading will need to be assessed in more detail.

The loading of nitrogen to groundwater has resulted in a large number of groundwater bodies failing to achieve good chemical status. Significant rising trends have also been identified in a number of water bodies. For phosphorus, the first RBMP cycle identified that there was a risk from this pollutant, but there is uncertainty as to whether it is giving rise to failure (i.e. is there significant leaching of phosphorus applied to the soil zone).

The nitrogen and phosphorus loading to groundwater will be a result of both diffuse and point sources. For nitrate the assessment of loading from diffuse sources (e.g. agricultural) is more straightforward as this pollutant is not affected by sorption and its transport through the unsaturated and saturated zone is well documented. Under anaerobic conditions, nitrate can be lost due to transformation to nitrogen gas. For ammonium, which may transform to nitrate, sources may include atmospheric deposition, fertilisers and point sources such as landfill leachate or sewage effluent discharge. The fate of transport of ammonium is more complicated due to sorption and transformation to nitrate.

The assessment of the loading to groundwater from phosphorus applied to the land surface is complicated by the sorption of this compound in the soil and its leaching may be controlled by a range of environmental factors. As a result there is uncertainty as to whether phosphorus applied in fertilisers is being leached from the soil and impacting groundwater.

For many aquifer situations (e.g. dual porosity aquifers) there may be a significant delay for nitrate and phosphorus leached from the soil zone to arrive at the water table. This further complicates the analysis of the impact of pressures on groundwater quality and in particular the timescale for the benefit of measures to be realised.

1.2 Objectives

Entec UK Ltd (Entec) was commissioned by SEPA, EA, EPA and NIEA in March 2010 to undertake a research project on the N and P loadings to groundwater.

The objectives of the project are:

- To identify potential nitrogen and phosphorus loads arising from a point source (such as landfill sites, sewage effluent discharges to ground and graveyards) and diffuse (agricultural and non agricultural) activities;
- To advise Agencies on additional issues that need to be considered when evaluating potential cumulative impacts of N and P on groundwater;
- To identify a suitable methodology that could be used by the Agencies to assess cumulative impacts of N and P on groundwater;
- To enable Agencies to perform more detailed analysis of groundwater pressures for the next RBMP classification exercise;
- To enable Agencies to provide justification for the development of the Programme of Measures for the next RBMP cycle.

The steering group for this project comprised:

- Malcolm Roberts (SEPA);
- Alex Pritchard (SEPA);
- Vincent Fitzsimons (SEPA);
- Donal Daly (EPA);
- Tony Marsland (EA);
- Tanya Bowell (EA).

1.3 Scope of Work

The original project was divided into three phases as follows:

- Phase 1 Literature Survey;
- Phase 2 Evaluation of N and P Loading; and
- Phase 3 Evaluation of Methods.

The original scope is described in the Entec report rp001i1 'Cumulative Pollutant Loadings to Groundwater' dated February 2010. On completion of Phase 1 the scope of Phases 2 and 3 was revised following a progress meeting in 30th April 2010 and the changed scope is set out in letter of 5th May 2010 (27510/C19) and is summarised as follows:

- Phase 1 Literature Survey;

- Phase 2 Development of methodology to determine cumulative N and P loading from agricultural and non-agricultural sources of pollution;
- Phase 3 Assessment of N and P loading to eight representative catchments.

This document represents the results of this study.

This is a research report prepared for SEPA, EA, EPA and NIEA by Entec. As such it does not necessarily reflect the position of the participating Agencies but may influence their approaches and procedures. Each Agency may apply the outputs of this report in the context of its own procedures, legislation and government policy.

1.4 Conversion Factors

A review of the literature has identified that nitrogen and phosphorus may be reported in different forms. Definitions of the some of the main forms are given in Box 1.1.

Box 1.1 Forms of N and P	
Form	Definition
Soluble reactive phosphorus	A measure of the phosphorus available for plant uptake, generally predominantly orthophosphate. This term is sometimes interchanged (somewhat inaccurately) with the term "dissolved inorganic phosphorus".
Total phosphorus	A measure of the phosphorus present in a water sample in all forms, reactive and unreactive, dissolved and particulate.
Total dissolved phosphorus	The sum of soluble reactive phosphorus (SRP) and soluble unreactive phosphorus. This last is generally predominantly organic phosphorus.
Total organic nitrogen (TON)	TON is the sum of nitrate (NO ₃), nitrite (NO ₂), organic nitrogen and ammonia (NH ₃) all expressed as N.
Ammoniacal Nitrogen	Ammonia occurs as the ammonium ion (NH ₄ ⁺) and as unionised ammonia (NH ₃).
Kjeldahl nitrogen	Sum of organic nitrogen, ammonia (NH ₃) and ammonium (NH ₄).

In Box 1.2 a summary is provided of conversion factors for different forms of nitrogen and phosphorus.

Box 1.2 N and P Conversion Factors		
Form	Form	Conversion Factor (e.g. column 1 to column 2)
PO ₄	as P	0.326
P ₂ O ₅	as P	0.436
NO ₃	as N	0.226
NH ₃	as N	0.82
NH ₄	as N	0.78

Example: 0.2 mg/l as PO₄ is equivalent to 0.2 x 0.326 = 0.065 mg/l as P

1.5 Environmental Standards

In this report the terms environmental standard and Threshold Values have been used (Section 3.1).

In the context of environmental impact a standard for a substance is a concentration and an associated compliance regime, that when exceeded indicates an adverse environmental outcome, such as pollution. The compliance regime will consist of a summary statistic (such as a mean, 95%ile, or an absolute limit), a time period over which compliance is assessed and, in the case of groundwater, the area over which these criteria are applied (e.g. at a point or as a spatial average).

The application of the same numeric value can have dramatically different effects dependent upon the compliance regime. For example the Drinking Water Standard for nitrate of 50 mg/l is a Maximum Admissible Concentration at the point of supply to a consumer. The 50 mg/l "standard" for nitrate in the Groundwater Daughter Directive is an average applied over a groundwater body. In this case the "standard" is in practice not applied as a standard but as a Threshold Value for the further assessment of chemical status. Threshold Values as noted in this latter context should not be confused with regulatory standards (as noted in UKTAG guidance paper 11b(iii) - Application of Groundwater Standards to Regulation)." (UKTAG 2008a).

2. Literature Search

The main aim of the literature search has been to identify and report information on loadings associated with different activities rather than to provide a detailed description of the processes by which pollution occurs. The activities considered in the review are:

- Landfills - inert and non hazardous (Section 4);
- Graveyards (Section 5);
- On-site wastewater treatment systems discharging to groundwater (Section 6);
- Leaking sewers (Section 7);
- Leaking water mains (Section 8);
- Atmospheric wet and dry deposition (Section 9);
- Urban areas (Section 10);
- Diffuse agricultural activities - arable and grassland (Section 11);
- Point source agricultural activities - farmyard dirty water, constructed wetlands, slurry (Section 12);
- Each of the above chapters has been broken down as follows:
 - General description of the activity and factors affecting pollutant loading;
 - Summary of published literature on pollutant loadings;
 - Estimation of pollutant loadings.

A summary of attenuation processes is provided in Section 13.

The information has been used to assess N and P loadings for a range of catchment types (see Sections 14 and 15).

There is a considerable volume of published literature in N and P losses to groundwater and a pragmatic approach was adopted. Therefore the literature review has focused on recently published (i.e. in the last 5 years) papers, books and articles, although older references were considered where they are regarded as authoritative or definitive. The review was largely restricted to references relating to the UK, except where this identified that there was limited information available.

A reference list is provided in Section 16.

3. Estimate of Loadings

For each activity (Sections 4 to 12) an estimate is provided on N and P loadings. This information has then been used to determine loading rates for a number of example urban and agricultural catchments as described in Section 14.

As far as possible the information on N and P loadings has been summarised in table format. Where possible information on loadings has been expressed as kg N or P /ha/year, although in some cases loadings may be expressed as kg N or P/person/year. For some pollutant sources (e.g. landfill leachate) information is presented as a concentration (mg/l N or P) and this has been used to calculate a loading as Kg N or P ha/year based on estimated discharge or leakage rates. The loadings are intended to represent 'generic' loading rates rather than site or licence specific loading rates.

Calculations have been undertaken for a number of catchments representative of various climate zones within the UK and Ireland:

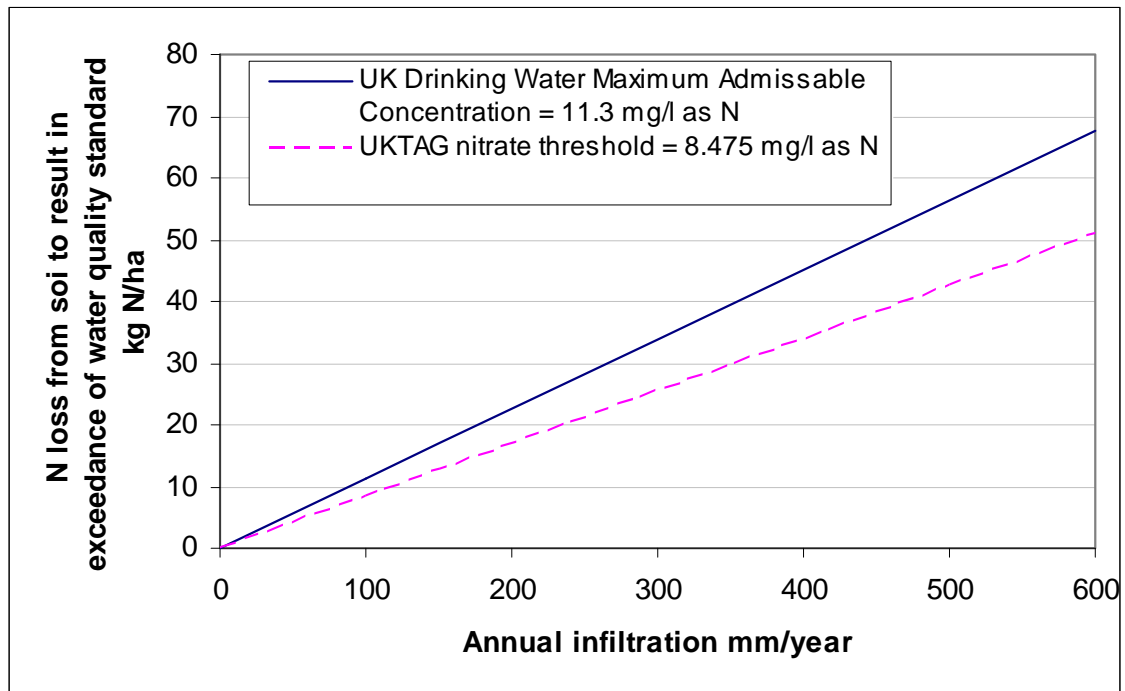
Low rainfall (e.g. East Anglia): Hydrological effective rainfall = 150 mm/year;

Moderate rainfall (e.g. Central England): Hydrological effective rainfall = 300 mm/year;

High rainfall (e.g. Scotland): Hydrological effective rainfall = 600 mm/year.

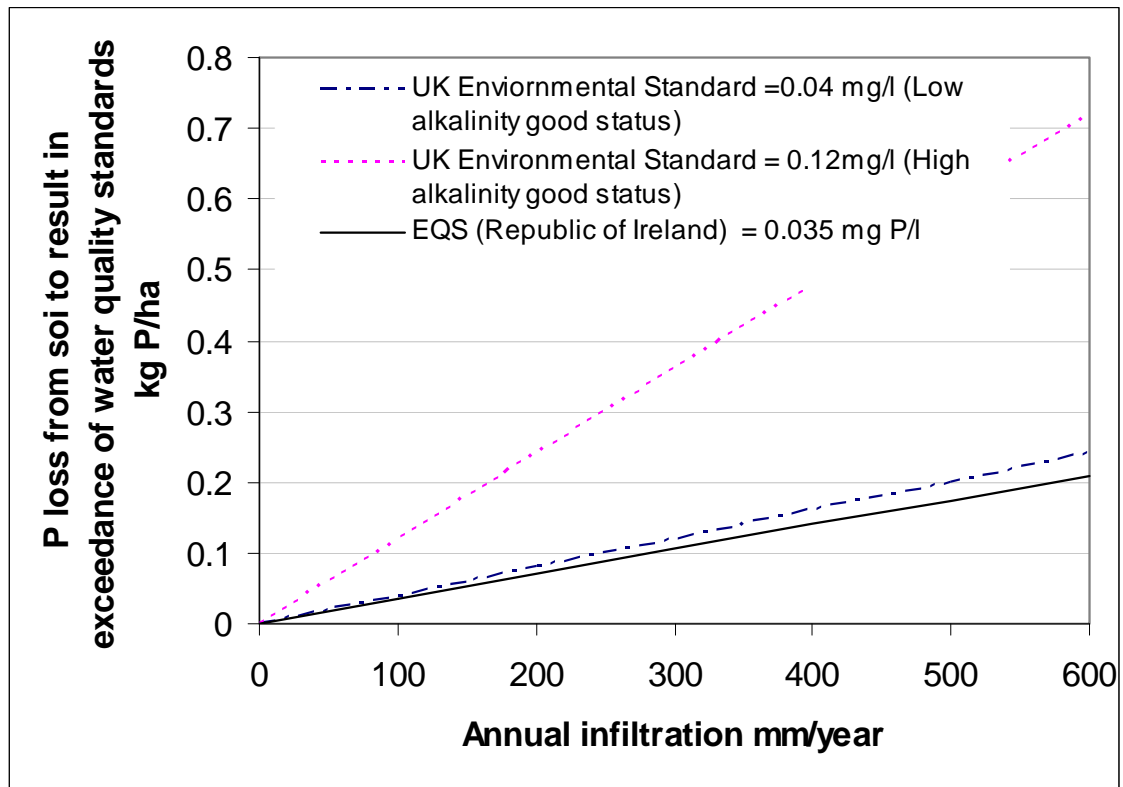
The amount of N that would need to be leached from soils to result in exceedance of the UKTAG nitrate threshold value of 8.475 mg/l as N¹ (Section 1.4) is shown in Plate 3.1. This plate is included to provide a reference to compare reported application rates and leaching rates of N. This plate indicates that for infiltration rates of 150 and 600 mm/year the loading would need to exceed 13 and 50 Kg N/ha/year respectively. Also shown in Plate 3.1 is the loading required to exceed the maximum admissible concentration for drinking water of 11.3 mg/l as N.

¹ UKTAG Threshold set as 75% of the drinking water standard (UKTAG, 2007)

Plate 3.1 Calculation of N Loading Required to Exceed Water Quality Standards

The amount of P that would need to be leached from soils to result in exceedance of surface water UK environmental quality standards of 0.04 to 0.12 mg/l as P is shown in Plate 3.2. The Republic of Ireland environmental water quality standard of 0.035 mg P/l is also shown. This plate is included to provide a reference to compare reported application rates and leaching rates of P, and indicates that relatively low losses (<1 kg P/ha) are required to result in exceedance of water quality standards.

Plate 3.2 Calculation of P Loading Required to Exceed Water Quality Standards for Rivers



4. Landfill

Landfill sites are classified as inert, non-hazardous and hazardous. Waste can only be accepted at a landfill if it meets the waste acceptance criteria (WAC) for that class of landfill. This review has only considered inert and non-hazardous sites.

Non-hazardous sites can accept municipal waste along with non-hazardous wastes (including inert wastes) of any other origin. There are no numerical WAC limits for non-hazardous landfills. Inert landfill sites can accept waste which meets the inert WAC limits. The definition of inert waste in the Landfill Directive is:

'waste that does not undergo any significant physical, chemical or biological transformations. Inert waste will not dissolve, burn or otherwise physically or chemically react, biodegrade or adversely affect other matter with which it comes into contact in a way likely to give rise to environmental pollution or harm human health. The total leachability and pollutant content of the waste and the ecotoxicity of the leachate must be insignificant, and in particular not endanger the quality of surface water and/or groundwater.'

The types of wastes going to landfill have changed over time as legislation (the Landfill Directive implemented through the Environmental Permitting Regulations 2010) and waste management practices have changed. The most significant changes over the last 10 years (aside from the classification of landfill sites into the three main classes and the re-permitting of existing landfill sites) are:

- The requirement (from 2005) for waste destined for landfill to meet WAC. Waste acceptance criteria have been set for hazardous, stable non-reactive hazardous and inert landfills. The WAC are laid down in Council Decision 2003/33/EC;
- The requirement (from 2007) to treat waste prior to disposal to existing non-hazardous or inert landfill sites. For municipal waste this may require mechanical sorting and biological treatment prior to disposal. Inert waste does not have to be treated if it is not technically feasible to do so. Treatment is not required if it would not reduce its quantity or the hazards that the waste poses to human health or the environment. For new landfills (permitted since 2002) this has been a requirement since the date they were permitted;
- The ban on liquid waste (from 2007) being disposed of at existing non-hazardous and inert landfill sites. New landfills (permitted since 2002) have been banned from accepting liquid wastes since they were permitted.

4.1 Leachate Quality

Leachate composition will depend on a range of factors including: type of wastes (including any pre-treatment of waste), waste saturation (i.e. unsaturated or saturated), the age of the waste and infiltration to the waste (both as a result of rainfall and leachate recirculation).

The results of analysis of landfill leachate will typically include ammoniacal nitrogen, nitrate and nitrite. Ammoniacal nitrogen is the dominant form of nitrogen present. The concentrations of nitrate and nitrite will typically be low and less than 1 mg/l as N (Robinson, 1995). Results are sometimes provided for Kjeldahl nitrogen which is the sum of organic nitrogen, ammonia (NH₃) and ammonium (NH₄).

4.1.1 Non-Hazardous Landfill

The majority of published data on leachate quality relates to municipal waste landfilled in the 1980's, 1990's and early part of the 2000's (i.e. prior to the requirement to treat wastes). This information is summarised in Table 4.1.

Table 4.1 Summary of Leachate Quality for Non-hazardous Landfill Sites (Non Treated Municipal Wastes)

Determinand (Units as mg/l)	Minimum	Median	Mean	Maximum	Reference
Ammoniacal nitrogen as N	4.4	723 (most likely)		3640	Default leachate Environment Agency 2007 (LandSim ¹) based on Robinson 1995
Phosphate as P	<0.01	0.8 (most likely)		7.4	
Ammoniacal nitrogen as N	<0.2	453	491	1700	Robinson, 1995
Phosphate as P	<0.1	1.1	3	15.8	
Ammoniacal nitrogen as N		267	481		E Agency, 2003a
Ammoniacal nitrogen as N		405	611		E Agency, 2001a
Ammoniacal nitrogen as N		394	429		Robinson, 1995 (municipal waste only)
Phosphate as P		0.8	2.5		
Ammoniacal nitrogen as N		596	635		Robinson, 1995 (municipal with some commercial)
Phosphate as P		2.9	4.1		

1. LandSim is a modelling package developed by the Environment Agency to assess the risk to groundwater from landfill leakage.

There is more limited information on leachate quality for mechanically and biologically treated (MBT) waste (also referred in the literature as mechanical biological pre-treatment waste). The main sources of information on MBT waste are Environment Agency (2004a) and Bone et al (2003). Mechanically sorted waste tends to have a high ammonium concentration and only after composting do ammoniacal nitrogen concentrations decrease with leachate quality dependent on the degree of composting.

Bone et al (2003) gives a summary of recommended leachate quality for MBT waste for groundwater risk assessments and this is summarised in Table 4.2.

Table 4.2 Recommended Mechanical Biological Pre-Treatment (MBP) Waste Leachate Quality for Groundwater Risk Assessment (Bone et al 2003)

Determinand (units as mg/l)	Mechanical Sorted Municipal Waste (methanogenic)	MBP Waste High Composting (initial)	MBP Waste High Composting (later)	MBP Waste Low to Medium Composting	Range from Composted Wastes
Ammoniacal nitrogen as N	4000	30	200	50 to 1000	1.8 to 1130
Phosphate as P	20	0.5	3	1 to 15	0.3 to 12.4

Leachate quality will also vary with time as a function of changing geochemical conditions (e.g. from acetogenic to methanogenic conditions) and as nitrogen and phosphate are removed from the waste mass via leachate abstraction or leakage to the surrounding environment. The rate of leaching will be a function of the volume of infiltration to the total field capacity of the waste.

A method for calculating the change in leachate quality is given in the LandSim manual (Environment Agency, 2007) which is based on the following equation:

$$C_t = C_o \cdot \exp(-\kappa \cdot LS)$$

Where:

C_t = Leachate concentration after time t (mg/l)

C_o = Initial leachate concentration (mg/l)

κ = Kappa value (kg/l) which is a species and waste specific parameter

LS = Liquid to solid ratio at time t (l/kg) which can be calculated as the total infiltration to the waste after time t divided by the waste mass.

The Landsim default kappa value for ammonium is 0.59 kg/l. There are no published kappa values for phosphorus. Plate 4.1 illustrates the change in ammonium concentrations over time for a 20 m thickness of waste with a density of 1000 kg/m³ with an infiltration of 300 mm/year.

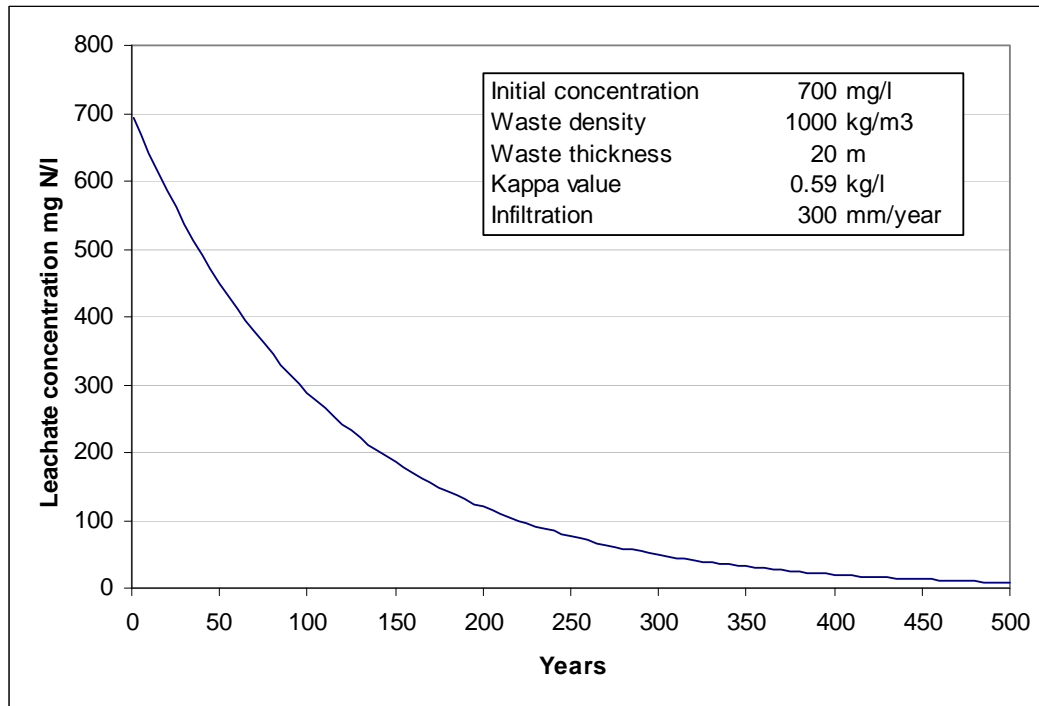
Plate 4.1 Calculated Change in Leachate Quality Over Time

Table 4.3 provides a further estimate of the reduction in loading over time as a result of flushing of the waste mass.

Table 4.3 Estimate of Reduction in Leachate Loading Over Time as a Result of Flushing of the Waste Mass

Infiltration to Waste mm/year	Percentage Reduction in Loading			
	After 10 years	After 20 years	After 100 years	After 500 years
150	4.3	8.5	35.8	89.1
300	8.5	16.2	58.7	98.8
600	16.2	29.8	83.0	100.0

Calculation assumes waste thickness of 20 m, waste density of 1000 kg/m³ and Kappa value of 0.59 kg/l.

4.1.2 Inert Landfill

For inert sites, an initial review of UK and European literature indicates that there is very limited data on leachate quality for N and P. This is partly a reflection of the fact that there are no waste acceptance criteria for N or P and as by definition inert waste should not include organic and soluble waste. The concentration of N and P in leachate would therefore be expected to be low.

Older inert landfill sites may include some organic waste (e.g. wood, paper and small amounts of domestic waste). There is limited published information on leachate quality for such sites; however Westlake et al (1991) provides information for industrial and commercial waste sites and sites receiving demolition and ‘inert’ waste. These data are summarised in Table 4.4.

Table 4.4 Summary of Leachate Quality for Older Inert Sites (Westlake et al 1991)

Determinand (Units as mg/l)	Minimum	Median	Mean	Maximum
Industrial Commercial				
Ammoniacal nitrogen as N	0.21	15.6	28.2	170
Phosphate as P	0.02	0.5	4.1	3.2
Demolition and Inert Wastes				
Ammoniacal nitrogen as N	0.4	0.9	34.5	95
Phosphate as P	0.01	0.1	1.2	13

4.2 Leakage Rates and N and P Loading

The N and P loading from a landfill site will depend on its area, the leakage rate through the base and sides of the site and the leachate concentration. The loading will also vary with time as leachate quality changes, site management practices change (e.g. leachate abstraction ceases) and as the engineering performance of the cap or basal liners deteriorates. These changes have not been taken into account in this assessment.

The leakage rates from a landfill will depend on:

- Infiltration to the waste which will depend on cover material (active areas) and capping material (restored areas);
- Landfill cap (e.g. engineered cap);
- Basal liner (e.g. composite liner);
- Head of leachate on the basal liner;
- Age of the cap and or liner.

For older (closed) landfills there is a potential that there is no engineered cap and/or basal liner and no leachate management. For these sites it can be assumed that the leakage rate would be equivalent to infiltration through the surface of the landfill. Leachate for older landfills may be characterised by lower N and P concentrations as a result of flushing of the waste (Section 4.1.1)

The rate of leakage will therefore be site specific and depend on climate, engineering and leachate control measures. Models, such as LandSim, can be used to calculate loading rates and how these change with time, however for the purposes of this study the following cases have been considered to provide an initial estimate of N and P loading rates:

1. Landfill with no engineered cap or basal liner. In this case infiltration rates of 150 mm/year, 300 mm/year and 600 mm/year have been assumed (see Section 3);
2. Landfill with engineered cap (clay cover) and a leakage rate of 30 mm/year assumed (approximately equivalent to leakage through a clay liner with a hydraulic conductivity of 10^{-9} m/s subject to a hydraulic gradient of 1);
3. Landfill with engineered composite liner subject to a leachate head of 1m. Calculated leakage rates using LandSim indicate leakage rates are likely to be <10 mm/year. A value of 10 mm/day has been used for this study. This scenario is only relevant to non hazardous landfill sites where a high level of engineering is required.

4.2.1 Loading Calculations

In Tables 4.5 and 4.6 estimates are provided of the N and P loading (per hectare) for different leachate quality and leakage rates. A summary of the equations used to calculate loadings is given in Appendix B. The calculations are based on an average loading due to flushing of waste over a 10 year period.

Table 4.5 Calculated N Loadings from Non-Hazardous Landfill Sites (No N Losses due to Attenuation)

Landfill	Leakage Rate m/year	Loading Kg N/ha/year			
		Initial Leachate Concentration mg N/l			
		723 mg/l (untreated municipal waste) (LandSim default most likely value)	453 mg/l (Robinson 1995, median value)	200 mg/l (MBP waste ¹) (Bone, et al 2003)	28 mg/l (Industrial Commercial waste) (Table 4.4)
Non engineered landfill	0.15	1061	660	293	41
Non engineered landfill	0.3	2076	1292	574	80
Non engineered landfill	0.6	3978	2476	1100	154
Landfill with engineered cap	0.03	216	134	60	8
Landfill with engineered basal composite liner	0.01	72	45	20	3

1. The available data (Table 4.3) is used as a surrogate for the likely composition of nitrate in the future.
2. Calculations assume waste thickness of 20 m, waste density of 1000 kg/m³ and Kappa value of 0.59 kg/l.

Table 4.6 Calculated P Loadings from Non-Hazardous Landfill Sites

Landfill	Leakage Rate m/year	Loading Kg P/ha/year			
		Leachate Concentration mg P/l			
		0.8 mg/l (untreated municipal waste) (LandSim default most likely value)	1.1 mg/l (Robinson 1995, median value)	3 mg/l (MBB waste ¹) (Bone, 2005)	4 mg/l (Industrial Commercial waste) (Table 4.4)
Non engineered landfill	0.15	1.2	1.6	4.4	5.9
Non engineered landfill	0.3	2.3	3.2	8.6	11.5
Non engineered landfill	0.6	4.4	6.1	16.5	22.0
Landfill with engineered cap	0.03	0.2	0.3	0.9	1.2
Landfill with engineered basal composite liner	0.01	0.1	0.1	0.3	0.4

1. The available data (Table 4.3) is used as a surrogate for the likely composition of leachate in the future.

2. Calculations assume waste thickness of 20 m, waste density of 1000 kg/m³ and Kappa value of 0.59 kg/l.

Non-hazardous waste is currently disposed of in engineered landfill sites (composite liner) such that leakage rates are likely to be low and therefore N and P loading will also be relatively low (Tables 4.5 and 4.6). The main loading will be from older landfill sites (mainly closed) where there was limited or no engineering measures.

These loading calculations make no allowance for attenuation in the unsaturated zone below the landfill.

4.3 Summary

In Table 4.7, proposed default values are given for leachate concentration and these have been used in the catchment loading calculations (Section 14).

Table 4.7 Default Nitrogen and Phosphorus Concentrations

Landfill	Leachate Concentration mg/l			
	Nitrogen as N		Phosphorus as P	
	Initial Concentration	Concentration as a Result of Flushing of Waste ¹	Initial Concentration	Concentration as a Result of Flushing of Waste ¹
Non hazardous (untreated municipal waste)	723	707	0.8	0.8
Non hazardous (treated municipal waste)	200	192	3	2.9
Inert landfill ²	1	1	0.1	0.1
Older 'Inert' landfill (industrial commercial waste)	28	27	4	3.9

1. Calculated as average concentration for waste flushed over a 10 year period and assumes infiltration rate of 300 mm/year, waste thickness of 20 m, waste density of 1000 kg/m³ and Kappa value of 0.59 kg/l.

2. Assumed that the concentration of N and P in leachate in inert sites is low.

5. Graveyards

The burial of human and animal corpses in cemeteries and their subsequent degradation may result in N and P loading to groundwater. Information on the loadings from graveyards has mainly been taken from Environment Agency 2002a and 2004b.

A summary of the information on different types of cemetery is given below:

Human Burials

Conventional burials: Burial is in a coffin to a typical depth of 1.8 m with a grass or stone chipping cover over the grave. Coffins are typically made of chipboard or MDF in paper veneer. About 50% of burials involve embalming. The estimated number of burials for a large town (population of 150 000 to 250 000) is 1000/year (Environment Agency 2004b). The Defra statistics web sites indicate an annual death rate of 9 per 1000. The typical dimensions of a grave are 2.1 x 1.2 m and the typical density of graves is 1976 graves per hectare.

Green burials: Burial is in a biodegradable coffin to a typical depth of 1.3 m with grass or shrub cover over the grave. The Environment Agency (2004b) reports that there are 50 to 100 green cemeteries in Great Britain. The typical density of green graves is 1580 graves per hectare.

Human mass burials have not been considered as part of this literature review.

Animal Burials

Commercial pet burials: Most domestic pets are buried in owner's gardens or landfilled by veterinary practices. Animals (mainly dogs) can also be buried in pet cemeteries, although a literature search indicates that most pets are cremated. Burials are typically to a depth of at least 0.9 m with a density of about 9000 to 10 000 burials per hectare.

Mass animal burials: The main mass animal burials are associated with the foot and mouth outbreak in 2001 when over 4 million animals (sheep, cattle, pigs) were culled. Statistics on the numbers of animals culled are available on the Defra Animal Health website. Animal burials were either on farm or at licensed landfill facilities. Farm burial sites were typically 4 m deep with a minimum thickness of unsaturated zone of 1 m and a 2 m cover. Typically less than 1000 livestock were buried on a farm site, but larger numbers (several hundred thousand) were often disposed of at regional centres. Defra holds a database of burial sites. Burial sites either took ash (incinerated carcasses) or carcasses.

Mass burials will represent a finite source, whereas human and pet burials will represent a constant source on the basis that there will be new burials each year.

On farm burials have been banned since 2003 (except in remote areas), with the carcasses either being sent to an incinerator or rendering plant.

5.1 Nitrogen and Phosphorus Release

5.1.1 Human Burials

There are limited published data on the loading and/or leachate quality from graveyards and in particular from animal burials.

Information on potential contaminant release from decomposition of a human corpse is given in Table 5.1.

Table 5.1 Potential Contaminant Release (kg) from a Single 70kg Burial (Environment Agency 2002a and 2004b)

Year	Release of N Kg/year	Release of P Kg/year
1	0.68	0.25
2	0.34	0.125
3	0.17	0.063
4	0.09	0.032
5	0.04	0.016
6	0.02	0.008
7	0.01	0.004
8	<0.01	0.002
9	<0.01	0.001
10	<0.01	<0.001
Total	1.35	0.5

Decomposition is usually complete within 10 years with most of the release occurring in the first year. However slower rates of decomposition may occur under anaerobic or waterlogged conditions.

The amount of infiltration through a typical grave is given in Table 5.2

Table 5.2 Estimate of Water Flux through a Typical Grave Area (Environment Agency, 2004b)

Grave Cover	Surface Infiltration l/Year	Infiltration From Grass Surrounds l/Year	Total l/Year
Chippings	750	250	1250
Grass	500	500	1000
Green burial	250	760	1010

Assumes:

- 1 A standard grave size of 2.1 x 1.2 m.
- 2 Mean annual rainfall of 650mm and typical evapotranspiration losses.
- 3 1976 graves per hectare for conventional burials.
- 4 1580 graves per hectare for "green" burials.

5.1.2 Animal Burials

The amount of N released from decomposition of an animal carcass is given in Table 5.3 (Environment Agency 2003b).

Table 5.3 Potential Annual Releases (kg) of Pollutants from Burial of One Tonne of Slaughtered Stock

Year	Release of Kg N/year
1	2.26
2	0.94
3	0.47
4	0.23
5	0.16
6	0.16
7	0.08
8	0.08
9	0.08
10	0.06
Total	4.5 (average 0.45 kg N/year over 10 years)

There are no similar data for phosphorus, although using the data given in Table 5.1 an estimate of the amount of phosphorus released per tonne of slaughtered stock is 1.7 Kg P/year over 10 years.

The weight of different livestock is given in Table 5.4, together with an estimate of the amount of N released.

Table 5.4 Livestock Weight and Estimate of N Released

Parameter	Livestock Weight kg (juveniles)	Livestock Weight kg (adult)	Estimated Slaughter Weight Per 1000 Animals (kg)	Comment	N Released Per 1000 Animals (kg N) ¹	Source
Cattle (beef)	40 - 70	500	347000	Assumes 66% adult (500 kg), 34% juvenile (50 kg)	1562	Environment Agency 2003b
Cattle (dairy)	25 - 50	450 - 650	373000	Assumes 66% adult (550 kg), 34% juvenile (30 kg)	1679	Environment Agency 2003b
Sheep	8 - 35	65 - 80	31760	Assumes 33% adult (80 kg), 67% juvenile (8 kg)	143	Environment Agency 2003b
Pigs	2 – 18	150	27600	Assumes 15% (150 kg) adult, 85% juvenile (6 kg)	124	Environment Agency 2003b
Poultry (adult)		3	3000		13.5	Environment Agency 2003b

1. Calculation based on 1 tonne of slaughtered livestock releases 4.5 Kg N (Table 5.3) over 10 years..

Farm burials, except in remote areas, have been banned since 2003, such that the main losses are likely to be associated with permitted waste disposal sites.

The leachate concentration in an animal burial site will be a function of:

- The method of slaughter and age of the carcasses before burial;
- Whether animals have been cremated prior to burial (i.e. disposal of ash only);
- The addition of disinfectants or materials such as lime;
- The size and degree of containment of the burial pit;
- The leachate level within the waste, including any facilities for leachate drainage and abstraction within the burial pit.

There is limited published information on loading and leaching quality associated with mass animal burials. There are published data for a site in Scotland where 440 000 carcasses (mainly sheep) were landfilled (MacArthur et al 2002) and this is summarised in Table 5.5. Information on sampling of leachate (Environment Agency 2003b) in mass burial sites in England and Wales is given in Tables 5.6 and 5.7. Leakage rates will depend on the design of the landfill (see Section 4).

Table 5.5 Leachate Quality: Mass Burial Site Scotland (MacArthur et al 2002)

Parameter	Number of Samples	Minimum	Maximum	Mean	Median	Standard Deviation
Phosphate as P (mg/l)	198	1	476	55	25	77
Ammonia as N (mg/l)	199	28	19200	3294	2700	2702

Table 5.6 Leachate Quality: Mass Burial Sites, England and Wales (Environment Agency 2003b)

Parameter	Number of Samples	Range	Mean
Phosphate as P (mg/l)	7	10 - 334	110
Ammonia as N (mg/l)	7	1000 -7000	4000 (suggested)

Leachate quality for mass burial sites can be characterised by higher strength leachate than non-hazardous landfill sites.

Table 5.7 Leachate Quality: Leaching of Ash at Mass Burial Sites, England and Wales (Environment Agency 2003b)

Parameter		Range	Mean
Ammonia as N (mg/L)	Proposed values for risk assessment	2.7 - 2390	32

The loading from pets has not been calculated as this is likely to be relatively small as most animals are either buried in owners' gardens, landfilled by veterinary practices or cremated at pet cemeteries.

5.2 Loading Calculations

Estimates of the loading from human burials are given in Table 5.8 for the following cases:

1. Small churchyard (10 burials a year);
2. Large municipal site (350 and 1000 burials a year);
3. Green site (30 burials a year).

This calculation is only valid if the rate of burial is maintained.

A cemetery will comprise new graves (less than 10 years), older graves (where losses from a corpse can be assumed to be negligible) and grassed or paved areas. An estimate of the total loading (kg/ha) has been based on the loading from burials and from grassed areas. For grassed areas the loading will be largely dependent on atmospheric deposition and fertiliser use. For this calculation a loss of 10 kg N/ha has been assumed.

Table 5.8 Estimates of N and P Loading From Human Burials

	Number of Burials Per Year	Loading Kg N/Year	Loading Kg P/Year	Land Take for New Graves (m ²)	Loading Kg N/ha/Year	Loading Kg P/ha/Year
Small churchyard	10	13.5	5	50.6	23.4	5.1
Large municipal site	1000	1350	500	5060.7	1354.9	500.0
Green burial	30	40.5	15	189.9	50.3	15.1

Assumes:

1. Release of 0.5 Kg P and 1.73 Kg N from decomposition of human corpse (see Table 5.1) plus loss of 10 kg N ha/year and 0.1 Kg P/ha/year from remaining areas.
- 2 1976 graves per hectare for conventional burials.
- 3 1580 graves per hectare for "green" burials.

An estimate of loading rates from large animal burial sites is given in Table 5.9

Table 5.9 Estimates of N and P Loading From Animal Mass Burial Site

Landfill	Leakage Rate m/year	Loading Kg N/ha/year		Loading Kg P/ha/year	
		Mean leachate concentration 4000 mg/l as N ¹	Ash - Mean leachate concentration 32 mg/l as N ²	Mean leachate concentration 110 mg/l as P ¹	Ash – No data
Non engineered landfill	0.15	6000	48	165	-
Non engineered landfill	0.3	12000	96	330	-
Non engineered landfill	0.6	24000	192	660	-
Landfill with engineered cap	0.03	1200	10	33	-
Landfill with engineered basal composite liner	0.01	400	3	11	-

1. See Table 5.6

2. See Table 5.7

5.3 Summary

In Table 5.10, proposed default values are given for loading from graveyard or animal burials and these have been used in the catchment loading calculations (Section 14).

Table 5.10 Estimates of N and P Loss from Human and Animal Burials

Year	Release of N Kg/year	Release of P Kg/year
Human burial ¹	1.35 per person	0.05 per person
Animal burial ^{1,2}	0.45 per tonne of stock	0.17 per tonne of stock

1. Over a 10 year period. If the rate of burial is maintained values should be multiplied by 10.

2. The weight of different livestock is given in Table 5.4.

6. Waste Water Treatment Systems Discharging to Ground

Liquid effluent discharges to the ground (typically via infiltration systems) occur largely from septic tank systems, package treatment plants, and sewage treatment works. Non sewage related effluents, e.g. from the treatment of industrial wastewaters, may come from a variety of other treatment plants.

Discharges can range from $<1 \text{ m}^3/\text{d}$ (e.g. septic tank system serving a domestic property with less than 5 people) to several $1000 \text{ m}^3/\text{d}$ for a large sewage treatment work (STW) discharge to ground.

The number of septic tanks systems is large. For example it is estimated that there are 350 000 septic systems in Ireland (EPA, 2006) and the Environment Agency (2009) estimates that there are over 300 000 in England and Wales. The Environment Agency (2009) estimates that there are about 490 consented STW discharges to ground in England & Wales. Many of these discharges are small (less than $50 \text{ m}^3/\text{d}$), but there are clusters of larger discharges and several of these occur in Nitrate Vulnerable Zones.

6.1 Effluent Quality

The chemical composition of liquid effluent will depend on the effluent source (sewage or trade), the type of treatment system (septic tank, package treatment plant, sewage treatment works), and the state/condition of the treatment system. Sewage effluent is likely to be more consistent than the potentially large range in compositions from the treatment of other wastewaters (e.g. trade effluent).

The chemical composition of a typical septic tank and package treatment plant is given in Table 6.1. Package plant manufacturers quote that the plant should reduce ammoniacal nitrogen concentrations to less than 20 mg/l as N and more expensive plants can treat to 5 mg/l as N. A study by BGS (2007) measured higher concentrations in effluent from a package treatment plant although information on the condition of the plant was not available. However, the treatment process typically involves transformation of ammonium to nitrate and the latter form of nitrogen is not always measured and therefore assessments based on ammonium measurements alone may underestimate the total nitrogen loading.

Table 6.1 Effluent Quality

Contaminant	Ammonium (as N) mg/l	Phosphorous as P (mg/l)	Source
Concentration in sewage	~39 (residential properties)		British Water (2009)
Domestic effluent	17 to 62	5 - 20	EPA 2007 CoP
Domestic waste water from single property	39	10	EPA (2007)
Septic Tank Discharge	81	15.8	BGS (2007)
Septic Tank Discharge	38 - 50	8 - 33	EPA (2007)
Package Treatment Plant	16		Package treatment manufacturers. EPA 2007
Package Treatment Plant	16 (<1 to 100)		Investigation of package treatment plants Caithness
Package Treatment Plant	69	10.5	BGS (2007)
Reed bed system	22 (<1 to 55)		Investigation of package treatment plants Caithness
Treated effluent STWs	9 - 31 (Total inorganic N)	3 - 11	See Table 6.4
Treated effluent (SE England)	13 – 40 (28)	3 – 11 (6)	Entec, 2009.
Treated effluent STWs (England and Wales)	10 - 31 (Total inorganic N)		Estimated typical effluent quality from analysis of WIMS data

For package treatment plants effluent quality will depend on the type of plant and treatment process. For some treatment systems (STWs, package treatment plants), ammonium will be transformed to nitrate and measurements of ammonium alone may underestimate the total N loading.

Non-domestic sources of sewage effluent may have distinct characteristics that produce higher or lower strength effluent. The treated effluent from a sewage treatment works will be of a higher quality as a result of a higher standard of treatment. Average N and P concentrations in treated effluent for a number of STWs in SE England are given in Table 6.4.

The chemical composition of trade effluent will be dependent on the activities which produce waste water and the type of treatment process. Some trade effluents may also vary through the year.

6.2 Treated Sewage Effluent Discharge Rates

The discharge rate for treated effluent discharges can be based on measured discharges (typically for larger discharges such as STWs) or estimates based on the type of premise (Table 6.2) and the number of persons or based on the dry weather flow. The dry weather flow can be calculated based on the number of people served by the works and domestic water use (Box 6.1).

Table 6.2 Typical Rates of Sewage Generation (from British Water, 2009)

Premise	Sewage Generation Rate (Person/Litres/Day)	Premise	Sewage Generation Rate (Person/Litres/Day)
Domestic	180	Hotels, pubs and clubs	
Industrial		Prestige hotel	300
Office/factory without canteen	50	3* or 4* hotel	250
Office/factory with canteen	100	Bedroom only	80
Open industrial site e.g. construction, quarry, without canteen	60	Residential conference/training	350
Schools		Non-residential conference/training	60
Non-residential without canteen	50	Holiday camp	227
Non-residential with canteen	90	Restaurants (per customer)	30
Residential	200	Public House (per customer)	12
Hospitals and residential care homes		Amenity Sites	
Residential old peoples/nursing home	350	Local community sports club	40
Small hospitals	350	Health club/sports centre	50
Large hospitals	450	Golf club	20
		Caravans (touring) not serviced	100
		Caravans (static) serviced	180
		Campsites	75

For domestic properties the volume of effluent can be estimated from: Discharge = 180 x (0.5 x No. of households + Total number of bedrooms)/1000.

Table 6.2 indicates a typical water use of 180 litres/day for domestic properties although the Irish EPA considers that a rate of 150 litres/day is more appropriate (EPA, 2006). Statistics published by the Environment Agency on their website indicate that the average household water use in 2007/2008 in England and Wales was 148 litres/day. Information published by Watchwater (Scotland) on their website gives a household use for 2006 of 140 litres/day.

Box 6.1 Dry Weather Flow (DWF)

DWF is the average daily flow to a sewage treatment works during a period without rain

An estimate of DWF can be obtained using the following formula:

$$DWF = PG + I + E$$

where:

P = Population served by the works

G = Domestic water consumption (typically 140 to 240 litres per head per day)

I = Infiltration of groundwater into the sewer (typically 50% of PG)

E = Trade effluent flows.

A summary of discharge rates and dry weather flows (l/person) is given in SNIFFER 2006a and are summarised in this paragraph. The Environment Agency has assumed a discharge of 180 l/person in estimating total phosphorus discharges reported on its public web site (<http://www.environment-agency.gov.uk/yourenv>). This figure is higher than other quoted figures for household water usage which are more typically 150 l/person/day, but which take no account of other discharges to sewer such as trade effluent. Analyses of consented dry weather flows and population equivalents reported by Stapleton et al. (2002) for 17 United Utilities treatment works showed that dry weather flow was equal to 237 l/person/day. Neal et al. (2005) reported that average flow from six Thames Water treatment works was equal to 222 l/person/day. These higher rates of loss indicate the contribution from other discharges.

Lerner (2000) reports a higher flow of 320 l/person based on estimated sewer flows for Nottingham.

6.3 Loading

Estimates of the N and P loading from the disposal of treated effluent to the ground are given in Tables 6.3 and 6.4 based on typical effluent quality and the number of people served by the treatment system.

Table 6.3 Estimates of N Loading From Treated Sewage Effluent

Number of People Served by Treatment Plant	Loading Kg N/Year	
	Ammoniacal Nitrogen Concentration in Effluent	
	20 mg/l as N (e.g. Package Treatment Plant or STW)	50 mg/l as N (e.g. Septic Tank)
5	5	14
10	11	27
50	55	137
100	110	274
1000	1095	2738

Assume water consumption per person = 150 l/d and that N in treated effluent is a ammonium only.

Table 6.4 Estimates of P Loading from Treated Sewage Effluent

Number of People Served by Treatment Plant	Loading Kg P/Year	
	Phosphate Concentration in Effluent	
	10 mg/l as P (e.g. package treatment plant or STW)	15 mg/l as P (e.g. septic tank)
5	3	4
10	5	8
50	27	41
100	55	82
1000	548	821

Assume water consumption per person = 150 l/d.

These calculated loading rates are slightly higher than estimated loading rates (Table 6.5) used in the SNIFFER WFD19 screening tool (SNIFFER, 2006a). The figures in Table 6.5 appear anomalous as higher loadings are quoted for sewage treatment work compared to septic tanks for which lower levels of treatment would be expected. The loadings given in Table 6.7 are considered, therefore, to be more realistic.

Table 6.5 N and P Loadings from Septic Tanks and Sewage Treatment Works (STW) (Sniffer 2006a)

	Septic Tank (kg/yr/person)	STW (kg/yr/person)
Nitrogen	1.64	2.41
Phosphorus	0.3	0.44

These estimates make no allowance for attenuation of N or P below the disposal area (see Section 6.4).

6.4 Attenuation of Effluent in the Drainage Blanket

Data from studies undertaken by the Irish EPA (EPA, 2006) and the Environment Agency (BGS, 2007) indicate that significant attenuation of ammonium takes place within the drainage blanket (see Box 6.2). Additional information from a literature review of the chemical and microbiological impacts of treated sewage effluent disposal into aquifer on groundwater quality is given in Environment Agency (2002a).

Box 6.2 Summary of Research on Sewage Disposal

BGS (2007). The BGS study investigated the impact of treated sewage disposal on Chalk groundwater beneath drainage fields serving a number of domestic properties. The BGS study did not encounter ammonium (NH_4) in groundwater beneath and down-gradient of the drainage field of a septic tank serving eight domestic properties, suggesting that it had attenuated or been diluted within a short distance of the point of disposal. Information on where there was an increase in nitrate as a result of transformation of ammonium is not provided.

EPA (2006) investigated the impact of sewage disposal at four domestic properties in typical settings and found that significant ammonium and phosphate attenuation occurred within the drainage field as shown in Table 6.6. This table indicates that the reduction of P in drainage ranges from 67 to 99% (average 88%). For N, whilst there is a significant reduction in ammonium (which in part will be due to transformation to nitrate, although measurements of total N indicate that at some sites there was a net loss of N), the reduction in the total nitrogen loading is variable ranging from 0 to 80% (average 40%).

Table 6.6 Changes in Effluent Loading with Depth (EPA, 2006)

Type of Treatment System	Site 1 Septic Tank	Site 2 Secondary Treatment	Site 3 Septic Tank. Infiltration System Includes Stratified Sand Filter	Site 4 Secondary Treatment. Infiltration System Includes Stratified Sand Filter
Discharge l/d	419	282	329	492
Nitrogen loading g N/d				
Effluent loading g/d	22.6 (54)	18 (64)	8.6 (49.7)	12.1 (49.2)
% reduction in loading (attenuation) at 1m depth	68	8	80	0
Phosphorus loading as g P/d				
Effluent loading g/d	5.9 (12.2)	9.5 (33.6)	1.6 (9.2)	2.1 (8.4)
% reduction in loading (attenuation) at 1m depth	99	67	100	86

() Numbers in brackets concentration in mg/l.

6.5 Summary

In Table 6.7, proposed default values are given for loading from sewage effluent discharges and these have been used in the catchment loading calculations (Section 14).

Table 6.7 Estimates of N and P Loading from Septic Tanks and Package Treatment Plants.

Source	Parameter	Concentration mg/l as N or P ¹	Loading Kg N or P/Person/Year ²	Percentage Reduction in loading if Drainage Blanket is present ³
Package treatment plant	Nitrogen	20	1.1	40
	Phosphorus	10	0.5	90
Septic Tank	Nitrogen	50	2.7	40
	Phosphorus	15	0.8	90
Sewage treatment plant	Nitrogen	20	1.1	Dependent on design
	Phosphorus	7 ⁴	0.4	Dependent on design

1. See Table 6.3

2. Assumes water usage of 150 l/person/day

3. See Box 6.2 and Table 6.6.

4. Table 6.1 (average)

7. Sewers

Urban sewerage systems can be divided into:

- Foul sewers (sewage and trade effluent);
- Surface water run-off;
- Combined sewers (surface and foul drainage).

Sewer systems from residential and commercial and industrial areas are likely to be separate. The latter will be dominated by trade effluent discharges.

Foul sewers and combined sewers will route waste water to sewage treatment works. Surface water drainage systems will typically discharge to surface water courses or to ground (e.g. SuDS). The only treatment is likely to be interceptors. The main risk from surface water systems is associated with misconnections of foul drainage. Defra (2004a) report some 5% of houses and 20% of industry may be mis-connected.

In rural areas sewage is mainly directed to non mains systems such as septic tanks (see Section 6).

Leakage will be dependent on:

- Age and condition of sewer (higher rates of leakage from old sewers);
- Maintenance of sewer;
- Construction of sewer (the majority of leakage is from joints);
- Backfill around sewer;
- Groundwater level in relation to sewer (leakage will be negligible where the sewer is below the water table).

Limited information is available on rates of leakage. Values obtained are:

- Lerner, 2000. Leakage rate as 1.75% of sewer flow;
- Ellis and Revitt, 2002. 3 to 5% of total annual sewer flow;
- Nottingham. Leakage equivalent to 9 to 10 mm/year (Wakida and Lerner, 2005);
- Doncaster. 20 to 50 mm/year (or 5 to 12 % of total urban drainage) (Cronin et al, 2005);
- Greater London. Leakage equivalent to 10 to 25 mm/year or 5% of sewer flow (Bishop et al, 1998).

The concentration of contaminants in sewerage will vary according to population density, inflow of surface water run-off, and groundwater infiltration. Typical composition of sewerage is given in Table 7.1.

Estimates of sewer flows are usually based on population density and water use per person. Information on the population can be obtained from census data (Census 2000 and www.statistics.gov) and estimates of water use per person typically range from 140 to 240 l/person (Section 6.2), although Lerner (2000) estimates a water use of 320 l/person for Nottingham. The population density of major urban areas is typically 4000 to 5000 persons/km² (e.g. Nottingham 4200 persons/km² and Greater London 5100 person/km², www.statistics.gov). In comparison the average rural population density in England is 382 person/Km² (Commission for rural communities).

Table 7.1 Typical Composition of Domestic Sewage (Bishop et al 1998)

Contaminant	Concentration mg/l	
	Medium	Strong
Total nitrogen as N	45	85
Organic N	15	35
Free ammonia (NH ₃)	30	50
Nitrite	0	0
Nitrate	0	0
Total phosphorus as P	9	15
Organic P	3	5
Inorganic P	6	10

Sewage strength is typically classed as either weak, medium or strong.

Wakida and Lerner (2005) estimate that 13% of the nitrogen loading in Nottingham was from leaking sewers with N concentrations of 30 mg/l as N.

An estimate of potential N and P losses from leaking sewers is given in Table 7.2.

Table 7.2 Estimate of Loading Rates from Leaking Sewers

Leakage Rate mm/m ² /year	Loading	
	Nitrogen Kg N ha/year (assuming Sewage Effluent Concentration of 45 mg/l)	Phosphorus Kg P ha/year (assuming Sewage Effluent Concentration of 9 mg/l)
10 mm/year (e.g. Nottingham, Wakida and Lerner, 2005)	4.5	0.9
25 mm/year (e.g. London, Bishop et al 1998)	11.25	2.25
50 mm/year (e.g. Doncaster, Cronin et al 2005)	22.5	4.5

7.1 Summary

In Table 7.3, proposed default values are given for sewage effluent and these have been used in the catchment loading calculations (Section 14). A default leakage rate of 2% of sewer flow is suggested. Sewer flows can be estimated assuming usage of 230 l/person/day. This rate is higher than quoted figures for household usage but this takes account of other effluent discharges.

Table 7.3 Default Nitrogen and Phosphorus Concentrations in Sewage Effluent (from Table 7.1)

Determinand	Concentration mg/l	Loading Kg/Person/Year ¹
Nitrogen as N	45	0.075
Phosphorus as P	9	0.015

¹. Assumes usage of 230 l/person/day and leakage rate of 2% of sewer flow

8. Mains Water

The N and P loading will depend on mains water leakage rates and treated mains water quality. Information on mains water leakages and quality can typically be provided by water companies.

Reported leakage rates range from 10 to 40% with an average of 22.8% for England and Wales (OFWAT, 2007), and individual Water Companies may provide information on their web sites. Scottish Water (2005) report that leakage rates in Scotland were up to 48%, although actions are in place to reduce leakage rates.

Phosphate is also added to mains water to prevent lead solvency. Dosing rates are currently 0.5 to 1.0 mg/l although higher rates (up to 1.5 mg/l) are used where the alkalinity of the water is high (SNIFFER, 2008). Nitrate concentrations in mains water will be less than 11.3 mg/l as N (drinking water standard).

Leakage rates for urban areas are typically based on the volume of leakage divided by the urban area (Lerner, 2000).

An estimate of possible losses from leaking water mains is given in Table 8.1.

Table 8.1 Estimate of Loading Rates from Leaking Water Mains

Leakage Rate	Loading Kg N or P ha/year			
	Nitrogen		Phosphorus	
	5 mg N/l	7.5 mg N/l	0.5 mg P/l	1.5 mg P/l
67 mm/year ¹	3.3	5.0	0.3	1.0
100 mm/year ¹	5.0	7.5	0.5	1.5
134 mm/year ¹	6.7	10.0	0.6	2.0

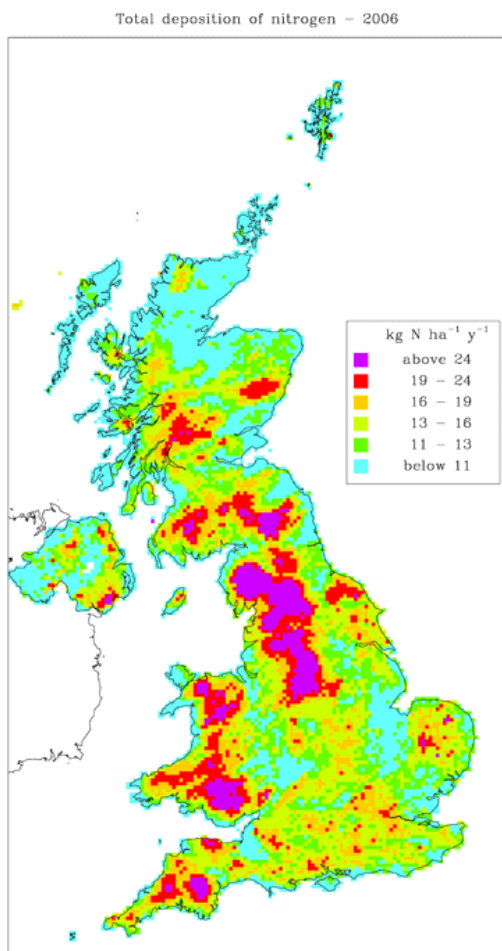
¹ Calculated assuming population density of 40 person/ha, water use of 230 l/person per day (Section 6.2) and leakage rate of 20, 30 and 40%.

9. Atmospheric N and P

Nitrogen is deposited both in rainfall and directly from the atmosphere in the form of ammonia, nitrogen oxides and nitrate, contributing to nitrate loss from soils (MAFF, 1995). This atmospheric nitrogen is derived from nitrous oxides from industry and motor traffic and ammonia emissions from farming (Addiscott, 1996). The Defra report 'Ammonia in the UK' (Defra, 2002) provides detailed information on the emissions sources and on atmospheric deposition rates.

Information on the total deposition of nitrogen is available on the CEH web site for the UK (<http://www.uk-pollutantdeposition.ceh.ac.uk/>) with a resolution of 5km² based on the national ammonia monitoring network and the FRAME model (Plate 9.1). Deposition rates are typically in the range 5 to 20 kg N/ha/year. Higher deposition rates are mainly associated with high rainfall (Wales, SW England and NW England, S Scotland), urban areas or areas with high livestock numbers.

Plate 9.1 Total Deposition of Nitrogen (from CEH Web Site)



Addiscott (1996) and MAFF (1995) suggest average atmospheric deposition in the range of 35-50 kg N/ha/yr in central and SE England, although this range is much higher than loading rates published on the CEH web site. The ADAS MANNER (Manure Nitrogen Evaluation Routine) model uses an atmospheric deposition rate of 15 to 35 Kg N/ha/year (Defra 2004c).

Studies indicate that around 30% and 20% of atmospheric N deposition on arable land and grassland respectively is leached (Addiscott, 1996). For a deposition rate of 20 kg N/ha/year this represents a loss of 4 to 6 kg N/ha/year.

In non-agricultural areas (i.e. areas covered by woodland or rough grazing) atmospheric N deposition can form the major or sole N input to soils.

There is more limited data on the atmospheric deposition rates for P in the UK and Ireland. The amount of P in atmospheric deposition (wet plus dry) is relatively low (typically 0.1 to 0.2 kg P/ha/year) and typically forms a relatively small proportion of the soil P budget for arable and managed grass (SNIFFER, 2008). However this loading may be more significant in non-agricultural areas, where atmospheric P may be the only input to the system.

In summary, the loading of P and N from atmospheric deposition is taken to be 15 to 35 Kg N/ha/year and 0.1 to 0.2 Kg P/ha/year.

10. Urban Sources of N and P

10.1 Introduction

Land use in urban areas mainly comprises:

- Industrial/ commercial areas (buildings, car parks, factories);
- Residential areas (houses, gardens and allotments);
- Sport and leisure facilities (e.g. golf courses);
- Parks;
- Construction sites;
- Roads.

Urban areas are defined as settlements with a population of over 10 000. Information on population density has been obtained from Census 2000 (www.statistics.gov).

Sources of N and P losses from urban areas are summarised in Table 10.1 (from Lerner 2000).

Table 10.1 Components of N and P Loss in Urban Areas (from Lerner 2000)

Source	Mechanism	Comments
Parks and gardens	Loading of N and P applied as fertiliser	Limited published data on application rates
Allotments	Loading of N and P applied as fertiliser	
Recreational grassland and golf courses	Loading of N and P applied as fertiliser	
Liquid effluent spreading	Loading of N and P from sludge or effluent applied to land	For this study this component has been assumed to be negligible for the study areas
Construction areas	Disturbance of soil, resulting in mineralization of soil organic matter and release of N and P	Published data limited to N
Land affected by contamination	Leaching of soils that have been contaminated through historical industrial activity (i.e. spills and leaks). For example former gas works sites	
Landfill leachate	Leakage of N and P from unlined Landfill sites	See Section 4
Leaking sewers	Leakage of effluent from sewers	See Section 7

Table 10.1 (continued) Components of N and P Loss in Urban Areas (from Lerner 2000)

Source	Mechanism	Comments
Septic tanks	Leakage or drainage from septic tanks and associated drainage systems	See Section 6
Leaking water mains	Leakage from water mains. Concentrations in leakage should be less than the drinking water standard. Previous studies (Lerner, 2003) have shown that leaking water mains is the main contributor of N in urban areas	See Section 8
Leaking highway drainage drains	Runoff from land surface will contain N and P (mainly from atmospheric deposition). This run off will either be diverted to surface water drains or soakaways	Published data on run-off water quality indicates low concentrations of N and P (e.g. N concentration of less than 5 mg N/l)
Highways drainage to infiltration areas	Run off from land surfaces will contain N and P (mainly from atmosphere deposition). This run off will either be directed to surface water drains or infiltration areas	See above
Leaking rivers	Leakage from rivers to groundwater	Not considered
Cemeteries	Leakage of N and P from graves (not included in Lerner 2000)	See Section 5

Note Lerner 2000 only considers N losses.

Information on land use within urban areas can be obtained from the following sources:

- Corine Land Cover Map which differentiates land use into: continuous urban fabric; discontinuous urban fabric (mainly residential areas with gardens); green urban areas; sport and leisure facilities; larger industrial and commercial units; and construction sites;
- Land cover map 2000, although this only differentiates between urban and suburban land use;
- Vision of Britain web site (www.visionofbritain.org.uk) which provides a summary of land use statistics for 2001 including information on area of buildings (domestic and non domestic), gardens, green spaces, road and rail;
- Ordnance survey maps.

10.2 N and P Loading

A methodology for estimating urban loads of nitrogen to groundwater has been developed by Lerner (2000) which comprises two methods: component approach; and integrated approach. The component approach is considered the most appropriate for this study and has been expanded to include the loading from P.

Table 10.2 provides a summary of the values for nitrogen loading identified from the literature, although information on nitrogen loading was largely taken from Lerner (2000 and 2003) and

Wakida and Lerner (2002, 2005). Estimated loading rates for the different land uses and activities are also given in Table 10.2, although these should be treated with caution as some of these land uses may represent a small part of the urban area and the total loading from leaking water mains and sewers is likely to dominate the nitrogen balance (Section 10.5).

Table 10.3 provides additional information relevant to P loading identified from the literature, however information is more limited. For parks, gardens, allotments and other green areas the loss of P has been assumed to be negligible due to sorption in the soil.

Table 10.2 Summary of Information Available on Nitrogen Loading

Land Use or Activity	Percentage Area Fertilised %	Fertiliser Application or Loss of N Kg/N/ha/yr	% Nitrogen Leached	Source	Estimated Loading Kg N/ha/year	Comment
Parks and gardens	25	200	10	Lerner 2000	5 (An estimated loading of 4.6 Kg N/ha is given in Defra 2008).	Limited published data on fertiliser applications to parks, gardens, allotments
Allotments	50	200	25	Lerner 2000	25	
Recreational grassland and golf courses	50	200	10	Lerner 2000	10 (An estimated loading of 9.2 Kg N/ha is given in Defra 2008).	
		N Loading per Person Kg N/person/yr	Percentage N Reaching Groundwater %			
Construction activities		60	100	Wakida and Lerner 2002	60	Previous estimate Lerner 2000, N loss = 400 Kg N/ha
Loading from land affected by contamination		175	100	Lerner 2000	175	Dependent on previous industrial activity
Land Use or Activity		N Concentration in Leachate mg N/l	Percentage N Reaching Groundwater %			
Loading from landfill (unlined sites)		100 (old landfill site) For more recent landfill sites see Section 4 and Table 4.7.	20	Lerner 2000 (see Section 4 which suggests higher leachate concentrations, landfills in urban areas may represent older waste)	60 (assumes leakage rate of 300 mm/year and N concentration of 100 mg N/l)	Leakage assumed to be equivalent to infiltration over landfill area

Table 10.2 (continued) Summary of Information Available on Nitrogen Loading

Land Use or Activity	Leakage Rate	N Concentration in effluent mg N/l	Percentage N Reaching Groundwater %	Source	Estimated Loading Kg N/ha/year	Comment
Loading from leaking sewers	180 to 230 l/person (Section 6) 320 l/person (Lerner 2000) or Leakage rate expressed as equivalent depth of infiltration over urban area = 10 to 50 mm/year (Section 7) or 1.75 % of sewer flow (Lerner, 200) to 3 to 5% of flow (Ellis and Revitt, 2002)	30 (Lerner 2000) 45 (Table 7.1)	100	See Section 6 Lerner 2000	7.5 Kg N/ha/year (Calculation based on leakage rate of 25 mm/year and N concentration of 30 mg N/l)	
Land Use or Activity		N Loading per Person Kg N/person/yr				
Loading from septic tanks		3.5 2.7	50 40	Lerner 2000 Table 6.7	Not calculated	

Table 10.2 (continued) Summary of Information Available on Nitrogen Loading

Land Use or Activity	Leakage Rate %	N Concentration in Water Supply mg N/l	Percentage N Reaching Groundwater %	Source	Estimated Loading Kg N/ha	Comment
Loading from leaking water mains	25%	<11.3 mg/l as N, dependent on source of water supply	100	Lerner 2000	6 Kg N/ha/year	Leakage targets have been set to reduce leakage rates
	22.8% (England and Wales 2006-2007)			OFWAT 2007	Calculation based on population density of 40 persons/ha, use of 220 l/p/d, N concentration of 7.5 mg N/l and leakage of 25%	
	48% (Scotland 2003) ¹			Scottish Water 2005		
Land Use or Activity	% Rainfall Entering Drainage Area	N Concentration in Infiltration Drainage mg N/l				
Infiltration drainage from highways	100	3.5	100	Lerner 2000	No calculation	Measurements of highway drainage indicate concentrations of 0/25 N mg/l (Road Drainage and the Water Environment). Although published data on the total N content of atmospheric deposition indicate loading rates from can exceed 20 kg N/ha.
		3.2 (urban areas), 2.4 roads and motorways ²		Mitchell 2001		
Leakage from surface water drains serving roads and paved areas	100	3.5	100	Lerner 2000	No calculation	

1. Mains water can be estimated from either household utilisation (150 l/person/d), however this will not include other uses and therefore usage of 230 l/person/d is suggested.

2. Event mean concentration in run-off.

Table 10.3 Summary of Information Available on P Loading

Land Use or Activity	Concentration or Loading	Source	Comment
Parks and gardens	No published data		Losses likely to be low
Allotments	No published data		
Recreational grassland and golf courses	No published data		
Construction activities	No published data		
Loading from land affected by contamination	No published data		
Loading from landfill (unlined sites)	1 to 4 mg P/l	See Section 4, Table 4.7	
Loading from leaking sewers	9 - 15 mg P/l	See Table 7.1 and 7.3	
Loading from septic tanks	0.4 to 0.8 Kg P/person/year	See Table 6.7	Percentage reaching groundwater 10% based on attenuation in drainage blanket (Table 6.7).
Loading from leaking water mains	0.5 - 1.5 mg P/l, dependent on source of water supply and dosing	SNIFFER 2000 and Section 8.	
Drainage from highways pr leakage from surface water drains serving roads and paved areas	0.34 mg P/l (urban run-off) 0.18 mg P/l (road run-off)	Mitchell 2001	

10.3 Recharge to Groundwater

Recharge to groundwater from urban areas will include:

- Mains water leakage;
- Sewer leakage;
- Recharge from open space (parks, gardens etc.);
- Recharge from surface water drainage areas (e.g. SuDs);
- Leakage from surface water drains;
- River leakage.

Table 10.2 provides a summary of leakage rates from water mains and sewers. There are more limited data on leakage rates from surface water drains.

10.4 Urban Development

New urban development (e.g. new housing, industrial and commercial areas) will result in a change in N and P loading from:

- Increase in total water mains use and therefore leakage (although lower leakage rates are likely to be associated with new water mains);
- Increase in total sewer leakage (although lower leakage rates are likely to be associated with new sewers);
- Nitrogen loss associated with construction, although this will represent a single loss and in the longer term could result in lower nitrogen loading if higher leaching land uses (e.g. arable land) are replaced by housing. No information was identified on P loss from disturbance of soils.

These higher losses will be partly offset by the lower leaching associated with unfertilized grass and from surface water infiltration.

10.5 Calculated N and P Loadings

A spreadsheet model has been developed (Section 14) to calculate urban loading. Tables 10.4 and 10.5 provide a summary of the calculated loading for two example urban areas (Nottingham and Exeter). A description of the data sources and calculations used to derive these loading rates is given in Section 14.2.1, Appendix B and Appendix D.

Table 10.4 Nitrogen Loading for Two Example Catchments

Source	Exeter % Nitrogen Loading	Nottingham % Nitrogen Loading
Parks and gardens	32.58	26.22
Allotments	1.44	0.37
Recreational grassland and golf courses	1.77	0.00
Loading from cemeteries	1.05	1.97
Loading from construction activities	7.75	4.72
Loading from land affected by contamination	0.00	1.65
Loading from landfill	8.04	2.07
Loading from leaking sewers	32.47	18.40
Loading from septic tanks	0.00	0.00
Average loading Kg N/ha	14 kg N/ha	15 kg N/ha
Average Infiltration mm/year	252 mm per year	251 mm per year
Average nitrate in recharge to groundwater mg N/l	4.1 mg N/l	5.9 mg N/l

Table 10.5 Phosphorus Loading for Two Example Catchments

Source	Exeter % Phosphorus Loading	Nottingham % Phosphorus Loading
Parks and gardens	4.36	2.72
Allotments	0.04	0.01
Recreational grassland and golf courses	0.13	0.00
Loading from cemeteries	2.67	3.63
Loading from construction activities	0.00	0.00
Loading from land affected by contamination	0.00	0.08
Loading from landfill	0.09	0.42
Loading from leaking sewers	61.45	45.30
Loading from septic tanks	0.00	0.00
Average loading Kg P/ha	1.5 kg P/ha	1.9 kg P/ha
Average Infiltration mm/year	252 mm per year	251 mm per year
Average nitrate in recharge to groundwater mg P/l	0.4 mg P/l	0.7 mg P/l

10.6 Summary

Table 10.4 indicates that the main nitrogen loading in Nottingham is from parks and gardens, leaking water mains and sewers, with leaking water mains providing the largest contribution (Plate 10.1). For Exeter, the main loading is from park and gardens, which reflects the greater proportion of residential land use (Plate 10.2). The lower contribution from water mains leakage reflects lower nitrate concentrations in mains water supply (about 50% lower than Nottingham). The predicted N concentration in recharge to groundwater is higher for Nottingham reflecting the contribution from sewers and mains water losses.

Table 10.5 indicates that the main phosphorus loading in Nottingham (Plate 10.3) and Exeter (Plate 10.4) is from leaking water mains and sewers. The calculation for water mains assumes that mains water is dosed with phosphorus to prevent lead solvency (Section 8).

Plate 10.1 Percentage Loading of N from Different Urban Sources (Nottingham)

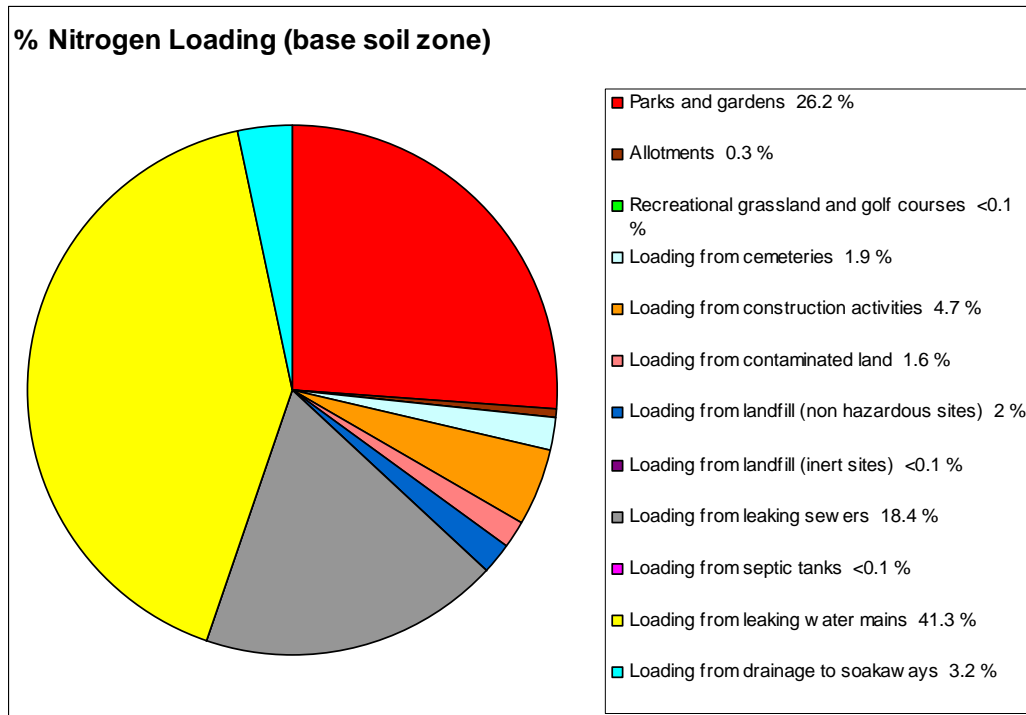


Plate 10.2 Percentage Loading of N from Different Urban Sources (Exeter)

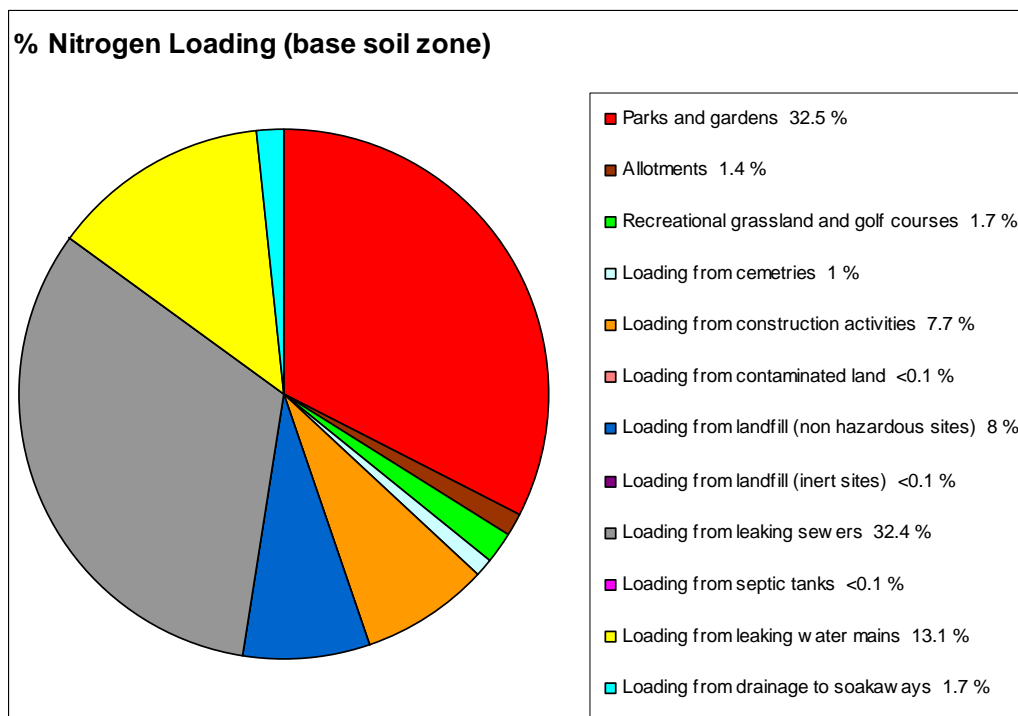


Plate 10.3 Percentage Loading of P from Different Urban Sources (Nottingham)

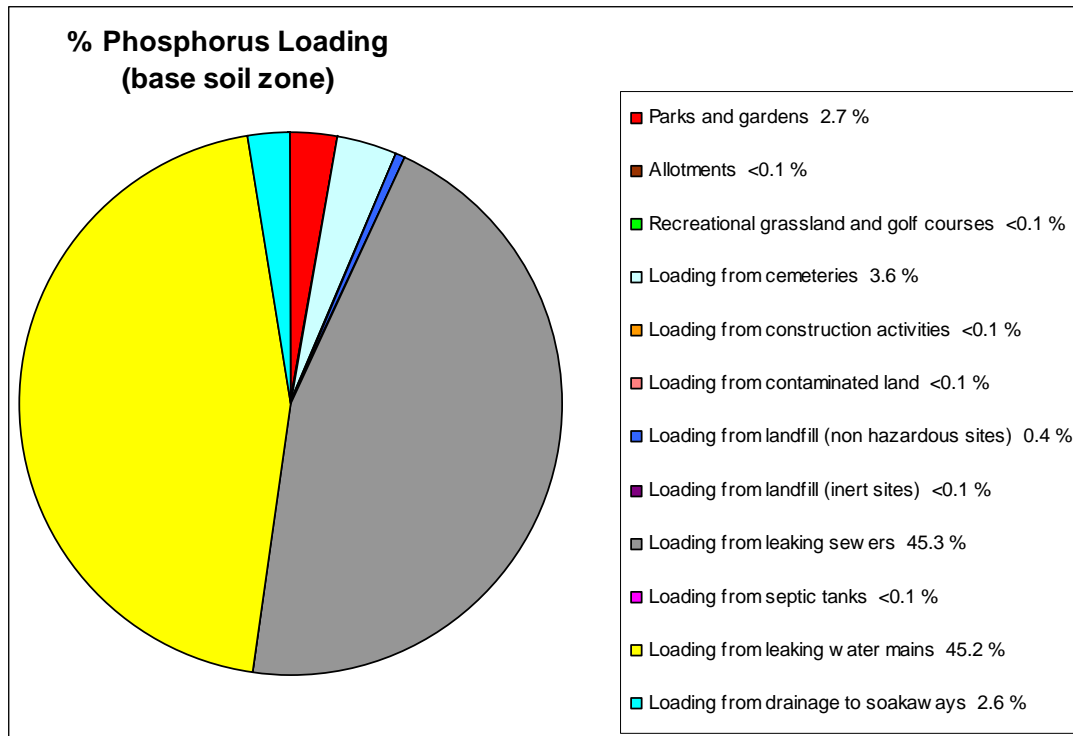
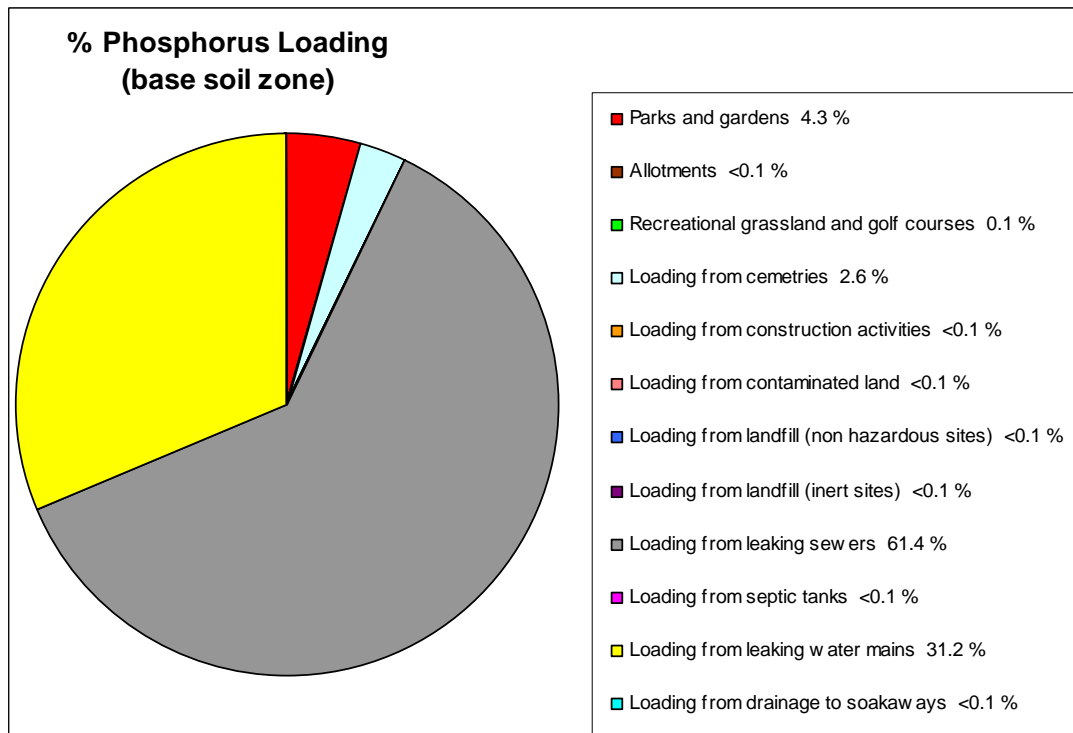


Plate 10.4 Percentage Loading of P from Different Urban Sources (Exeter)



11. Agricultural Diffuse Sources of N and P

11.1 Introduction

This section considers the leaching of N and P from agriculture. Substantial research exists on the subject of N and P losses from soils and it has not been possible to conduct a detailed review of the full breadth and depth of the existing literature available within the scope of this study. Literature review has focussed on key paper and data sources to determine N and P loads.

Losses of N and P from rough grazing and woodland are also including in this section.

11.2 Overview of N and P Leaching

11.2.1 Nitrogen

Nitrogen (N) supply in the soil depends on:

- The existing soil mineral nitrogen (nitrate and ammonium);
- Mineralisation of nitrogen from soil organic matter (reflecting the organic matter content of the soil, as well as past cropping and management practices). Agricultural soils typically contain several thousand kg N/ha in soil organic matter, a few percent of which is mineralised each year. As a guide, a soil that has a topsoil organic matter content of 10% may release 60-90 kg/ha more potentially available nitrogen than an equivalent soil with 3% organic matter content, or 150-200 kg/ha where the topsoil organic matter content is 20%. This nitrogen becomes available gradually through the year. In contrast, the nitrogen in crop debris is released rapidly as a 'pulse' following incorporation into the soil;
- Influx from atmospheric deposition (Section 9);
- Rate of application of inorganic fertilisers and organic fertilisers (manures, slurries).

Some crops (e.g. legumes) will also fix nitrogen from the air through nitrogen-fixing bacteria in nodules on their roots.

Nitrogen may be lost from the soil through:

- Uptake by crops and vegetation. The rate of uptake of nitrogen varies according to crop type, land management practices (e.g. cultivation practices, timing of nitrogen applications and crop planting and harvest), climate and the source of nitrogen available (e.g. inorganic or organic fertiliser);
- Denitrification (in anaerobic soils and water logged soils) and loss to the atmosphere as nitrous oxide and nitrogen gasses;

- Volatilisation and loss to the atmosphere as ammonia gas (e.g. from manures spread on the land surface);
- Leaching of nitrate or ammonium from the soil (soil drainage).

Most nitrogen in the soil that is available to crops is present as water soluble nitrate, or as ammonium, which is converted by soil microbes into nitrate. If soil nitrate production exceeds the rate that it is taken up by crops, excess nitrate is vulnerable to being washed out of the soil by percolating rainfall or irrigation. The nitrogen load that may potentially be leached as nitrate to groundwater is thus a function of the balance of inputs of nitrogen to the soil and the rate of uptake by crops.

There are a range of models used to predict nitrate leaching from the soil zone (NEAP-N, NIRAMS, SNIFFER diffuse pollution tool). These are based on modelling the soil nitrogen cycle and determining how much nitrate is available for leaching. The amount leached will depend on the amount of infiltration through the soil.

11.2.2 Phosphorus

Phosphorus (P) occurs in soil in both inorganic and organic forms. Organic P is associated with organic matter, plant residues, manures and microbes. Inorganic phosphorus occurs in soil solution or is present as aluminium, iron or calcium compounds. Crops will utilise soluble P (mainly orthophosphate) which represents a small percentage of the total P content of the soil. Iron and aluminium compounds fix (sorb) P under acidic soil conditions and calcium and magnesium compounds will preferentially fix P under alkaline conditions.

The amount of soluble P will vary depending on:

- The existing soluble P. Concentrations are typically low (<0.3 mg/l, Johnston and Dawson 2005);
- Mineralisation of soil P. Agricultural soils typically contain several hundred kg P/ha, a few percent of which is mineralised each year;
- Influx from atmospheric deposition (Section 9);
- Rate of application of inorganic fertilisers and organic fertilisers (manures, slurries);
- Removal by crop uptake and harvesting. The rate of uptake of P varies according to crop type, land management practices (e.g. cultivation practices, timing of applications and crop planting and harvest), climate and the source of P available (e.g. inorganic or organic fertiliser);
- Fixing of P by aluminium, iron or calcium compounds and immobilization by microbes;
- Soil erosion;
- Leaching of P from the soil (soil drainage or surface water run-off).

The plant available P is typically estimated using the Olsen method to give an Olsen P in soil (Section 11.3). The Olsen P (expressed as mg/kg) is measured using a sodium bicarbonate soil extract at pH 8.5.

The amount of P that can be leached from soils is a function of the amount of available P (Section 11.11), and losses are typically only significant (>1 mg/l) where the available P is high (11.11). Current recommended rates of fertiliser application (Section 11.3) are based on balancing applications with crop removal and ensuring that there is not a build up of P in the soil.

Soil P balances (Johnston and Dawson, 2005) for non-manured arable soils in England and Wales showed a build up of P in the 1970's to mid 1990's, but subsequently there has been a reversal in the soil balance which reflects a decrease in the use of inorganic fertilisers.

11.3 Sources of N and P

11.3.1 Inorganic Fertilisers

Information on rates of fertiliser application was obtained from the following sources:

- British survey of fertiliser practice (BSFP), www.Defra.gov.uk/evidence/statistics/foodfarm/enviro/fertiliserpractice/. This web site provides results of annual surveys of fertiliser use for England, Wales and Scotland. The BSFP data is based on strategic samples of 1300-1500 farms sampled across England and Wales (and Scotland since 1983), representing around 10 000 fields or 2.5% of the total crops and grass area in Britain. A breakdown of fertiliser application data is available for regions, but this is based on a small survey and therefore may not be as statistically reliable as the national data set;
- Fertiliser statistics Northern Ireland, www.darchi.gov.uk. This website provides information on total fertiliser use (tonnes);
- Fertiliser statistics Ireland. www.agriculture.gov.ie. This website provides information on total fertiliser use (tonnes);
- Fertiliser manufacturers association. www.fertilizer-assoc.ie/publications.htm. This web site has publications on surveys of fertiliser usage (Coulter et al 2003).

A summary of the fertiliser statistics obtained from these sources is given in Appendix A. Long term trends in fertiliser used in Great Britain are shown in Plates 11.1 and 11.2. This plate illustrates that there has been a decrease in the use of P and N over the last 20 years.

Plate 11.1 Rates of Inorganic Fertiliser N Applications to Tillage Crops and Grassland

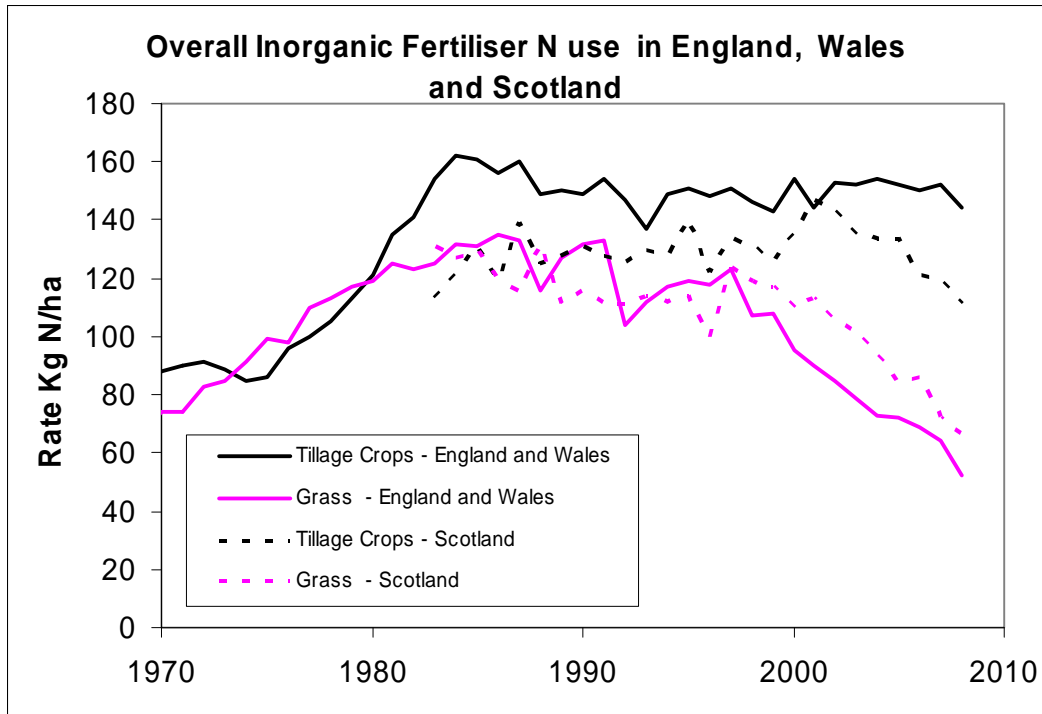


Plate 11.2 Rates of Inorganic Fertiliser P Applications to Tillage Crops and Grassland

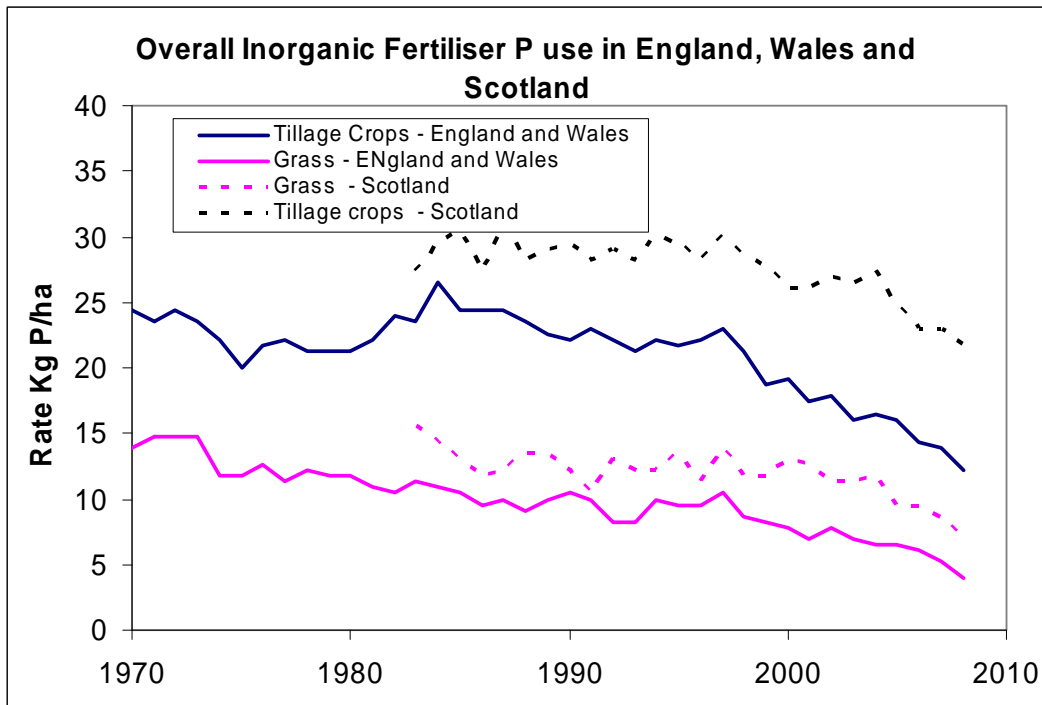


Plate 11.1 illustrates that there has been a decrease in application of inorganic fertiliser N since the mid 1980's; autumn and winter applications of fertilisers to tillage crops have also decreased substantially since the mid-1980s. Plate 11.2 shows a general decrease in the application of fertiliser P since the 1970's.

Information on recommended rates of fertiliser use is given in the following documents:

- Defra, 2000. Fertiliser Recommendations for Agricultural and Horticultural Crops (RB209);
- DAFF 2008. Explanatory Handbook for Good Agricultural Practice Regulations;
- DARDNI 2008. Code of Good Agricultural Practice (COGAP);
- Defra, 2009a. Protecting our Water, Soil and Air. A Code of Good Agricultural Practice for farmers, growers and land managers;
- Scottish Government 2005. Code of Good Practice. Prevention of Environmental Pollution from Agricultural Activity.

These recommended rates are based on a number of factors:

- Crop type and whether planted in the winter or spring;
- Type of fertiliser (inorganic, organic);
- Soil nitrogen and phosphate content;
- Soil type (e.g. sand, loam etc);
- Rainfall;
- Previous cropping and manuring history.

The aim of these guidelines is to optimise crop yields and to minimise N and P losses and thus prevent pollution of surface water or groundwater.

For P, Defra recommends that the rate of fertiliser applications to soils should be based on the Olsen P index and the amount of P removed by the crop. In Great Britain, soils are given an index (0 to 9) based on the soil Olsen P. Most agricultural soils will have an Index of 0 to 4 (Johnston and Dawson, 2005). Higher rates are used on soils with a P Index of 0, and rates are typically 0 if the index is 3 or higher. The aim of recommended applications rates is to maintain an Olsen P index of 2 (16 to 25 mg/litre) for arable crops and grassland and an Olsen P index of 3 (26 to 45 mg/kg) for vegetables. For soils with a low P index, additional fertiliser can be added to help build up the soil P content. The aim is to maintain the soluble phosphate content of the soil.

A similar index system is used in Ireland, although based on a different method of analysis (Morgan Test) of soil available P. This test is more appropriate to acidic soils.

11.3.2 Organic Fertilisers

Organic fertilisers, as applied to agricultural land, are usually derived from farmyard manures (FYM) from housed cattle and pigs, poultry manures, or slurries from pigs or cattle, poultry

manures, or alternatively from treated sewage sludges (also called bio-solids). Some industrial wastes such as paper waste or brewery effluent are also applied to land (BSFP, 2008).

The proportion of organic manure and sludge applications that are ultimately leached is mainly related to application rates, the available N and P content of the manures (which depends on the type and forms of organic fertilisers used and their methods of application), effective rainfall after application and soil type. Guidance on the handling and use of manures on farms, including determination of optimal application rates of organic manures to meet crop requirements whilst avoiding unnecessarily high leaching is published by Defra (2000), DAFF (2008), DARDNI (2008) and Scottish Government (2005). Uncertainty on the N and P content in organic fertilisers presents difficulties to farmers in deciding how much fertiliser to use.

Managed manures (e.g. slurries and FYM) will be applied to grass and arable crops. For grazing livestock (e.g. cattle and sheep) the input will generally be to grass only. Nitrogen and phosphorus cycling in grazed grassland systems is considered in more detail in Section 11.10.

Composition

The composition of fresh animal manures will depend on the size, gender, age and market for which the animal is being bred (BSFP, 2008). The Typical N and P composition of fresh animal manures is given in Table A4, Appendix A. Livestock manures typically contain a relatively high proportion of readily available nitrogen (i.e. greater than 30% of total nitrogen is present in a readily available form). Farmyard manures typically contain lower amounts of available N (less than 30% of total nitrogen is present in a readily available form). Poultry manure contains the greatest content by weight of N and P of all FYM sources (Appendix A), although cattle and pigs are likely to represent the greater volumes of manures. Information on the composition of slurries and manures is given in Appendix A from information provided in Defra (2000) and DAFF (2008).

The readily available nitrogen content of a manure application will usually be taken up by grass or lost to the environment during the first season following application. The remaining organic nitrogen will be added to the soil organic matter pool and will contribute to the supply of soil nitrogen for several seasons (Defra, 2000).

The manner in which manures and slurries are stored can significantly change their composition, as will the addition of any bedding material used. Slurries may become diluted by the addition of rainwater or farmyard dirty water and by the volatilisation of ammonia which can significantly decrease the N content (Defra, 2005). Composted manure can also lose up to 80% of its N through the driving off of ammonia, compared to stockpiled manures (Defra, 2005). Anaerobic or aerobic treatment of slurries and also composting of manures will alter their composition mainly with respect to N.

Application Rates

The amount of available N and P will vary according to the method of application of managed manures and slurries. Spreading of organic fertilisers over the land surface will result in higher N and P losses due to surface water run-off and of ammonium to ammonia gas. Ploughing in of organic fertilisers or injection beneath the soil surface will reduce losses and increase the amount of P and N available to plants.

The recommended methods (i.e. Defra, 2000) for assessment of organic manure requirements includes consideration of the nutrient content and availability of different types of manures, timing of applications, method of applications, soil types and seasonal rainfall following

application. The guidance suggests that total nitrogen applied in organic manures should not exceed 250 kg/ha/year. The NVZ Action programme requires that, since December 2006, organic manure applications are limited to 170 kg total N/ha/year on non-grass areas and 250 kg total N/ha/year on grassland (Defra 2009b).

In comparison to inorganic fertilisers, less detailed data is generally available on the rates, timings and methods of organic manures applications as monitoring and control of these aspects are less straightforward than with inorganic fertiliser usage. The British Survey of Fertiliser Practice (Defra, 2007) provides information on the percentage of arable crops and grassland receiving organic fertilisers and estimated application rates. Table A6, Appendix A shows that for the sample of fields analysed, cattle FYM is the greatest manure spread by volume in Britain, with the greatest application taking place on winter sown crops, although spring sowings receive a slightly lower coverage. There is likely to be significant regional variation in the amount of manures and slurries applied to agricultural land reflecting livestock numbers. The timing of applications may also vary depending on the available storage. Not all livestock manures produced in a catchment will necessarily be spread to land. In some parts of eastern England, for example, a significant fraction of the poultry manure produced goes for incineration.

Leaching

The amount of manure nitrogen leached following application to land is mainly related to the application rate, the readily available-N content and the amount of rainfall after application. The amount of readily available N will depend on the type of manure, the age of the manure, the time of spreading and soil type (Table A5, Appendix A).

The ADAS MANNER (Manure Nitrogen Evaluation Routine) estimates nitrate leaching from manure applications for a variety of manure types (e.g. FYM, slurry), soil types and climates, taking account also of any delay between application and incorporation (ploughing down) of manure. The MANNER model is freely available from ADAS (<http://www.adas.co.uk/MANNER/tabid/270/Default.aspx>).

Tables 11.1 and 11.2 show illustrative results from the MANNER model for a hypothetical field with a sandy silt loam soil, manure application on 1-Oct at a rate of 10 tonnes/ha or 10 m³/ha, and 359 mm of rainfall between the application date and the end of soil drainage (31 Mar).

Table 11.1 MANNER Predicted Nitrate Leaching from Managed Manure Applications

	Total Applied N (kg/ha)	Leached N (kg/ha)
Cattle FYM fresh	60	8
Pig FYM fresh	70	9
Layer manure	160	46
Broiler / turkey litter	300	72
Dairy slurry	30	7
Beef slurry	23	6
Digested sludge cake	75	6

Table 11.2 MANNER Predicted Nitrate Leaching as a Function of Delay to Incorporation, for an Application of Dairy Slurry at 10 m³/ha (total applied N = 30 kg/ha)

Incorporation	Leached N (kg/ha)
Deep injection	12
< 2 hours	9
2 - 6 hours	8
6 - 12 hours	7
12 - 24 hours	7
1 - 2 days	6
> 2 days	6

Nitrate leaching from arable and grassland is further discussed in Sections 11.9 to 11.11.

11.4 Nitrogen Mineralisation

Nitrogen mineralised from soil organic matter or from crop residues can provide an additional source of nitrogen available to crops. This is included in the calculation of Soil Nitrogen Supply (SNS). For soils with a low organic matter content, the amount of N mineralised will usually not be significant, but the release of N from crop residues can occur rapidly and provide appreciable quantities of N. The management of crop residues (e.g. ploughed down or removed) is, therefore, significant in the estimation of SNS.

11.5 Nitrogen Fixation

Some crops (e.g. legumes) are able to fix significant amounts of nitrogen from the atmosphere. Information on the Scottish Agricultural College web site (www.sac.ac.uk) indicates that clover can fix between 180 and 250 kg N/ha/year. For this reason, fertiliser recommendations for England and Wales (Defra, 2000) indicate that no nitrogen fertiliser should be applied to most crops of peas or beans.

11.6 Crop Yields

Crop yields will be a function of the rate of fertiliser application and will tend to increase with increasing fertiliser use; however there will be an optimum application rate above which yields may either decrease or show no improvement (Defra, 2009a).

Statistics on crop yields are published by Defra (www.Defra.gov.uk/evidence/statistics/) and DARDNI (<http://www.dardni.gov.uk/index/dard-statistics.htm>) and information can be downloaded from their web sites. N and P will be removed at harvest. For cereals the amount of N and P removed will also depend on whether the straw is baled and removed or ploughed back into the soil. Care should be taken to allow for any difference in crop yield at harvest and yield at standard moisture content.

Plates 11.3 and 11.4 compare estimated² N and P removed in crops with fertiliser applications. Plate 11.3 indicates that trends in crop yields follow application rates for N, but for P yields have been maintained even though fertiliser applications have decreased.

Plate 11.3 Comparison of Crop Yields and Fertiliser Application Rates – N

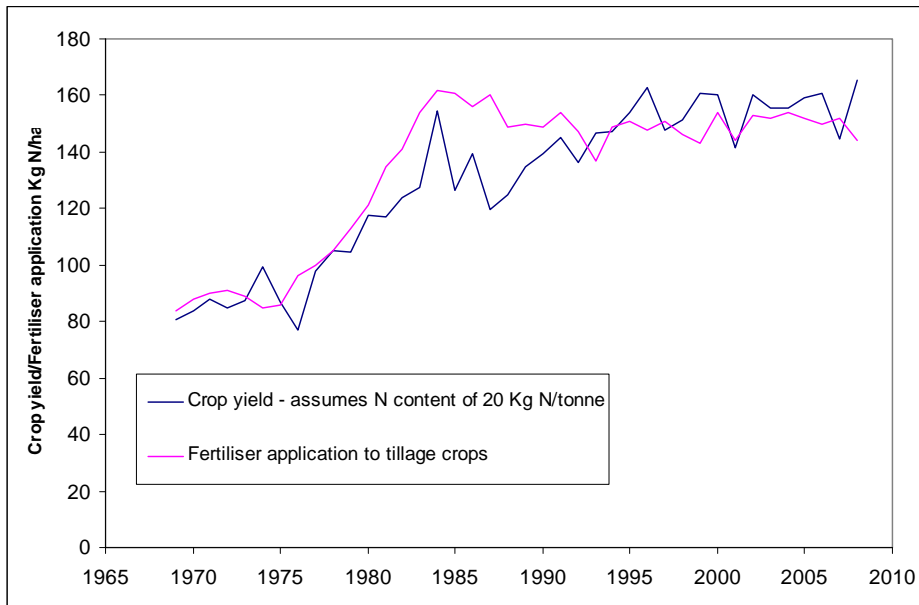
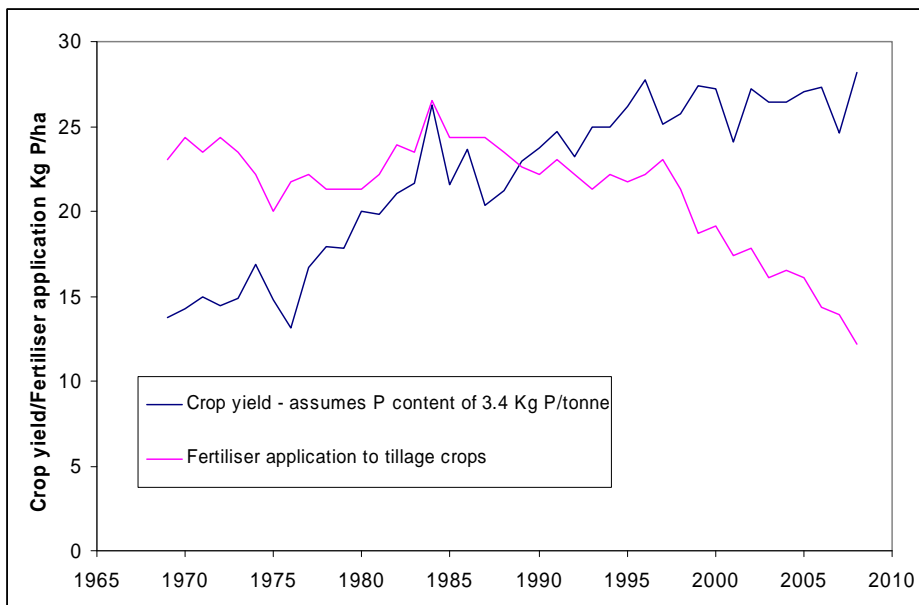


Plate 11.4 Comparison of Crop Yields and Fertiliser Application Rates – P



² Estimate based on crop yield statistics (tonnes/ha) multiplied by assumed N or P content in crop. The N and P content in crops can be variable such that these calculations should be treated as indicative only.

11.7 Volatilisation

Ammonia can be lost from organic fertilisers. The amount lost will depend on the method of storage and spreading of manure and slurry and, on arable land, the delay before the application is ploughed down. Highest losses will occur where spreading occurs over the land surface (e.g. broadcast slurry) and lowest losses will occur where slurry is applied below the surface (e.g. deep injection). Defra (2000) estimates that about 40% of the readily available content of manures is commonly lost following surface application to land. Estimates of total ammonia losses by agricultural sector are given on the following web site: <http://www.northwyke.bbsrc.ac.uk/AmmoniaInventoryWebsite/AmmoniaInventory.html>.

Ammonia may also be lost from types of inorganic fertiliser. For example, Defra (2000) reports that 0.3 to 3% of N applied as ammonium nitrate fertiliser may be lost as ammonia. Chambers et al (1997) found that typically 65% of the ammonium-N content of farmyard manure (FYM) and 35% of the ammonium- and uric-acid-N content of poultry manure could be lost in this way.

Manure management exerts a strong influence on ammonia volatilisation rates, both during storage and after spreading. Agriculture is a major contributor to ammonia emissions, and efforts to reduce ammonia emissions have focussed on, among other things, reducing losses from slurry stores and from livestock housing. The method of spreading, delay before incorporation (ploughing down) and dry matter content of the manure or slurry also control volatilisation losses. Slurries may be injected below the soil surface, or spread below surface vegetation (trailing shoe) to reduce losses when applied to grassland, although injection is not practical on stony soils. Solid manures applied to arable land should be ploughed down soon after application to minimise losses. In NVZs, regulations state that surface-applied organic manures applied to bare soil or stubble must be incorporated within 24 hours of application (Defra, 2009b). However, ammonia abatement must be considered in the context of the wider nitrogen mass-flow in farming systems; there is little benefit in reducing ammonia-N losses during storage (and hence increasing the N content of manures) if this results in increased N leaching post-application (i.e. pollution swapping).

11.8 Denitrification

Denitrification can be a significant process in clay or water logged soils, however direct measurement of denitrification losses are difficult (Addiscott, 1996). Addiscott (1996) reports that the estimated loss of N due to denitrification from modelling of experiments undertaken at Rothamstead was about 10%.

Estimated nitrate losses from denitrification (as a % of fertiliser applied) from soil types used in the NIRAMS model (Dunn et al, 2004) are:

- Free draining sandy soil 0%;
- Sand loam textured soil 20%;
- Clay loam textured soil 35%.

Models (e.g. DNDC) have been developed to represent denitrification in the soil zone and details are available on the following web site <http://www.dndc.sr.unh.edu/>.

11.9 Nitrate Leaching Losses

Nitrate leaching is complex and depends on a number of factors including:

- Availability of nitrate-N in the soil which will depend on the balance of N inputs, soil mineralization, crop uptake and soil losses;
- Availability of nitrate-N in fertilisers applied to the soil. For example, manures are often more leachable than artificial fertilisers and slurries more leachable than farmyard manures (MAFF, 1995; Andrews et al, 1997);
- Effective rainfall draining the soil (which will vary seasonally), Drainage will only occur when the soil is at field capacity, although by pass flow may occur via cracks and worm holes. The amount of nitrate lost from managed grass is largely dependent on the amount of effective rainfall (Rodda et al, 1995);
- Soil types and physical properties - e.g. higher infiltration in sandy soils will allow significantly greater leaching rates than in less permeable clays. By-pass flow may be more significant in clay soils;
- Soil environment. Denitrification losses will be greatest in anaerobic and/or water logged soils;
- Crops grown - the efficiency of nitrogen uptake will depend on crop types, e.g. sugar beet is more efficient in its use of nitrogen fertiliser than winter wheat, whereas oilseed rape and potatoes are much less efficient;

Research (Defra, 2000) has shown that the efficiency of use of fertiliser nitrogen by winter wheat and winter barley varies depending on the soil type.

- **Light sand soils.** 70% efficiency of use (i.e. 70 kg/ha N taken up by the crop for every 100 kg/ha fertiliser nitrogen applied). For many crops on light sand soils, the lower nitrogen recommendation takes account of this factor and the lower yield potential of these soils;
- **Medium, clay, silty, organic and peaty soils.** 60% efficiency;
- **Shallow soils over chalk and limestone.** 5% efficiency.

Land management practices - many aspects of agricultural management strongly influence nitrate leaching. The seasonality of cultivation and harvesting is a major influence; autumn sown or winter cover crops may absorb residual nitrate (after the autumn harvest) and protect the soil from over-winter leaching, whereas bare soils are vulnerable to high rates of infiltration and leaching (MAFF, 1995). Similarly the timing of fertiliser applications (in relation to effective rainfall) is critical (MAFF 1995, Addiscott, 1996). The ploughing up of land can lead to large releases of nitrogen. Excess nitrate may also be supplemented by the conversion of mineralised and fertiliser nitrogen in crop residues (roots and discarded above ground material) left after the autumn harvest (MAFF, 1995). Drainage increases N leaching by improving conditions for microbes in soil and allowing freer movement of soil water (Addiscott, 1996). Cultivation methods directly influence the soil conditions. Baseline soil mineralization rates also reflect past cropping and management practices (Addiscott, 1996).

Although some nitrate leaching can occur in spring (e.g. during intense rainfall events), most nitrate leaching in the UK occurs during the autumn and winter when soils reach field capacity (MAFF, 1995).

Most fertiliser N is applied during the spring. Autumn applications of fertilisers may lead to almost all of the applied nitrogen being leached due to the poor utilisation by crops at this time of year. Such applications have dramatically decreased since the mid-1980s due to increased awareness of this inefficiency (Addiscott, 1996). In 1985 about two thirds of the winter cereals and nearly 90% of winter oilseed rape in England and Wales received autumn and early winter nitrogen. These proportions have reduced to 5% of winter cereals and 24% of winter oilseed rape in 2006 (Defra, 2007).

Most of the reviewed literature focuses on the practical management of these factors towards reducing nitrate leaching towards deriving guidance for agricultural management, such as presented in Defra (2000) (see also <http://www.defra.gov.uk/environment/quality/water/waterquality/diffuse/nitrate/help-for-farmers.htm>).

From the above discussion, the loading to groundwater from leaching of soils will be dependent on a range of factors. In undertaking the literature review the aim was to identify information on typical losses from different crops and soil types. This proved difficult as many of the references relate to experiments undertaken in the 1980's and 1990's (when fertiliser applications may have been higher) or to models which have been used to determine nitrate loading on a national or catchment scale (e.g. NEAP-N, NIRAMS, SNIFFER diffuse pollution tool). In many cases these models do not provide information on model parameters, but refer out to specific references. It was not possible to obtain relevant source references in the time available for this review, although the available information is summarised. In addition these models have already been used to calculate loadings on a national basis, such that the relevant information is an integral part of the models. The NEAP-N and NIRAMS models are discussed in more detail in Section 11.10.

Some crops have a higher nitrogen or phosphorus requirement than others and, all else being equal; therefore present a higher risk of incidental loss of N and P from applied fertilisers. Premium milling wheat, for example, has a higher grain nitrogen content than wheat for stock feed, and thus usually receives greater applications of fertiliser nitrogen. Potatoes receive high rates of phosphorus compared with cereals. By contrast, late-harvested crops such as beet continue to take up nitrogen later in the season and therefore utilise fertiliser applications more efficiently, reducing the risk of nitrate leaching.

11.9.1 Arable Land and Nitrate Leaching

Soil leaching models for arable soils (e.g. NEAP-N, NIRAMS, SNIFFER diffuse pollution tool) are based on a soil nitrogen balance with the purpose of calculating the amount of residual nitrogen which is equated to the amount of nitrogen available for leaching. A typical equation for the nitrogen soil balance is:

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

An example of the input for the calculation of residual N is given in Dunn et al 2004 and summarised in Table 11.3.

Table 11.3 Database of N Values Used to Determine Residual Soil N (Dunn et al, 2004)

Crop	N Fertiliser	N Crop Offtake	N Atmospheric Deposition	Net Organic N Mineralisation	N Residual
	Kg N/ha/yr	Kg N/ha/yr	Kg N/ha/yr	Kg N/ha/yr	Kg N/ha/yr
Winter wheat	202	173	10	70	109
Spring barley, rye	99	107	10	45	47
Winter barley	166	139	10	45	82
Oats	121	105	10	45	71
Maincrop Potatoes	125	137	10	45	43
Spring oil seed rape	137	100	10	45	92
Winter oil seed rape	210	140	10	0	80
Kale and cabbage	140	72	10	45	123

The nitrate loss in soil drainage is typically calculated as a function of the amount of N available for leaching, the soil type as illustrated by the following equation (taken from the SNIFFER diffuse pollution tool):

$$NL_t = NAL_t \times (1 - \exp(-KNL \times (WAL_t / SATC)))$$

Where:

NL_t is the N leached at time t (kg N/ha)

NAL_t is the N available for leaching (kg N/ha)

KNL is the leaching coefficient (in the range 0.7 to 1.2)

WAL_t is the water available for leaching (mm)

SATC is the soil saturated capacity (mm).

The NEAP-N model adopts a similar approach although with a slightly different parameterisation. Nitrate at risk of leaching is calculated as a function of cropping, manure production and fertiliser application, and the fraction leached as a function of soil type (field capacity) and excess winter rainfall (soil drainage).

As noted in the previous section it has proved difficult to identify published data on rates of leaching from different crop types. Table 11.4 provides a summary of losses given in Macaulay Institute (2001).

Table 11.4 Leachable Nitrate (kg N/ha/yr) for Different Crop Types (Macaulay Institute, 2001)

Crop Type	Leachable Nitrate (Kg N/ha)
Set-aside and fallow	100
Cereals	50
Oilseed rape (including linseed)	70
Potatoes	90
Peas and other outdoor vegetables for human consumption	110
Fodder Beet	90
Brassicas for stockfeeding	70
Fruits	85
Grass for mowing	75
Grass for grazing under 5 years old	50
Grass for grazing 5 years old and older	15
Rough Grazings	1
Woodland	1
Semi-natural vegetation	1

It is noticeable that the values of leachable or residual N in Tables 11.3 and 11.4 differ significantly for some crops and land uses. Of particular significance is the difference in values for winter wheat, a ubiquitous crop in much of England, for which Dunn et al quote a residual N of 109 kg-N/ha, while Macaulay Institute quote a single value of leachable N of 50 kg-N/ha for all cereals. The latter also quote a high figure of 100 kg-N/ha for set-aside and fallow land. Without further sources of information it is not possible to further constrain these figures, but it is noted that the variations between the quoted figures indicate significant uncertainty.

The NEAP-N model (Lord and Anthony, 2000) estimates the fraction of leachable nitrate actually lost in a given winter as a function of drainage volume and the field capacity of the soil, using a statistical model based on the SLIM model (Addiscott, 1996). The calculated proportion of leachable nitrate lost in soil drainage depends on the ratio of cumulative soil drainage and soil field capacity. With this model, soils with low field capacity (for example, sands) experiencing high drainage will lose most or all leachable nitrate over the course of a winter, while higher field capacity soils or lower drainage volumes will leach less nitrate.

The amount of residual nitrogen nitrate leached is calculated using the following equation (after Anthony et al, 1996):

$$\varepsilon = h/\phi$$

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

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

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

Soil field capacity was estimated as a function of soil texture class, based on soils data from the Soil Survey and Land Research Centre (SSLRC), as shown in Table 11.5. Soil texture is described with the standard notation of Sand (S), Loam (L), Clay (C) and Silt (Z) and combinations thereof. For example, the symbol ZCL denotes a silty clay loam soil. Further information on assessment of soil texture using this terminology is given in Appendix 1 of Fertiliser Recommendations England and Wales (RB209, Defra, 2000 and updated 2010), a hyperlink to which is included in the catchment spreadsheets.

Leaching rates associated with organic fertilisers are less easy to predict than for inorganic fertilisers due to the greater uncertainty in the content and availability of the nitrogen in the manures and sludges (depending on their sources and forms).

The approach taken in the catchment worksheet calculations follows the soil N balance approach described above to determine the N available for leaching, and the NEAP-N approach to calculating the proportion of this which is lost.

Table 11.5 Typical Field Capacity by Soil Texture Class (from Anthony et al, 1996)

Soil Texture	Topsoil	Subsoil
S	18.30%	15.10%
LS	24.50%	21.50%
SL	31.50%	27.10%
SCL	34.80%	31.70%
SC	34.80%	37.50%
CL	40.50%	35.20%
SZL	35.30%	34.20%
ZL	37.50%	34.90%
ZCL	43.60%	38.10%
ZC	48.10%	41%
C	48.30%	44.10%

11.10 Grassland and Nutrient Cycling

Grassland agricultural systems may be broadly divided into managed systems, which are likely to receive fertiliser inputs and may be grazed or cut for hay or silage, and rough grazing land, more typical of upland catchments which are likely to be extensively grazed by cattle or sheep and receive little or no fertiliser. Although nitrate and phosphorus losses to groundwater are likely to be far greater per unit area from lowland, intensive grass than from rough grazing land, there are very large areas of rough grazing land in the UK and Ireland, particularly in Scotland

and Wales. 85% of the agricultural land in Scotland is classified as Less Favoured Areas (LFAs), much of which will be upland grazing (Scottish Parliament Research Note 01/37, 2001). 80% of the agricultural land in Wales is similarly classified (Welsh Assembly Government³).

Grasslands differ substantially from tillage systems in that the grass is a perennial crop, the land is left undisturbed by ploughing and cultivation, major differences exist in the patterns of organic matter accumulation and mineralization, and most importantly, they differ in the extent of nitrogen recycling that occurs through grazing and excretal returns by animals.

11.10.1 Managed Grassland

Managed grass may be grown for hay or silage, or grazed, or a combination of both. Fertiliser inputs are used on grassland to stimulate dry matter growth. Inorganic fertiliser use on grazed grass is usually directly correlated with stocking density.

Losses of fertiliser nitrates on grassland tend to be small. Grassland can make efficient use of nitrogen applications of up to 400 kg N/ha/yr without any appreciable leaching of nitrate (Addiscott, 1996).

However, application of nitrogen fertiliser to grassland allows higher stocking rates of grazing animals. High leaching losses can be associated with grazing animals due to the poor utilisation of dietary N by grazing ruminants which results in a large proportion of the N consumed being excreted and recycled back to pastures (MAFF, 1995). Measurements presented in Addiscott (1996) show nitrate losses from grazed grassland fertilised with 400 kg N/ha/yr of around 25% and 50% on undrained and drained grassland respectively. Experiments broadly suggest that 250 kg N/ha/yr is probably the most nitrogen can be applied safely to grazed grassland (Addiscott, 1996).

Compared with arable land, managed grass (particularly in older swards) is characterised by high levels of soil organic matter which can give rise to substantial rates of mineralization and high levels of soil mineral nitrogen (SMN).

Nitrogen Inputs

The principal sources of nitrate inputs to the soil (and hence of nitrate at risk of leaching to groundwater) are therefore:

- Fertiliser inputs (inorganic and organic);
- Mineralisation;
- Excreta (dung and urine) from grazing animals.

This last source represents, to some extent, recycling of nitrogen, since nitrate in excreta will be at least partly the same nitrate in grass consumed by the animal. In the context of a farm nitrogen budget, the main inputs to the system are therefore fertilisers and stock feed (including concentrates).

³ <http://wales.gov.uk/topics/environmentcountryside/farmingandcountryside/maps/lfamap>

In addition, some swards may contain clover which fixes atmospheric N. Atmospheric deposition forms an additional but less significant source of nitrogen.

Grass requires a balanced nutrient supply for maximum yield. Phosphorus fertiliser is therefore usually applied to managed grass for grazing or cutting at a rate dependent on the soil P index. The principal pathways of phosphorus loss from managed grassland are rather different from those of nitrate loss, and this is further discussed in Section 11.12.

Nutrient Losses

Nitrate is removed from the grassland system through:

- Offtake in cut grass or in produce (milk, liveweight gain);
- Volatilisation of ammonium-N (from applied slurry or FYM and from urine from grazing animals);
- Denitrification;
- Leaching of soil nitrate.

Nitrogen Losses

This section summarises various literature estimates of nitrate losses from managed grassland systems and rough grazing land under various management regimes, climates and soil types. It should be noted that published data may represent losses as Kg N/ha/year and/or mg N/l. In some cases it has not always been possible to represent the data in consistent units.

Nitrate models (such as NCYCLE, Rodda et al 1995) have been developed to predict nitrate losses from the soil zone and have been incorporated in models such as NIRAMS (Dunn et al 2004). An example of predicted leaching losses from grass is given in Table 11.6.

Table 11.6 Simulated N Leaching from Grassland for Weather Conditions at Crichton Farm, Dumfries (Dunn et al 2004)

	Total N Input from Fertiliser and Animal Excreta (Kg N/ha)	Leached n Kg/ha/yr (free draining soil) ¹
Grass for moving (<5 years old)	540	32 - 57
Grass for mowing (>5 years old)	540	33 - 78
Grass for grazing (<5 years old)	280	32 - 78
Grass for grazing (>5 years old)	256	34 -133

1. Lower figure denotes beef + cattle, higher figure dairy.

del Prado et al (2006) report the development and validation of the N-CYCLE-IRL model: a development of N-CYCLE applicable to Irish grassland systems. The model was applied to two model grassland systems (one grazed and one silage) typical of the borders, west and south of Ireland. Predicted nitrate concentrations in soil drainage for the grazed system are as shown in Table 11.7. Soil types considered are sandy loam (SL), loam (L) and clay loam (CL).

Table 11.7 Simulated Nitrate Concentrations in Leachate from a Dairy System (del Prado et al , 2006)

Stocking rate (LU/ha)	Fertiliser N (kg-N/ha)	Average Nitrate Concentration in Leachate (mg-N/l)		
		Well drained (SL)	Moderately drained (L)	Poorly drained (CL)
<1.2	58	5.8 (46)	4.3	0.7
1.2 - 1.5	101	7.7 (62)	5.6	1.1
1.5 - 1.9	137	9.5 (76)	6.8	1.5
1.9 - 2.25	182	11.8 (94)	8.4	2
2.25 - 2.6	248	15.7 (126)	10.9	3
2.6 - 2.9	297	18.7 (150)	13	3.8
>2.9	348	22.1 (177)	15.2	4.6

Note: Figures in brackets indicate estimated loss Kg N/ha assuming hydrological effective rainfall of 0.8 m/year. Concentrations only are provided in del Prado (2006) and these calculated loadings should be treated with caution and have been estimated for well drained soils only. 1 Livestock unit (LU) is equivalent to one 550 kg dairy cow.

The same authors report average simulated nitrate concentrations in leachate from silage systems as shown in Table 11.8. These results assume various climatic conditions representative of different parts of Ireland (agroclimatic zones).

Table 11.8 Simulated Nitrate Concentrations in Leachate from Silage Systems (del Prado et al, 2006)

Region in Ireland	Soil Type	Fertiliser Application (Kg N/ha/yr)	Leached N N/ha/yr)	Leached N (mg-N/l)	Denitrification Loss (Kg N/ha/yr)
South east	Moderately drained (L)	136	23.5	4.3	19.2
Dublin	Moderately drained (L)	126	16.7	5.6	17.2
Mid east	Poorly drained (CL)	141	4.8	1.1	15.1
Midlands	Well drained (SL)	137	32.5	6.5	5.7
Border	Poorly drained (CL)	116	4.1	0.8	12.8
South west	Poorly drained (CL)	123	6.4	0.6	19.2
South	Well drained (SL)	151	43.3	5.3	7.5
West	Poorly drained (CL)	102	4.2	0.6	12.7

Defra (2004b) report the results of modelling nitrate losses from intensive and extensive grassland systems, representative of:

- Intensive dairy farming in three locations (West Wales, Devon and South Cheshire);
- Suckler beef rearing in two locations (Cumbria and County Durham);
- Upland sheep in two locations (Cumbria and County Durham);
- Model farm systems were specified as follows:
 - Dairy farming. Intensive, with inorganic fertiliser applied at 250 kg inorganic N ha⁻¹. Slurry was applied at 40% Feb-Apr, 10% May-July, 24% Aug-Oct and 26% Nov-Jan. Silage fields also received inorganic N (depending on the number of cuts, up to 346 kg N ha⁻¹) + slurry N. Silage was followed by aftermath grazing;
 - Suckler beef. Fertiliser N rates were 100 kg N ha⁻¹ on silage ground, and 60 kg N ha⁻¹ (plus manure) on grazed fields. Stocking rate was 0.8 cows ha⁻¹ and 0.7 calves ha⁻¹. Feed was 280 kg concentrate cow⁻¹;
 - Upland sheep. Swards were: grass receiving 80 kg N ha⁻¹ on grazed only swards, and 120 kg N ha⁻¹. Stocking rate 8 ewes ha⁻¹ and 1.4 lambs ewe⁻¹. Concentrate feeding was at 100 kg ewe⁻¹ yr⁻¹.

Climate, soil type and atmospheric deposition of N were assumed as shown in Table 11.9. Baseline nitrate losses were calculated using the NGAUGE model as shown in Table 11.9.

Table 11.9 Model Farm Landscape Characteristics and Baseline Predicted N Losses (Defra, 2004b)

Site	Soil type	Drainage	Temperature (Degrees C)	Effective Rainfall (mm)	Atm Deposition (kg-N/ha/yr)	Baseline Predicted N Loss (kg/ha)
Devon/Dairy	Clay Loam	Poor	11-11.5	>500	25	31.3
West Wales/Dairy	Clay Loam	Poor	11.5-12	350-400	15	36.3
South Cheshire/Dairy	Loam	Moderate	11.5-12	300-350	25	51.1
Cumbria/Beef	Loam	Moderate	<9	>500	35	30
Cumbria/Sheep	Loam	Moderate	<9	>500	35	32
Co. Durham/Beef	Loam	Moderate	9-10	350-400	35	22.2
Co. Durham/Sheep	Loam	Moderate	9-10	350-400	35	23

For the catchment spreadsheets described in section 14, the N-CYCLE model (Rodda et al, 1995) was used to predict nitrate leaching from managed grassland (grazed or mown) for each of three soil types, three climate zones and a range of fertiliser application rates. N-CYCLE predicts the cycling of nitrogen through organic and inorganic forms, inputs from fertiliser, dung, urine and atmospheric deposition, removal from the soil through plant uptake and animal intake and losses through volatilisation, denitrification and leaching.

The N-CYCLE model was made available to the project free of charge by Rothamsted Research (North Wyke). The results of the model runs are summarised in Section 14.

11.10.2 Summary

Addiscott (1996) suggests that leaching of nitrate from ungrazed managed grassland is likely to occur at very low rates, even under high rates of fertiliser application. However, the addition of grazing animals significantly increases the risk of leaching, and nitrate losses increase with increasing stocking densities. Intensive dairy systems therefore present an elevated risk of nitrate leaching, since they often combine high rates of manure production with high rates of fertiliser application to stimulate grass growth for grazing. By contrast, low input grazing land typical of that found in LFAs is thought to leach relatively little nitrate.

11.10.3 Rough Grazing Land

Rough grazing land is assumed to receive no nutrient fertiliser inputs. The principal inputs of N and P to the soil are assumed to be excreta from grazing animals (i.e. recycling of nutrients from grass) and atmospheric deposition of N. Although inputs are very low compared with managed systems, many upland areas are characterised by thin soils and high rainfall, and therefore a high proportion of soil mineral nitrogen is at risk of leaching. Despite this, losses of nutrients to groundwater are much less than from managed grass. For example, Dunn et al (2004) assume a leaching rate of 2 kg-N/ha based on data from Department of the Environment.

11.10.4 Influence of Ploughing up of Grassland

The ploughing up of old permanent grassland, and grass ley on farmland can release a large flush of leachable nitrate. Cultivation disturbs balances by changing soil aeration levels (stimulating the activities of microbes and other soil organisms) and promoting the release of mineralised N. This is especially true of old grassland, where greater N mineralisation over time has produced more nitrate. Ploughing up of grassland during the Second World War resulted in increase in nitrate concentrations in chalk and limestone aquifers in England.

MAFF (1995) reports leaching losses of up to 876 kg N/ha over the first year after autumn ploughing of long-term grassland, with a mean value of 252 kg N/ha over eight trials. The same report suggests 100 and 200 kg N/ha is likely to be released following ploughing of a three year ley. Other studies report leaching losses of between 110 and 180 kg N/ha for young (<4 years old) grassland and 260 kg N/ha for older (>4 years old) grassland (Tester et al. 1985; Andrews et al, 1997). Addiscott (1996) alternatively applies an exponential relationship based on field data for the amount of organic nitrogen in the soil and the time since the ploughing out of the permanent grassland.

11.10.5 Woodland

Mature woodlands would not normally receive nitrogen fertiliser and the principal input of nitrogen to woodland therefore occurs through atmospheric deposition. Uptake of nitrogen by woodlands is typically 3-4 kg-N/ha/yr (CEH, 1998), which when compared with a typical rate of atmospheric deposition of 15-35 kg-N/ha/yr results in a potential excess of about 10-30 kg-N/ha/yr.

Nitrate loadings in soil drainage from woodland are typically low, however, reflecting the potentially large uptake of nitrogen by forest-floor vegetation and low rates of soil drainage beneath mature stands. Macaulay Institute (2001) suggests leachable nitrate from woodland of about 1 kg-N/ha/yr (Table 11.4), which when diluted in recharge of 150 mm would result in a nitrate-N concentration of less than 1 mg-N/l.

11.10.6 Summary of Approach

Because of the large range in potential nitrate leaching rates from agricultural land, a simplified model was developed to estimate the loading of N (Section 14). This model can be used with available national datasets, but can also be extended to use more detailed cropping information, where available. The model approach for all rural land uses except managed grassland uses a soil N balance calculation to estimate the nitrate at risk of leaching. In this method, the residual N is calculated as the difference between inputs of nitrogen to the soil (fertiliser, mineralization, etc.) and exports from the soil (crop offtake, volatilisation). Data on soil type and hydrologically effective rainfall (HER) are used to estimate the fraction of this nitrate which is leached from the soil. Due to the greater complexity of nitrogen cycling on cut or grazed grassland, the N-CYCLE model was deployed to estimate nitrate leaching from managed grassland. More details on the model setup and output are given in Sections 14 and 15.

11.11 Leaching of P

A review of phosphate leaching from soils is given in SNIFFER (2008) and Johnston and Dawson (2005). Although P losses from arable and grassland are much lower than N losses, relatively low concentrations of phosphorus in receiving surface waters can be sufficient to cause eutrophication. Most phosphorus transfer occurs in surface runoff and shallow interflow (Haygarth, 1997), suggesting that sorption of P to soil limits P transfer to groundwater in matrix flow, and that the dominant transfer pathway to groundwater is likely to be in rapid fissure flow. The majority of the literature therefore focuses on phosphorus transfer to surface waters, with few studies considering P in groundwater.

SNIFFER (2008) provides a review of investigations of leaching of phosphate from soils. Further information is given in Heckrath et al (1995), Maguire and Sims (2002), McDowell and Sharpley (2001), Horta and Torrent (2007), Watson et al (2007) and Fortune et al (2005). The majority of these studies show that the concentration of P in soil drainage increases in relation to the soil P content (Olsen P) and that there is a change point. Below this change point P concentrations in soil drainage are relatively low (<0.15 mg/l), and above the breakpoint concentrations can be significant (>1 mg/l as P) (Heckrath et al, 1995). Heckrath et al (1995) identified that this change point was for a soil concentration of 60 mg/kg. Fortune et al (2005) report the results of studies on several different soil types and found the change point was between 20 and 100 mg/kg. It is noted that current practice is to minimise fertiliser applications

to soils with high P (i.e. in Great Britain fertilisers should not be used for soils with an Olsen P of greater than 45 mg/kg).

Water soluble P (DRP) loss to water from an intensively grazed grassland field, at Johnstown Castle Research Centre, was found to be over 4 kg P per ha per year (Tunney, 1997). This field received 30 kg fertiliser P per ha per year for the past 30 years and had a soil test of 17 (mg P per litre soil). This was about six times higher than on a less intensively farmed grassland field that received very little P fertiliser in the past and had a soil test of 4.

Owens et al (2008) report measurements of soil phosphorus content through profiles of agricultural soils. They found that soil P contents in arable soils decreased sharply below the plough layer. For grassland soils, while there was significant variation, soil P levels were reduced below depths of about 10cm.

The approach used in the catchment spreadsheets to estimate N loss (i.e. a soil N balance) does not transfer well to an estimation of P losses. This is because P binds well to soil, and the current practice of applying fertiliser at maintenance rates for P means that the calculated P soil balance will, in most cases, result in a net change in soil P over a season of close to zero. However, soil P can be lost in soil drainage (albeit with likely significant attenuation in the soil zone) and in association with eroded sediment, although this is unlikely to be a significant pathway to groundwater. P can also be lost from surface applied fertilisers (organic or inorganic) in the period between application and becoming bound to soil or taken up by the crop. It was therefore necessary to adopt a different approach to the estimation of P losses from agricultural soils.

There are a range of models that have been developed to model phosphate loss from the soil zone (e.g. PSYCHIC, PSALM, diffuse pollution tool (SNIFFER 2006a and b), WFD85 (SNIFFER, 2008)). PSYCHIC and SNIFFER (2008) use a relatively simple approach to estimate the P concentration in soil drainage based on the soil Olsen P index. These modelling approaches are summarised below:

PSYCHIC (Davison et al 2008):

$$P_{\text{loss}} = 0.4 \cdot PO^{0.33}$$

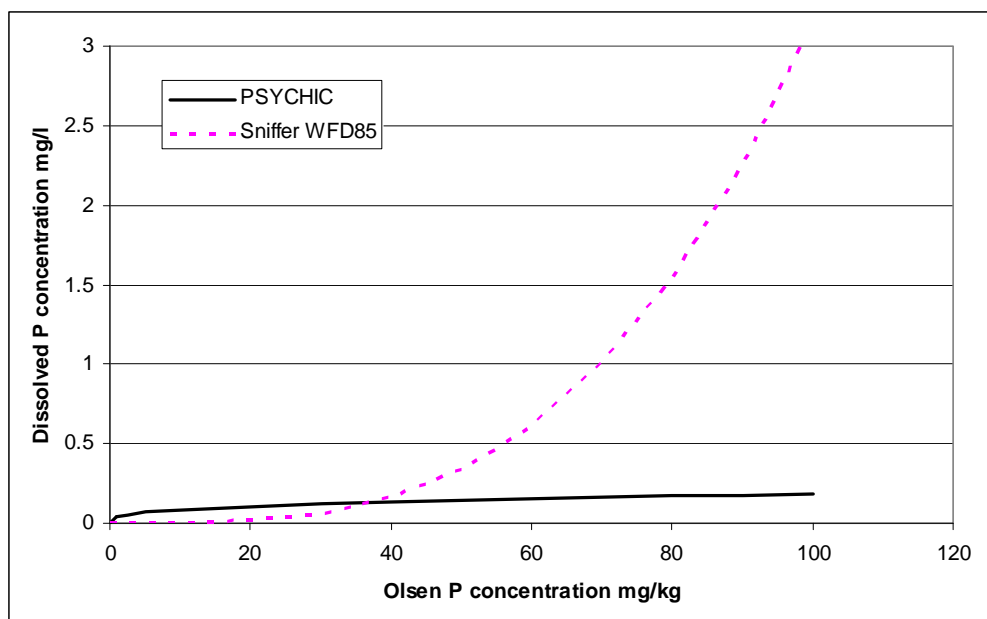
where PO = Soil Olsen P Index.

WFD85 (SNIFFER, 2008):

$$P_{\text{loss}} = (PO/70)^{(1/0.31)}$$

No allowance is made for soil type (e.g. concentrations in soil drainage might be expected to be higher for calcareous soils), which partly reflects the availability of experimental data, but could be represented by modification of the coefficients used in the above equations.

The calculated concentration of phosphorus in soil drainage using these two models is given in Plate 11.5. These calculated concentrations could be used with the amount of infiltration through soils to determine the soil P loading to groundwater.

Plate 11.5 Calculated P Concentration in Soil Drainage

The SNIFFER model provides a better representation of the observed behaviour reported by Heckrath et al (1995) and Fortune et al (2005), however both models predict similar levels of dissolved P for low Olsen P values (<40 mg/kg). The PSYCHIC model was developed to represent the P loss to surface water where the loading from the dissolved P in soil drainage represents a relatively small component of the total loading.

These models take no account of P inputs from the soil from fertilisers, although it is noted that current practice is to maintain soil P through balancing P inputs to P removal in crops. The PSYCHIC model does allow a component of incidental P loss (to surface water) where inorganic and organic fertiliser is applied to the soil surface and P is removed by rainfall. Fertilisers ploughed into the soil will be more readily taken up by soils or mobilized into soil store.

In Table 11.10, the typical Olsen P content of different soil types is summarised. These Olsen P values have been used to calculate the P content in soil drainage using the above equations. This table indicates that for most soils the P concentration in soil drainage is likely to be relatively low.

The Phosphorus Indicators Tool (PIT) (Heathwaite et al, 2003) is a simple modelling framework for the estimation of diffuse phosphorus transfer from agricultural land to surface waters. Like PSYCHIC, it is based around the concepts of source, mobilisation and delivery. Sources of phosphorus are fertiliser (organic and inorganic) and soil P. Mobilisation is the solubilisation of soil P and P from fertilisers, and the detachment of soil particles and associated particulate P. Delivery is the transfer of P in solution in surface runoff, flow through assisted drainage (where present) or via groundwater, or the transfer of eroded soil and associated particulate P in surface runoff or drainflow. The proportion of hydrological effective rainfall (HER) reaching streams via each pathway is estimated from the HOST soil classification (Boorman et al, 1995).

The mobilisation and delivery of P from each source is estimated by a set of model coefficients representing the fraction of each source of P which is transferred via each pathway. For example, the coefficient for transfer of soluble P from manures in subsurface matrix flow is 0.08 (or 8%), and the coefficient for delivery through drains as bypass flow is 1.0 (or 100%, indicating no losses in transit). Those elements of the PIT model relevant to transfer of P in solution from soil and fertilisers to groundwater have been incorporated in the catchment spreadsheets.

Table 11.10 Olsen P Content of Different Soil Types (Davison et al 2008)

Soil Type	Soil Category Olsen P (mg/kg) by Land Use			
	Combinable Crops and Cereals	Potatoes and Vegetable Rotations	Intensive Grass	Extensive Grass and Woodland
Sandy	42	45	25	21
Light	32	41	26	21
Medium/heavy	27	30	22	20

Soil Type	Soil P Concentration (mg/l) in Soil Drainage (PSYCHIC model)			
	Combinable Crops and Cereals	Potatoes and Vegetable Rotations	Intensive Grass	Extensive Grass and Woodland
Sandy	0.14	0.14	0.12	0.11
Light	0.13	0.14	0.12	0.11
Medium/heavy	0.12	0.12	0.11	0.11

Soil Type	Soil P Concentration (mg/l) in Soil Drainage (SNIFFER WFD model)			
	Combinable Crops and Cereals	Potatoes and Vegetable Rotations	Intensive Grass	Extensive Grass and Woodland
Sandy	0.19	0.24	0.04	0.02
Light	0.08	0.18	0.04	0.02
Medium/heavy	0.05	0.07	0.02	0.02

This table indicates that the P concentration in soil drainage for most soil types is relatively low, and it is only for soils with a high P content that high leaching losses would be expected.

11.11.1 Summary

Most phosphorus transfer from agricultural land is thought to occur in surface runoff and shallow interflow, and most research has focussed on surface water catchments for this reason. Phosphorus transfer to surface waters may occur in dissolved form (from soil or surface-applied

fertilisers) or in particulate form (in association with eroded soil). Particulate transfer is unlikely to be a significant factor in loading to groundwater, since attenuation in the soil matrix and unsaturated zone is likely to be high. There is a strong correlation between measured concentrations of dissolved phosphorus in runoff and soil P status (P index). Over long periods, P surpluses may build up on agricultural soils leading to elevated risk of phosphorus loss in runoff. Phosphorus concentrations in surface runoff may also be increased by removal of phosphorus from surface applied fertilisers, and fertiliser and crop management (the timing of fertiliser applications and delay before incorporation) may therefore influence rates of P loss. The contribution that this makes to groundwater remains unclear, however, since attenuation in matrix flow in the soil zone is likely to be significant. This is further discussed in Section 13. The dominant pathway for phosphorus transfer to groundwater is, therefore, likely to be rapid fissure flow. Although the quantity of P transferred to groundwater may be very small when considered as a fraction of the P applied to agricultural land and in agricultural soils, it may still be sufficient to cause concentrations in excess of water quality thresholds.

The information presented in this section has been used to develop a model of P loading to groundwater from agricultural land. The model estimates P loss from soil, as a function of soil P index, and from fertiliser applications through solubilisation of P. It draws on existing published research to estimate P mobilisation and delivery to groundwater. Further details of the setup and outputs from the model are given in Sections 14 and 15.

12. Agricultural Point Sources

12.1 Slurry and Manure Storage

Organic manures such as pig slurries can present a significant source of point-source pollution if not appropriately managed (Defra 2000). Current regulations and good practice requires slurry to be collected and stored prior to spreading on agricultural land.

Slurry and solid manures can be stored in a variety of ways. Liquid slurries are stored in steel tanks, slatted pits and lined lagoons. Solid manure can be stored as stockpiles in areas of spreading, stockpiles in a lined area and unlined or partially lined manure heaps/middens.

Nicholson and Brewer (1997) provide an estimate of the number and area of stores of solid manure in England and Wales. The total volume of stored manure was estimated as about 14.9 Mm³ with an estimated area of about 11.9 Mm². They also estimated that the majority of diluted livestock slurry and farmyard dirty water was stored in earth banked slurry lagoons (total estimated volume of 17.2 Mm³ and an estimated area of 7 Mm²). The number of unlined manure and slurry stores (middens) was estimated as 6840. No statistics were given for Scotland, Northern Ireland and the Republic of Ireland, although the methodology outlined by Armstrong et al (2004) for estimating the number of stores using agricultural census returns may be appropriate.

The potential volume of slurry produced can be estimated based on the number of livestock housed and the volumes of excreta per animal. Statistics on the volumes of excreta are given in Appendix A.

The amount of N and P in slurry is given in Table 12.1, however composition will change during storage due to volatilisation of ammonia, leaching losses and infiltration and rainfall. Storage facilities will have been designed to minimise infiltration and leaching losses.

Table 12.1 Amount of Nutrient Contained in 1m³ of Slurry (DAFF - Completing the Fertiliser Plan⁴)

Livestock Type	Total Nitrogen (kg)	Total Phosphorus (kg)
Cattle	5.0	0.8
Pig	4.2	0.8
Sheep	10.2	1.5
Poultry - layers 30% DM	13.7	2.9

4

<http://www.agriculture.gov.ie/media/migration/ruralenvironment/environment/nitrates/NSForm52010completingthefertiliserplan220610.pdf>

The main risk to groundwater will be from losses (leaching) from the bases of unlined storage facilities in contact with permeable ground. Pollution of groundwater from lined or enclosed storage is not common, and typically caused by structural or operator failure (Goody et al. 2001).

Unlined installations date from prior to 1991. Armstrong et al 2004, estimated that there are likely to be in the order of up to 1000 on the Chalk and Permo-Triassic Sandstone in England and Wales. The risk from unlined facilities will be higher where the unsaturated zone is thin, and or there is little protection from drift cover, and or there are fissures and fractures in the underlying strata which provide rapid pathways.

Unlined earth based slurry stores and unlined manure stores have some element of self sealing as the solid phase seals voids in the store side and base wall. Scraping of the store base during cleaning can lead to an increase in leaching as this seal is removed.

The risk to groundwater from unlined slurry stores in England and Wales was assessed by the BGS and further investigation was recommended at a smaller scale (Armstrong et al., 2004). This assessment was based on an estimate of the number of stores within a 10 km square and groundwater vulnerability (taking account of soil and drift type). The number of stores was based on the number of livestock (from agricultural census returns), typical volumes of excreta and an estimated slurry volume of 1500 m³ per store.

SNIFFER (2008) gives a summary of investigations of pore water below unlined slurry lagoons on chalk and sandstone. The sandstone sites showed limited downward movement. Greater depth of movement was observed at chalk sites; greater than 10m at some sites. The depth of movement was dependent on whether the based of the site was scraped. For scraped sites, pore water concentrations below the store exceeded 5 mg/l as P. The SNIFFER report also describes an investigation where groundwater pollution by phosphate was identified in a borehole 80m from the slurry store.

Summary

The data given in Table 12.1 indicate that the concentrations of N and P in cattle slurry would be 5000 mg N/l and 800 mg P/l respectively. The actual concentration in leachate draining to the subsurface from the slurry store is likely to be lower due to attenuation at the base of the store. For example, pore water profiling indicates that concentrations of P immediately below a slurry store can exceed 5mg/l with maximum concentrations of up to 60 mg/l as P (SNIFFER, 2008). Whilst these concentrations are high they indicate significant attenuation (>95%) below the slurry store, although no data are reported for the source term.

Conservatively assuming attenuation rates for N and P of 20% and 90% the concentration in drainage from slurry stores is estimated as 4000 mg N/l and 80 mg P/l respectively and these values have been used in the catchment loading calculations (Section 14 and Appendix D).

The main loading to groundwater will be from unlined manure and slurry stores.

12.2 Farmyard Dirty Water and Constructed Wetlands

Farmyard dirty water will typically contain manure, urine, effluent, milk and cleaning materials. Sources of farmyard dirty water (FDW) include:

- Water from washing down hardstanding areas;
- Water from washing down of equipment - dairy parlour areas/ vehicles;
- Dilute disinfectant/veterinary medicines from bio-security areas/ milking areas/ equipment;
- Roof rainwater.

Farmyard dirty water (FDW) was traditionally collected and held along with slurry in lagoons or tanks prior to spreading to land. However, with NVZ restrictions on slurry spreading, and the requirement for up to 5 months storage facility, the co-disposal of FDW with slurry is impractical due to the volumes of FDW involved and the need for management of farmyard clean and dirty water streams. Constructed Wetlands (CW) have been used more recently to treat FDW (Section 12.2.1).

An estimate of the volumes of FDW (GRU, 2004 and Armstrong et al, 2004) can be made based on: number of livestock housed; volume of water used for washing; and duration of housing. For example, a 50 cow herd housed in a farm for a 180 day period would produce about 315 m³ of FDW assuming 35 litres/cow/day (GRU, 2004). This assumes the bulk of excreta is managed separately.

The composition of FDW will vary depending on solid composition (mainly manures and urea) and the diluting volume of clean water (rainfall and clean water). The majority of the N and P content of FDW will therefore be controlled by:

- Dilution by rainfall and clean washing water;
- Dry weight content i.e. type of animal manure (Section 11.3.2).

Studies (Gouriveau et al, 2007 and Dunne et al, 2005) which have looked at the treatment of FDW by constructed wetlands report the following quality for FDW influent as shown in Table 12.2:

Table 12.2 Quality of Farmyard Dirty Water

Nitrate (as N) mg/l	Ammonium (as N) mg/l	Phosphate as P mg/l	Reference
6.3	0.5	0.07 (inorganic)	Gouriveau 2007
4	13	0.6 (inorganic)	Gouriveau 2007
-	28 to 47	5 - 7 (soluble reactive)	Dunne 2005

Loadings from FDW have not been calculated in this report as this will depend on its management, method of storage and treatment and point of disposal.

Proposed default values for the concentration of N and P in FDW are 17 mg N/l and 0.3 mg P/l respectively and these have been used in the catchment loading calculations (Section 14 and Appendix D).

12.2.1 Constructed Wetlands

Constructed Wetlands (CW) have also been used more recently to treat FDW to a standard suitable for discharge to surface water, although their effectiveness in removing pollutants of concern is strongly dependant on their design and capacity (GRU 2004, DARDNI 2008). CWs are man-made wetlands, which usually include an impermeable synthetic liner/ clay base filled with soils or selected substrates (e.g. sands or gravels) which have been planted with macrophytic vascular plants (reeds). The plants establish a submerged extensive root system, algal populations increase and with time, distinct aerobic and anaerobic zones develop in this root system. These components filter the effluent/ polluted waters channelled through the wetlands system, retaining solids and adsorbing or chemically altering pollutant species, allowing the cleaner water to move through to the discharge point.

The performance and, therefore, design of CWs depends on:

- Effluent quality and rate of supply. CWs are designed to treat dilute farm waste but there is no evidence that they are capable of dealing with raw slurry or silage effluent (DARDNI 2008);
- Hydrologic conditions (topography);
- Aquatic plant type and evapo-transpiration rates;
- Residence time of water in wetland;
- The quality of the influent to CWs is likely to be variable (Section 12.2).

The reported efficiency of CWs for removal of N and P (GRU, 2004) is:

- 40 to 90% for N;
- 27 to 68% for P, although this will vary seasonally.

Proposed default values for the concentration of N and P in drainage from CWs are 9 mg N/l and 0.3 mg P/l respectively and these have been used in the catchment loading calculations (Section 14 and Appendix D). These concentrations assume that the efficiency of CWs for removal of N and P is 50%.

13. Attenuation

This section provides an overview of attenuation processes for nitrogen and phosphorus (Section 13.1 and 13.2), provides a summary of available information related to specific activities (Section 13.3) and provides estimated attenuation rates for N and P (Section 13.4).

13.1 Nitrogen

13.1.1 Nitrate

A detailed account of attenuation processes for nitrate is given in Environment Agency 2005. This review identified that there was limited evidence for attenuation of nitrate in aerobic aquifer environments and that attenuation (denitrification) would mainly occur in anaerobic conditions and that losses could be as much as 100%. Anaerobic conditions are likely to be associated with water logged and organic rich soils.

13.1.2 Ammonium

Ammoniacal nitrogen will either be sorbed onto the rock matrix or transformed to nitrate (under aerobic conditions). Sorption may be reversible (the sorption process will simply retard the rate of contaminant movement) or irreversible (such as cation exchange). Ammonium can transform to nitrate (nitrification) under aerobic conditions.

A detailed account of attenuation processes for ammonium is given in Environment Agency 2003c. This publication also provides literature values for degradation of ammonium (transformation to nitrate) and partition coefficients for different aquifer materials. Partition coefficients for ammonium ranged from 0 to 6.5 l/kg, although values were more typically in the range 0-2 l/kg. There is limited information on degradation (transformation rates) in the unsaturated and saturated zone. Erskine (2000) calculates a degradation rate (half life of 1 to 6 years) for ammonium degradation in a sand and gravel aquifer downgradient of a landfill site. Degradation of ammonium is likely to be limited under anaerobic conditions, although Buss et al (2004) report that degradation could occur by anaerobic ammonium oxidation.

Further discussion on attenuation is given in Section 13.3, mainly in relation to landfills (Section 13.3.1) and sewage effluent disposal (Section 13.3.3).

13.2 Phosphorus

Soil P may be present in organic or inorganic forms and in dissolved or particulate forms. The movement of phosphorus through the soil and unsaturated zone will be as dissolved P, colloids, and as P sorbed on soil particles. Phosphorus will sorb to the soil and rock matrix, such that movement through cracks in the soil, worm burrows and other macropores reduces the contact time between percolating water and soil and thus decreases the natural attenuation capability of the soil (Ryan, 1998). Several authors (e.g. Dils and Heathwaite, 1996) have suggested preferential flow as mechanism for P to bypass the soil's natural sorbing capacity.

A review of sorption processes for P is given in SNIFFER (2008). P tends to sorb to aluminium and iron oxides and calcium carbonates. Lower rates of sorption are associated with the latter such that P is more likely to be mobile in calcareous soils and aquifers. Column experiments indicate that there are two components to sorption of P: relatively rapid and slow. The latter may include precipitation of metal (calcium, iron and aluminium) phosphate phases. The SNIFFER (2008) study notes that there is limited quantitative information on sorption and precipitation of P.

Leaching of P from soils has been identified in areas which have characteristics such as coarse textured soils (Eghball *et al.*, 1996), sandy soils with high permeability (e.g. Chen *et al.*, 1996), soils with low P sorption capacity (Breeuwsma and Reijerink 1992, Breeuwsma *et al.*, 1995) and areas with shallow water tables (e.g. Grant *et al.*, 1996). Sub surface drainage can increase drainage rates from soils and decrease the contact time with soils and therefore reduce attenuation. Sub surface drainage will tend to route flow to surface water and can be an important mechanism for loss of P (Sims *et al.* 1988).

In the SNIFFER (2008) study, P losses from the soil zone were calculated for Great Britain and Ireland using the approach described in Section 11.11. However the following limitations were noted:

- Only total soil P data are nationally available for Scotland;
- National data for Olsen P for England and Wales date from a survey undertaken between 1978 and 1983, when P levels in soil may have been higher;
- No national data for the Republic of Ireland.

Where data on Olsen P were available (Northern Ireland), the SNIFFER (2008) study found that there was a reasonable correlation between observed and predicted P concentrations in groundwater.

There appears to be limited published data on P sorption in the unsaturated and saturated zone. Table 13.1 provides a summary of values for retardation and partition coefficients obtained from an initial review of the literature.

Table 13.1 Summary of Partition Coefficients and Retardation Factors for P

Reference	Partition Coefficient (l/kg)	Retardation Factor
BGS (2007)		5 - 20
Robertson <i>et al.</i> (1998)		20 - 100 (field)
Robertson (2008)	4.8 (laboratory)	25 37 (field)
Lin and Banin (2006)	4-6 (laboratory) 20-55 (field)	

There is literature data on export coefficients describing the losses of P from soils to surface water (e.g. McGuckin et al, 1999; Johnes 1995), however there is limited information on P losses to groundwater. In the SNIFFER (2008) study a simple equation was used to estimate the concentration in recharge at the base of the unsaturated zone due to attenuation. This equation is as follows:

$$C = P_{\text{loss}} \cdot \exp(-\alpha)$$

Where:

C = concentration of P at the water table (mg/l)

P_{loss} = P concentration in soil drainage (mg/l)

α = attenuation factor (0-3, depending groundwater vulnerability), equivalent to a percentage decrease in P of 0 to 95% (Table 14.2)

The attenuation factors derived are as summarised in Table 13.2.

Table 13.2 Summary of Attenuation Factors (SNIFFER, 2008)

Vulnerability Class	Description	Attenuation (Expressed as Percentage Reduction in P)
5	Vulnerable to most water pollutants with rapid impact	0
4	Vulnerable to those pollutants not readily absorbed or transformed	10
3	Vulnerable to some pollutants with many significantly attenuated	63
2	Vulnerable to some pollutants but only when continuously discharged/leached	86
1	Only vulnerable to conservative pollutants in the long term when continuously and widely discharged/leached	95

There is limited information on the extent of plumes of P in groundwater. Robertson (2008) report that the length of plumes associated with septic tanks discharges range from 1 to 75 m. The longer plumes are associated with calcareous rich sediment, and shorter plumes (<3 m) with non calcareous (acidic) sand, silt, clay. Reducing, or acidic conditions promote the precipitation of aluminium and iron minerals whereas in oxidising and neutral pH conditions this does not occur. SNIFFER (2008) describes the monitoring results for a monitoring borehole located about 80 m from an unlined slurry lagoon.

In the case of karst aquifers, point recharge via swallow holes may allow the attenuation properties of the unsaturated zone to be by-passed, while rapid flow through the aquifer in solutionally widened fissures and conduits can also minimize attenuation and provide enough energy to facilitate particulate transport during high stage events. The extent to which phosphate is retained within karst aquifers is expected to vary according to the relative importance of diffuse and conduit flow. A study by Kilroy and Coxon (2005) of eight karst springs in Ireland identified that the concentrations of particulate P and dissolved organic P

increased following rainfall events, but that dissolved inorganic P showed greatest stability. The observed increases were greatest in September.

In summary controlling factors on attenuation rates for P are:

- Presence of preferential pathways allowing migration of P sorbed to particles and/or reducing the potential for soil interaction (e.g. sorption of dissolved P);
- Thickness and permeability of the soil and drift cover;
- Soil phosphate content (i.e. higher rates of leaching are associated with soils with a high Soil Olsen P index);
- Iron and aluminium content (higher sorption rates are associated with iron and aluminium minerals);
- Location of discharge (i.e. some activities may result in discharge below the soil zone).

13.3 Summary of Information on Attenuation Related to Specific Activities

13.3.1 Landfill

A detailed account of attenuation processes for ammonium is given in Environment Agency 2003c. As noted in Section 13.1.2 there is limited information on degradation (transformation rates) in the unsaturated and saturated zone. Erskine (2000) calculates a degradation rate (half life of 1 to 6 years) for ammonium degradation in a sand and gravel aquifer downgradient of a landfill site. However as geochemical conditions below landfill sites are typically anaerobic this process is likely to be limited. Downgradient of landfill sites conditions can become aerobic and nitrification may occur (Erskine 2000).

The majority of references for attenuation of ammonium in landfill leachate date from the 1980's and 1990's and these have not been reviewed as part of this study as relevant information will have largely been presented in Environment Agency 2003c, 2007 and Buss et al 2004. More recent references (Thornton et al 2001a and 2001b, and Fannin 2006) consider attenuation within mineral liners. There will also be a considerable amount of information from site specific groundwater risk assessments for landfill sites. A review of landfill risk assessments is considered to be beyond the scope of this assessment and it is noted that a landfill will only receive a permit if it can be demonstrated that there is no risk of pollution of groundwater by non hazardous substances (e.g. ammoniacal nitrogen). However these assessments will have only considered decreases in ammoniacal nitrogen along the groundwater pathway and not necessarily changes in total nitrogen (e.g. is there an increase in nitrate concentrations down gradient of the landfill). Lerner (2000) estimated that about 20% of ammoniacal nitrogen in leachate becomes nitrate and is leached to groundwater.

No specific references could be identified on the attenuation of phosphorus below landfill sites.

13.3.2 Effluent Discharges

Attenuation of sewage effluent will depend on the method of disposal, the rate of discharge, the type and construction of the drainage field, the area of discharge and the thickness and properties of the unsaturated zone. Attenuation within drainage blankets is discussed in Section 6.4. Literature on attenuation in the unsaturated zone is discussed in this section.

An assessment of the impact of STW discharges to ground was undertaken by Entec (2009). This involved the assessment of attenuation in the unsaturated zone. Attenuation factors were derived for both N and P by reference to chloride to correct for dilution. The results of this assessment are summarised in Table 13.3.

This assessment identified that attenuation was variable between sites. For example the reduction in ammonium concentrations ranged from 0 to 100%. Where ammonium concentrations decreased this was often accompanied by an increase in nitrate concentrations (i.e. ammoniacal nitrogen was nitrified to nitrate). The rates of nitrogen loss were also variable ranging from 0 to 100%. The results for phosphate were also variable with the reduction in loading ranging from 0 to 100%. No clear conclusions could be drawn on the reasons for variable attenuation rates although lower rates of attenuation were typically associated with high hydraulic loading rates.

CEEP (2006) provide a review of literature data on the fate of phosphorus and nitrogen from septic tanks which is summarised in Table 13.3.

Table 13.3 Fate of Phosphorus and Nitrogen

Reference	Summary
Johnson and Atwater 1988	96 to 99% P removal, 25% N removal
Robertson 2000	Reduced P to less than 0.05 mg/l P
Harman et al 1996, Robertson et al 1998	85% P removal in first 30cm of soil
Robertson and Blowes 1995	25% P removal in unsaturated zone
Robertson and Blowes 1995	100% P removal
Roberston et al 1998	23 to 99% removal (sorption) of P. 100% transformation of ammonium, but no net loss of N
Woods 1993	Most removal (sorption) in first 14cm of soil
Sawhney and Starr 1977	Most removal in first 15 to 30cm of soil

The main observations from this review are that P removal rates can be high (often greater than 90%) and that most of this occurs in the first 10 to 30 cm of sub-soil, although it is not clear from CEEP (2006), whether a drainage blanket is present. For nitrogen whilst significant decreases in ammonium occur, total N losses are variable and may be negligible.

Lerner (2003) estimates that 20 to 80% of ammoniacal nitrogen in sewage effluent becomes nitrate and is leached to groundwater.

Table 13.4 Effluent Loading and Attenuation of Phosphate and Nitrogen Loading for Treated STW Discharges in SE England (Entec 2009)

Site	Discharge m ³ /d	Aquifer	Ammonium as N		Total Nitrogen as N		Phosphate as P	
			Effluent Concentration mg/l	Attenuation in Unsaturated Zone (%)	Effluent Concentration mg/l	Attenuation in Unsaturated Zone (%)	Effluent Concentration mg/l	Attenuation in Unsaturated Zone (%)
1	795	Upper Chalk	8.2	100	40.2	0	7.0	71
2	8340	Upper Chalk	11.9	0	19.7	17	3.2	0
3	8340	Upper Chalk	3.2	93	14.7	17	3.7	73
4	1426	Upper Chalk	4.5	100	29.6	0	7.7	17
5	1110	Upper Chalk	6.8	0	22.8	70	4.5	23
6	1375	Chalk	0.3	100	16.2	0	3.9	9
7	7	Upper Chalk	0.8	100	12.9	17	7.6	67
8	18.5	Reading/Upper Chalk	25.6	63	39.6	50	8.0	0
9	250	Upper Chalk	32.5	94	33.9	17	4.8	0
10	690	Reading/Upper Chalk	0.3	100			4.0	100
11	8	Hythe Beds	12.4	100	35.3	100	7.2	
12	720	Upper Chalk	7.7	98	31.5	100	7.2	17
13	11	Hythe Beds	8.1	88	35.6	38	6.0	100
14	15	Upper Chalk	5.3	100	29.4	76	11.0	100

Table 13.4 (continued) Effluent Loading and Attenuation of Phosphate and Nitrogen Loading for STW Discharges in SE England (Entec 2009)

Site	Discharge m ³ /d	Aquifer	Ammonium as N		Total Nitrogen as N		Phosphate as P	
			Effluent Concentration mg/l	Attenuation in Unsaturated Zone (%)	Effluent Concentration mg/l	Attenuation in Unsaturated Zone (%)	Effluent Concentration mg/l	Attenuation in Unsaturated Zone (%)
15	455	Alluvium	1.2	100	19.2	33	5.5	0
16	167	Upper Chalk	2.6	100	28.6	0	6.9	0
17	36	Upper Chalk	1.3	0	33.4	100	7.7	100
18	8	Chalk	13.0	100	20.9	100	4.9	100
20	15	Middle Chalk	8.5	100			7.2	
21	10	Lower Chalk	28.9	100	35.3	38	8.9	72
22	14	Upper Chalk	3.4	0	29.5	0	7.8	0
Summary			0.8 - 13.2 (8.9)	0 - 100 (78)	12.9 - 40.2 (27.8)	0 - 100 (41)	3.2 - 11 (6.4)	0 - 100 (45)

13.4 Summary

An objective of this project was to derive attenuation factors for different soil and geological settings to reflect groundwater vulnerability to different activities. The literature review has identified that there is limited quantitative information on attenuation and, therefore, the attenuation factors provided in this section are based on a qualitative assessment of the data together with expert opinion. Therefore attenuation rates should be treated as indicative.

Suggested attenuation rates for N and P are given in Table 13.5 for a range of geological settings and activities. The number of hydrogeological settings considered has deliberately been kept simple reflecting the limited information available. This table only considers the subsoil and unsaturated zone as it is considered that attenuation in the soil has largely been taken into account in the determining N and P loading for different activities (Sections 4 to 12).

Attenuation is expressed as the percentage reduction in N or P.

Table 13.5 Attenuation Factors (Unsaturated Zone)

Activity and Hydrogeological Setting	N Attenuation Factor	Comment	P Attenuation Factor	Comment
Agriculture, woodland, grassland (i.e. drainage from soil zone)				
Fissured/karst ¹	0	No attenuation of nitrate (denitrification) and ammonium transformed to nitrate with low losses. Losses due to volatilisation considered as part of soil N model	0	No attenuation (assumes any attenuation associated with overlying soils)
Intergranular/dual porosity (< 2m)	0	Attenuation unlikely unless anaerobic conditions (i.e. water logged conditions	10 - 50	Guestimate ² and dependent on mineralogy
Intergranular/dual porosity (> 2m)	0	when losses may be high 80 to 100%)	25 – 75	(high rates of sorption associated with strata with iron content
Clay (<2 m)	50 – 90	High attenuation due to anaerobic conditions resulting in denitrification of nitrate (high N loss).	75 – 100	High attenuation due to sorption
Clay (> 2m)	90 – 100	Transformation of ammonium will be inhibited, but slow rates of movement and sorption (cation exchange likely to be significant). Weathering of the clay and the presence of cracks in the clay may provide rapid pathways and therefore lower losses are given for thin (<2m) clay.	90 - 100	High attenuation due to sorption

Table 13.5 (continued) Attenuation Factors (Unsaturated Zone)

Activity and Hydrogeological Setting	N Attenuation Factor	Comment	P Attenuation Factor	Comment
Landfill (including mass burial sites)				
Fissured/karst ¹	0	No attenuation. Ammonium assumed to be transformed to nitrate with no losses. Any attenuation will be associated with liner	0	No attenuation, any attenuation will be associated with liner (if present)
Intergranular/ dual porosity (< 2m)	0 – 20 (10)	Lerner 2000 suggests 20% of N reaches groundwater.	10 - 50	Guestimate
Intergranular/ dual porosity (> 2m)	0 – 40 (20)		25 - 75	Guestimate
Clay	90 – 100	Attenuation associated with sorption (e.g. cation exchange). Transformation of ammonium limited due to anaerobic conditions	90 – 100	High attenuation due to sorption
Sewage effluent discharges (N and P losses in drainage blanket considered in Section 6.4)				
Fissured/karst ¹	0	No attenuation	0	No attenuation
Intergranular/dual porosity (< 2m)	0 – 40 (20)	Main losses associated with drainage blanket (See Section 6.5).	0 – 50 (25)	Variable (0 - 100), site specific see Table 13.3
Intergranular/dual porosity (> 2m)	0 – 80 (40)	Available data indicates that N losses can occur in the unsaturated zone (0 to 100%, Table 13.3), possibly due to nitrification of nitrate.	0 – 100 (50)	
Clay (sewage effluent discharges unlikely as drainage rates too low)	90 – 100	Attenuation associated with sorption (e.g. cation exchange). Transformation of ammonium limited due to anaerobic conditions	90 - 100	High attenuation due to sorption
Cemeteries				
Fissured/karst ¹	0	No attenuation	0	No attenuation
Intergranular/dual porosity (< 2m)	0 – 40 (20)	Assumed to be equivalent to attenuation for effluent discharges	0 – 50 (25)	Assumed to be equivalent to attenuation for effluent discharges
Intergranular/dual porosity (> 2m)	0 – 80 (40)		0 – 100 (50)	
Clay	90 - 100	High attenuation due to anaerobic conditions	90 - 100	High attenuation due to sorption
Leaking sewers				
Fissured/karst ¹	0	No attenuation, ammonium transformed to nitrate with no losses	0	No attenuation
Intergranular/dual porosity	0 to 40 (20)	Higher loading and assumed to be equivalent to 50 % of attenuation for effluent discharges	25 - 75	Guestimate

Table 13.5 (continued) Attenuation Factors (Unsaturated Zone)

Activity and Hydrogeological Setting	N Attenuation Factor	Comment	P Attenuation Factor	Comment
Clay ³ (leakage rates likely to be low)	90 - 100	High attenuation due to anaerobic conditions	90 - 100	High attenuation due to sorption
Mains water leakages				
Fissured/karst ¹	0	No attenuation assumes no nitrification of nitrate	0	No attenuation
Intergranular/dual porosity	0	No attenuation (nitrification), water mains leakages imply ground free draining	25 - 75	Guestimate
Clay ³ (leakage rates likely to be low)	90 - 100	High attenuation (nitrification) due to anaerobic conditions, in practice leakages rates likely to be low unless permeable pathways present	90 - 100	High attenuation due to sorption

1. Assumes no low permeability cover and free draining. Where low permeability cover is present then attenuation rates for clay can be used.

2. Guestimate (high uncertainty on attenuation rates)

3. No division based on thickness of clays as base of grave, water main and sewer likely to be below weathered zone and cracks etc likely to be minimal. Attenuation rates would be expected to be lower where the clay is thin (<1 m).

14. Catchment N and P Loading

14.1 Introduction

The information on diffuse and point sources (Sections 4 to 12) has been used to determine the N and P loading for a range of urban and agricultural catchments. The catchments are:

- Industrial urban - Nottingham;
- Non industrial urban - Exeter;
- East Anglia arable;
- South/ central England intensive agriculture;
- Dumfries livestock;
- Angus arable;
- Tipperary livestock;
- Louth intensive agriculture (pig rearing units).

The input parameters, including default values for the N and P loading from different activities, are summarised in Appendix D. The default values are largely based on the information provided in Sections 4 to 12.

14.2 Methodology

14.2.1 Urban Catchments

A spreadsheet model has been developed to assist in the calculation of the N and P loading from urban areas. This spreadsheet model is based on Lerner (2000) (see Section 10) and is described in Appendix B. The equations used in the model are also summarised in this Appendix.

The N and P sources included in the model are:

- Losses from parks, gardens and allotments based on the input from fertiliser applications and atmospheric deposition;
- Leakage of contaminated water from landfill and land affected by contamination;
- Losses due to disturbance of soils (mineralization) as a result of construction;
- Losses from cemeteries;
- Leaking water mains;

- Leaking sewers;
- Surface water run-off to permeable areas (e.g. SuDs);
- Leakage from surface water drains.

These sources are described in Section 10 together with relevant supporting information.

The output from the spreadsheet includes:

- Total (Kg/year) and average (Kg/ha/year) loading for the urban area;
- Loading from each source (Kg/year and Kg/ha/year);
- Loading and percentage contribution from each source to the total urban loading;
- Average N and P concentrations in infiltration to groundwater (mg/l).

The data inputs for the two urban catchments are summarised in Appendix D.

14.2.2 Agricultural Catchments

A spreadsheet model has been developed to assist in the calculation of the N and P loading from agricultural areas. This spreadsheet model is described in Appendix C.

The N and P sources included in the model are:

1. N and P loading from arable and grassland (Section 11). Further discussion is given below;
2. N and P loading from rough grazing and woodland (as a function of atmospheric deposition) (Section 11);
3. N and P loading from landfills (Section 4);
4. N and P loading from cemeteries (Section 5);
5. N and P loading from animal burials (Section 5);
6. N and P loading from sewage effluent discharges to ground from septic tanks and STWs (Section 6);
7. N and P loading from leaking sewers (Section 7);
8. N and P loading from leaking water mains (Section 8);
9. N and P loading from surface water run-off to ground from paved areas such as roads (Section 10);
10. N and P loading from towns and villages. These loadings may be calculated separately using the urban spreadsheet or a loading estimated based on land use within the village with the losses from sewers and water mains calculated separately;
11. N and P loading from point sources such as constructed wetlands and slurry stores (Section 12).

These sources are described in Sections 4 to 12 together with relevant supporting information.

The output from the spreadsheet includes:

- Total (Kg/year) and average (Kg/ha/year) loading for the catchment;
- Loading and percentage contribution from each source to the total catchment loading;
- Average N and P concentrations in infiltration to groundwater (mg/l).

Attenuation of N and P in the unsaturated zone has been included in this assessment, although this has simply involved the use of attenuation factors (Section 13) based on the activity and groundwater vulnerability.

The data inputs for the agricultural catchments are summarised in Appendix D and the results of the assessment are described in Section 14.3.

The main loading will probably be associated with losses from arable and grassland and the approach adopted to calculate these losses is summarised in Sections 14.2.3 and 14.2.4.

14.2.3 Arable Loading - Nitrogen

The loading from arable land has been calculated based on the following equation:

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

The inputs for this calculation are summarised below:

$N_{\text{fertiliser}}$	Inorganic fertiliser application taken from fertiliser statistics for Great Britain, Northern Ireland and Ireland (Section 11.3.1)
$N_{\text{organic waste}}$	Calculated based on number of livestock and composition (see below)
$N_{\text{crop offtake}}$	Calculated based on statistics for crop yield and N content of crop (Section 11.6)
$N_{\text{atmospheric}}$	Atmospheric (wet and dry) deposition based on information on the CEH web site for the UK (Section 9)
N_{vol}	Volatilisation loss (Section 11.7) dependent on soil type
$N_{\text{mineralisation}}$	Nitrogen released by mineralisation (Section 11.4). 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
$N_{\text{denitrification}}$	Denitrification loss (Section 11.8) dependent on soil type

Information on population density, land use (including crop types, area of different crops and livestock numbers in each catchment has been based on the following:

- Agricultural parish return data (county summary);
- Land use maps (Land Cover Map 2000 and Corine);
- Population census data;
- Discussions with the Steering Group.

This information has been reviewed to determine the typical characteristics of a catchment.

The input from livestock numbers has been determined as follows. Annual total N and P excretion was calculated for various livestock types and this, in combination with livestock numbers from census data, used to calculate catchment-total N and P production in manures. This allows a coarse estimate to be made of typical loading rates in manure applied to agricultural land, but it should be stressed that this estimate carries significant uncertainty:

- The actual area of agricultural land receiving manures is not well constrained. Any given field is likely to receive manure no more often than 1 year in every 3 or 4. Some crops are more likely to receive manure than others;
- The estimates of manure production are based on average figures for livestock of various ages;
- Uncertainty in the amount of N lost due to volatilisation during storage and spreading;
- Manures may be imported or exported to or from catchments (although for larger catchments, net imports or exports are likely to be small);
- Not all manure produced will necessarily be spread to agricultural land. In parts of eastern England, for example, a significant fraction of poultry manure goes to incineration.

The amount of residual nitrogen nitrate leached has been calculated using the following equation (after Anthony et al, 1996) (Section 11.9):

$$\varepsilon = h/\phi$$

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

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

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

14.2.4 Managed Grassland - Nitrogen

In principle, a similar approach to that described above for arable land may be taken for managed grassland. For cut grass, crop offtake of N is simply the N content of the grass that is mown and removed. For grazed systems, the model is complicated by recycling of N by grazing animals. In this case the “crop offtake” is the N converted to produce (liveweight gain, milk etc.), but this is harder to constrain.

For grazed and mown grassland, the N-CYCLE model (Rodda et al, 1995) has, therefore, been used to estimate nitrate leaching, and this is further discussed in Appendix C. In summary, the N-CYCLE model predicts the rates of nitrate leaching for various climate zones (rainfall amounts and temperatures), soil types and drainage conditions and fertiliser applications, as shown in Tables 14.1 and 14.2. In each case, the sward was assumed to be more than 20 years old with a history as long term grassland. Atmospheric deposition was assumed at a rate of 25 kg-N/ha/year.

Table 14.1 N-CYCLE Predicted Nitrate Leaching (kg-N/ha/yr) from Grass Grazed by Dairy Cattle

Soil	Drainage	Zone	Fertiliser Input (kg/ha)										
			0	50	100	150	200	250	300	350	400	450	500
Sand	Good	1	3.2	11	22.8	38.6	58.2	81.3	107.5	136.4	166.9	196.8	228.3
		2	1.1	7.1	16.9	30.6	48.1	69.1	93.3	120.4	150	179.6	210
		3	0	3.9	11.9	23.7	39.1	58.1	80.3	105.5	133.4	163.2	192.5
Loam	Moderate	1	3.1	8.6	16.6	27	39.8	54.7	71.5	89.9	108.3	127.1	146.7
		2	1.3	5.5	12.1	21.1	32.4	45.8	61.2	78.4	97	115	133.9
		3	0	3.1	8.4	16	25.9	37.9	52	67.8	85.2	103.4	121.6
Clay	Poor	1	0.1	1.4	3.5	6.4	10.2	14.7	20	25.9	32.4	39	45.7
		2	0	0.9	2.7	5.3	8.7	12.9	17.9	23.5	29.6	36.3	42.8
		3	0	0.5	2	4.3	7.4	11.3	15.9	21.2	27	33.5	40

Table 14.2 N-CYCLE Predicted Nitrate Leaching (kg-N/ha/yr) from Cut Grass

Soil	Drainage	Zone	Fertiliser Input (kg/ha)										
			0	50	100	150	200	250	300	350	400	450	500
Sand	Good	1	5.1	9.4	15	21.8	30	39.5	50.2	62.2	76.7	92.4	109.6
		2	3.7	7.4	12.5	18.8	26.4	35.3	45.5	57	70.4	85.4	101.8
		3	2.5	5.7	10.2	16	23	31.4	41	52	64.2	78.8	94.5
Loam	Moderate	1	3.7	6.6	10.2	14.6	19.8	25.8	32.5	40.1	49.3	59.2	70
		2	2.7	5.1	8.4	12.4	17.2	22.8	29.2	36.4	44.9	54.3	64.6
		3	1.8	3.9	6.7	10.4	14.8	20.1	26.1	32.9	40.5	49.6	59.4
Clay	Poor	1	0.7	1.5	2.6	4	5.7	7.6	9.9	12.4	15.2	18.6	22.2
		2	0.6	1.3	2.3	3.5	5.1	7	9.1	11.6	14.3	17.5	21
		3	0.4	1	1.9	3.1	4.6	6.4	8.4	10.7	13.4	16.5	19.8

14.2.5 Phosphorus - Arable and Grassland

The phosphorus loading to groundwater from arable land and grassland is estimated using an approach based on the PIT (Phosphorus Indicators Tool) model (Heathwaite et al, 2003). Inputs of P in the form of manure and inorganic fertiliser are estimated from catchment livestock numbers and fertiliser survey data. Soil Olsen P is estimated from soil P index (a default index of 2 is assumed). Solubilisation of P from the soil and from applications of organic and inorganic fertiliser, and subsequent delivery to groundwater is estimated using the appropriate PIT coefficients. These are summarised in Table 14.3 below.

Table 14.3 Selected PIT Model Coefficients

Coefficient	Value
Solubilisation of inorganic fertiliser in subsurface matrix flow	0.08
Solubilisation of organic fertiliser in subsurface matrix flow	0.08
Solubilisation of soil P in subsurface matrix flow	0.01
Delivery of P to surface waters via groundwater (baseflow)	0.05

14.2.6 Alternative Approaches

Alternative approaches which were considered as part of this project were:

1. Use of export coefficients related to land use (arable, grass, etc), soil type and catchment characteristics. This approach has been developed for surface water and published export coefficients are available. However this approach cannot easily be modified to consider the losses to groundwater and no published export coefficients could be identified. Therefore these would need to be developed for this project and is considered to be beyond the budget for this project. For this reason this approach was not adopted.
2. Use literature values for N and P losses from the soil zone for different crop, soil and climate types. A review of the available literature (Section 11) indicates that there is insufficient data in the public domain to support this approach.

15. Summary of Catchment Predictions

15.1 Introduction

This section summarises the key predictions from the example urban and rural spreadsheets. Full details of all the input data (rural and urban) and output from the rural spreadsheets are given in Appendix D and Appendix E, respectively.

15.2 Catchment Input Data

15.2.1 Urban Catchments

Full details of input values for two example urban catchments (Nottingham and Exeter) are given in Table D3 (Appendix D).

Table 15.1 summarises the key characteristics of the catchments.

Table 15.1 Summary of Key Catchment Characteristics (Urban)

Catchment	Key Characteristics
Nottingham	Urban catchment with population density of about 4000 persons/km ² . Urban area includes about 65% of grassed areas (parks, gardens etc) with the remaining area largely comprising industrial/commercial areas, building and roads.
Exeter	Urban catchment with lower population density of about 2500 persons/km ² such that sewer flows and mains water usage will be lower compared to Nottingham. Area characterised by higher percentage area (~75%) of grassed areas (parks, gardens etc).

15.2.2 Rural Catchments

Spreadsheets have been prepared for six example rural catchments. The input data for these spreadsheets have been derived from national datasets such as agricultural census returns, and as such are intended to be illustrations of regional differences in agriculture, land use and climate rather than representative of real catchments. In all cases, agricultural and population census data at county or parish ward level were pro-rated to a hypothetical catchment area of 2500 ha, of which 2100 ha was assumed agricultural and 400 ha urban. Some data, such as unsewered population and urban land use, were not available and estimated figures have been included. Table D1 (Appendix D) indicates which figures are estimates and gives full details of all input values. It is likely that national agencies will have access to higher resolution data than were available to this project, and revised data values should be used if available. Table 15.2 summarises the key characteristics of each of the six illustrative catchments.

Table 15.2 Summary of Key Catchment Characteristics

Catchment	Key Characteristics
East Anglia (arable)	Dominated by arable land (the majority under cereals) with relatively little managed grass or rough grazing land. Large numbers of poultry and significant numbers of pigs but few other livestock. Low rainfall and permeable soils (high catchment Base Flow Index (BFI)).
South / central England (intensive)	Arable land dominated by cereal crops, but also significant areas of managed grassland. Cattle, pigs and sheep all present in significant numbers; poultry numbers less significant. Rainfall low to moderate. Soils moderately permeable. High human population density.
Dumfries (livestock)	Dominated by managed grass and rough grazing land with virtually no arable cropping. High numbers of cattle and sheep. High rainfall and less permeable soils (low catchment BFI). Low human population density.
Angus (arable)	Arable land dominated by cereal crops, but also significant areas of managed grassland, particularly rotational (temporary) grass. Livestock are mainly cattle but also significant numbers of poultry and some sheep. Low to moderate rainfall and moderately permeable soils.
Tipperary (livestock)	Grassland catchment with little arable cropping. Large numbers of cattle but few other livestock. Moderate rainfall and less permeable soils (low catchment BFI).
Louth (intensive)	Land use predominantly arable with little grassland, but agriculture dominated by pigs and poultry. Low rainfall and free draining soils.

15.3 Results

The results of the catchment calculations are included in Appendix E, together with a copy of the excel workbook.

15.3.1 Urban Catchments

A summary of the results for the two urban catchments is given in Section 10.4, Tables 10.4 and 10.5. These calculations confirm that the main sources of N and P are parks and gardens, leaking sewers and water mains. The high percentage loading from parks and gardens is a function of the area of parks and gardens, but concentrations of N in soil drainage are relatively low for this land use. For mains water leakages, the concentration of N will be below the drinking water standard such that the main risk to water quality will be associated with leaking sewers. For P, the concentrations of P in mains water can exceed the water quality standards for surface water (as a result of dosing of tap water, although this practice is being phased out), such that sewer leakage is likely to be the main risk in the longer term.

Higher concentrations of N are predicted for the Nottingham area which is a function of the higher concentration of N in mains waters in this area and higher sewer effluent losses. Nottingham is characterised by a higher population density such sewer losses are expected to be higher.

15.3.2 Agricultural Catchments

A full summary of the results for six example rural catchments is shown in Appendix E.

In general, nitrate inputs to groundwater in rural catchments are predicted to be dominated by drainage from agricultural land, particularly in more arable catchments. Of the non-agricultural sources, urban diffuse inputs and sewage effluent are predicted to be generally the most significant.

Predicted phosphorus inputs to groundwater are generally dominated by sewage effluent, although inputs from agricultural land are also significant. Tables 15.3 and 15.4 summarise the main outputs from the catchment spreadsheets for nitrate and phosphorus, respectively.

Table 15.3 Summary of Catchment Predictions (Nitrate)

Catchment	Predicted N Loading (kg-N/ha/yr)	Predicted Major Sources of Nitrate
East Anglia (arable)	24.0	Arable land (67%) and grassland (16%).
South / central England (intensive)	18.3	Arable land (39%), grassland (27%), sewage effluent discharges (16%).
Dumfries (livestock)	10.1	Managed grassland (53%), agricultural point sources (10%), landfills (12%), rough grazing land (10%).
Angus (arable)	13.4	Arable land (46%), managed grassland (34%).
Tipperary (livestock)	11.0	Managed grassland (75%), agricultural point sources (5%), urban areas (5%), agricultural point sources (15%).
Louth (intensive)	16.3	Arable land (63%), managed grassland (15%), sewage effluent discharges (6%).

Table 15.4 Summary of Catchment Predictions (Phosphorus)

Catchment	Predicted P Loading (kg-P/ha/yr)	Predicted Major Sources of Phosphorus
East Anglia (arable)	0.51	Sewage effluent discharges (70%), arable land (21%).
South / central England (intensive)	0.62	Sewage effluent discharges (72%), arable land (10%), sewer leakage (9%).
Dumfries (livestock)	0.07	Sewage effluent discharges (44%), managed grassland (24%), landfills (7%).
Angus (arable)	0.14	Arable land (38%), sewage effluent discharges (35%).
Tipperary (livestock)	0.10	Sewage effluent discharges (45%), managed grassland (31%).
Louth (intensive)	0.28	Sewage effluent discharges (53%), arable land (30%),

15.3.3 Comparison of Results with NEAP-N

Output from the NEAP-N model was provided by the Environment Agency (England and Wales) at no cost. This output consists of predictions of nitrate loadings in soil drainage (note, not loadings to groundwater) from agricultural land in England and Wales. The spreadsheet model predictions of nitrate in soil drainage for the Anglian, Southern England and Louth catchments could therefore be compared with NEAP-N.

For the Anglian and Louth catchments, agreement with NEAP-N is good. There is inhomogeneity in the NEAP-N output, but values of nitrate loading are typically in the range 30-40 kg-N/ha in Anglia (compared with a spreadsheet prediction of 37 kg-N/ha) and 30-45 kg-N/ha in Louth (compared with a spreadsheet prediction of 37 kg-N/ha). In southern England, agreement is less good, with NEAP-N predictions of 30-45 kg-N/ha in Hampshire somewhat higher than the spreadsheet prediction of 24 kg-N/ha.

The Southern England catchment is predominantly arable (as opposed to grassland) and it is possible that nitrate leaching from arable crops is underestimated by the spreadsheet method, particularly given the uncertainty in estimates of crop offtake and residual N. This is an area in which further work is desirable.

16. References

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Appendix A Fertiliser Use

6 Pages

Table A1 Average Fertiliser Usage in Great Britain (Defra, 2007)

	Tillage Crops Kg N ha/yr		Grass Kg N ha/yr		Tillage Crops Kg P ha/yr		Grass Kg P ha/year	
	England and Wales	Scotland	England and Wales	Scotland	England and Wales	Scotland	England and Wales	Scotland
1969	84	-	65	-	23		15	
1970	88	-	74	-	24		14	
1971	90	-	74	-	23		15	
1972	91	-	83	-	24		15	
1973	89	-	85	-	23		15	
1974	85	-	91	-	22		12	
1975	86	-	99	-	20		12	
1976	96	-	98	-	22		13	
1977	100	-	110	-	22		11	
1978	105	-	113	-	21		12	
1979	113	-	117	-	21		12	
1980	121	-	119	-	21		12	
1981	135	-	125	-	22		11	
1982	141	-	123	-	24		10	
1983	154	113	125	131	23	27	11	16
1984	162	121	132	127	27	30	11	14
1985	161	131	131	130	24	30	10	13
1986	156	119	135	120	24	27	10	12
1987	160	139	133	116	24	31	10	12
1988	149	125	116	132	23	28	9	13
1989	150	128	127	111	23	29	10	13
1990	149	131	132	116	22	30	10	12
1991	154	128	133	111	23	28	10	10
1992	147	125	104	111	22	29	8	13
1993	137	130	112	114	21	28	8	12
1994	149	128	117	112	22	30	10	12
1995	151	140	119	114	22	30	10	13
1996	148	122	118	100	22	28	10	11
1997	151	134	123	124	23	30	10	14
1998	146	131	107	119	21	29	9	12

Table A1 (continued) Average Fertiliser Usage in Great Britain

	Tillage Crops Kg N ha/yr		Grass Kg N ha/yr		Tillage Crops Kg P ha/yr		Grass Kg P ha/year	
	England and Wales	Scotland	England and Wales	Scotland	England and Wales	Scotland	England and Wales	Scotland
1999	143	126	108	117	19	28	8	12
2000	154	135	95	110	19	26	8	13
2001	144	147	90	113	17	26	7	13
2002	153	143	85	105	18	27	8	11
2003	152	135	79	102	16	27	7	11
2004	154	134	73	93	17	27	7	12
2005	152	134	72	84	16	25	7	10
2006	150	121	69	86	14	23	6	10
2007	152	120	64	72	14	23	5	9
2008	144	111	52	66	12	22	4	7

Table A2 Average Application Rate Fertiliser Use for Different Crop Types (Defra, 2007)

	England and Wales	Scotland	England and Wales	Scotland
	Kg N ha/yr	Kg N ha/yr	Kg P ha/yr	Kg P ha/yr
Spring wheat	82		13	
Winter wheat	182	178	32	41
Spring barley	104	93	28	27
Winter barley	136	146	32	34
Oats	108	81	34	27
Rye/triticale/Durum wheat	142		35	
Potatoes (seed or earliest)	146		85	
Potatoes (maincrop)	159	148	112	98
Sugar beet	92		49	
Spring oilseed rape	115		33	
Winter oilseed rape	195	172	31	34

Table A2 (continued) Average Application Rate Fertiliser Use for Different Crop Types (2008)

	England and Wales	Scotland	England and Wales	Scotland
	Kg N ha/yr	Kg N ha/yr	Kg P ha/yr	Kg P ha/yr
Linseed	60		23	
Forage maize	60		36	
Rootcrops for stockfeed	70		27	
Leafy forage crops	56		14	
Arable silage/other fodder crops	96		19	
Vining peas (for human consumption)	24		31	
Field peas (harvested dry)	37		35	
Field beans (harvested dry)	15		28	
Vegetables (brassicae)	112		48	
Vegetable Other	98		43	
Soft Fruit	32		22	
Top Fruit	71		46	
Other tillage	87		71	
All tillage	160	118	34	33
Grass less than five years old	123	120	20	21
Grass five years and over	88	81	12	12

Table A3 Rates of Fertiliser Use for Different Crop Types in Ireland (1995 to 2003) (Coulter et al, 2003)

	Fertiliser Use kg N ha/yr			Fertiliser Use kg P ha/yr		
	Root Crops	Cereals	Grass	Root Crops	Cereals	Grass
1995	161	137	123	76	26	16
1999	154	127	145	62	25	13
2000	146	160	136	70	25	13
2001	151	147	133	74	24	11
2002	142	157	126	57	25	11
2003	139	152	123	58	25	11

Table A4 Typical Dry Matter and Nutrient Content of Different Organic Manure Types (taken from BSFP, 2008 and MANNER NPK Defra 2004c)

	Dry Matter (%)	Total N (kg/t; kg/m ³)	Total P ₂ O ₅ (kg/t; kg/m ³)
Cattle FYM	25	6	3.5
Pig FYM	25	7	7
Sheep FYM	25	6	2
Duck manure	25	6.5	5.5
Layer hen manure	30	16	13
Broiler/turkey litter	60	30	25
Cattle slurry	6	2.7	1.2
Pig slurry	4	4	2
Digested liquid	4	2	1.5
Digested cake	25	7.5	9
Thermally dried	95	35	45
Lime stabilised	40	6	8
Composted green manure	65	7	2.8
Paper Crumble			0.1
Waste Food - General			0.7
Waste Food - Dairy			0.8
Waste Food - Soft Drinks			0.2
Waste Food - Brewing			0.8

BSFP British Survey of Fertiliser Practice

Table A5 Amount of Available N and P in Slurries and Manures from DAFF (2008)

	Total nitrogen (Kg N/tonne)	Availability of N (%)	Total P (Kg P/tonne)	Availability of P (%)
Slurry				
Cattle	5	30 - 35	0.8	100
Pig	4.2	35 - 40	0.8	100
Sheep	10.2	30 - 35	1.5	100
Poultry (layer)	13.7	30 - 35	2.9	100
Manure				
Farmyard manure	4.5	20 - 25	1.2	100
Poultry manure (broilers)	11	35 - 40	6	100
Poultry manure (layers) 55% dry matter	23	35 - 40	5.5	100

From Defra 2000

	Dry Matter	Total N (Kg N/tonne)	Availability of N to Crops¹	Total P (Kg P/tonne)	Availability of P to Crops¹
Farm yard manure					
Cattle farmyard manure		6	5 - 25	1.5	60
Pig farmyard manure		7	5 - 25	3.0	60
Sheep farmyard manure		6	5 - 25	0.9	60
Poultry layer	30%	16	10 - 50	5.7	60
Poultry broiler	60%	30	10 - 45	10.9	60
Slurry					
Dairy					
	2	1.5	5- 60	0.3	50
	6	3	5- 60	0.5	50
	10	4	5- 60	0.9	50
Beef					
	2	1	5- 60	0.3	50
	6	2.3	5- 60	0.5	50
	10	3.5	5- 60	0.9	50
Pig					
	2	3	5- 70	0.4	50
	6	4	5- 70	0.9	50
	10	5	5- 70	1.3	50
Dirty water		0.3	0- 80	<0.5	50

¹ Dependent on age of manure, soil type, time of application and method of application.

Table A6 Estimated Average Rates of Total Nitrogen from Organic Manure Applications to Winter Sown and Spring Sown Crops and Grassland by Manure Type, Great Britain 2008 (from BSFP, 2008)

	Cattle FYM	Cattle Slurry	Pig FYM	Pig Slurry	Layer Manure	Broiler/Turkey Litter	Other FYM	Other Farm Manure	Bio-solids	Other Non-farm
Winter sown										
Treated area %	7.4	1	1.1	0.4	1	2.4	0.6	-	1.9	1.2
Avg manure rate (t;m3/ha)	25	30	19	20	12	8	20	-	28	39
Fields in Sample	312	39	41	19	31	50	23	4	62	26
Spring sown										
Treated area %	23.1	2.2	1.8	0.9	0.8	2	-	-	1.3	0.6
Avg manure rate (t;m3/ha)	23	19	33	21	5	8	-	-	21	41
Fields in Sample	277	35	28	12	11	21	4	1	11	11
Grass										
Treated area %	23.2	24.3	0.5	0.7	0.4	0.6	2.1	0.5	0.6	0.3
Avg manure rate (t;m3/ha)	15	26	12	12	4	5	8	32	13	8
Fields in Sample	598	538	19	17	9	22	47	12	19	6

FYM Farmyard manure.

Appendix B

Urban Catchment Loading Excel Workbook

10 Pages

Introduction

These notes accompany the urban catchment spreadsheet models which carry out calculations of nitrogen (N) and phosphorus (P) loadings to groundwater. The spreadsheets require input data on catchment activities (e.g. the urban area, land use, mains water losses etc) and estimate N and P losses to groundwater from each source or sector. The spreadsheet model is based on Lerner (2000).

Calculations are carried out on an annual basis, and include the following sources:

- Losses from parks, gardens and allotments based on the input from fertiliser applications and atmospheric deposition;
- Leakage of contaminated water from landfill (non hazardous and inert) and land affected by contamination;
- Losses due to disturbance of soils (mineralization) as a result of construction;
- Losses from cemeteries;
- Leaking water mains;
- Leaking sewers;
- Surface water run-off to permeable areas (e.g. SuDs);
- Leakage from surface water drains.

The output from the spreadsheet includes:

- Total (Kg/year) and average (Kg/ha/year) loading for the urban area (base of soil zone and at water table);
- Loading from each source (Kg/year and Kg/ha/year);
- Loading and percentage contribution from each source to the total urban loading;
- Average concentration in infiltration to groundwater (mg/l).

For each source, an equivalent leaching rate is calculated expressed in terms of kg N/ha/year or kg P/ha/yr. The total loadings in an urban catchment are estimated based on the catchment land use (e.g. parkland, gardens), pollution sources within the catchment (e.g. leaking sewers) and other geographical data such as population and rainfall.

The worksheet requires the user to input data on the catchment (e.g. area of gardens, population etc), but also provides default values for some parameters (e.g. fertiliser application rate to gardens, water use per person). These default values can be overtyped by the user.

A copy of the master spreadsheet should be made and this copy should be used for the catchment analysis.

The remainder of this section describes the worksheet, the worksheet calculations, data inputs and spreadsheet results.

Worksheets

Each spreadsheet comprises worksheets as follows:

Readme	Brief description of the worksheet.
Data entry	Data entry (yellow cells). The master worksheet includes some default parameter values (light blue cells) which can be overtyped by the user. The user must enter details for catchment specific data (yellow cells).
Calculations_N	Calculation worksheet for N loading.
Calculations_P	Calculation worksheet for P loading.
Summary and pie chart_N	Summary of loading calculations for N.
Summary and pie chart_P	Summary of loading calculations for P.

Within each sheet the following colouring coding is used to help the user.

Yellow	Data entry.
Green	Data carried forward.
Blue	Default value, can be overwritten.
Pink	Drop down menu of options available to user.
Orange	No direct loss (assumes any loss associated with drainage to ground, leaking water mains or leaking sewers).
Purple	Calculated.

Some cells are marked as notes and the user can add extra information on the source of the data.

The worksheet has the following options which can be selected using a drop down menu (pink cells):

Loading from leaking sewers:

- Calculate loading based on average sewer leakage rate (as mm/m²/year over the urban area) ;
- Calculate loading based on population density;

Option selection will be dependent on the type of data available for the urban area, in most cases Option 2 is the most likely where leakage is estimated based on population density, water usage per person and estimated sewer leakage rates. The calculation also assumes that any STW discharges to ground are located outside of the urban area.

Loading from leaking water mains:

- Calculate loading based on population, water use and mains water leakage rate;
- Calculate loading based estimated leakage rate (Ml/d);

Option selection will be dependent on the type of data available for the urban area.

Loading from septic tanks:

- Calculate loading based on effluent concentration (mg/l) and water usage per person;
- Calculate loading based effluent loading (Kg /person).

Option selection will be dependent on the type of data available for the urban area. For most urban areas the number of individuals using septic tanks is likely to be small.

As previously noted, when creating a spreadsheet for a new catchment it is not necessary to change the default model parameters (light blue cells) and these values may be accepted “as is”. More advanced users may wish to change these model parameters. Input parameters (yellow cells must be input by the user. Green and purple cells contain formulae and should not be changed.

Worksheet Calculations

A summary of the calculations for each source is given in Table B1. These calculations are carried out in the “calculation” worksheet. The spreadsheet calculations for N and P are identical except for the loading for gardens, parks, allotments and recreational grassland. For nitrogen the calculation is based on fertiliser applications rates, but for phosphorus the calculation is based on the Soil P Index.

Data Input

If the user is happy to accept default model parameters then the only action required in setting up a new catchment spreadsheet is the population of catchment specific data. Table B2 provides a summary of the information that needs to be entered into the spreadsheet.

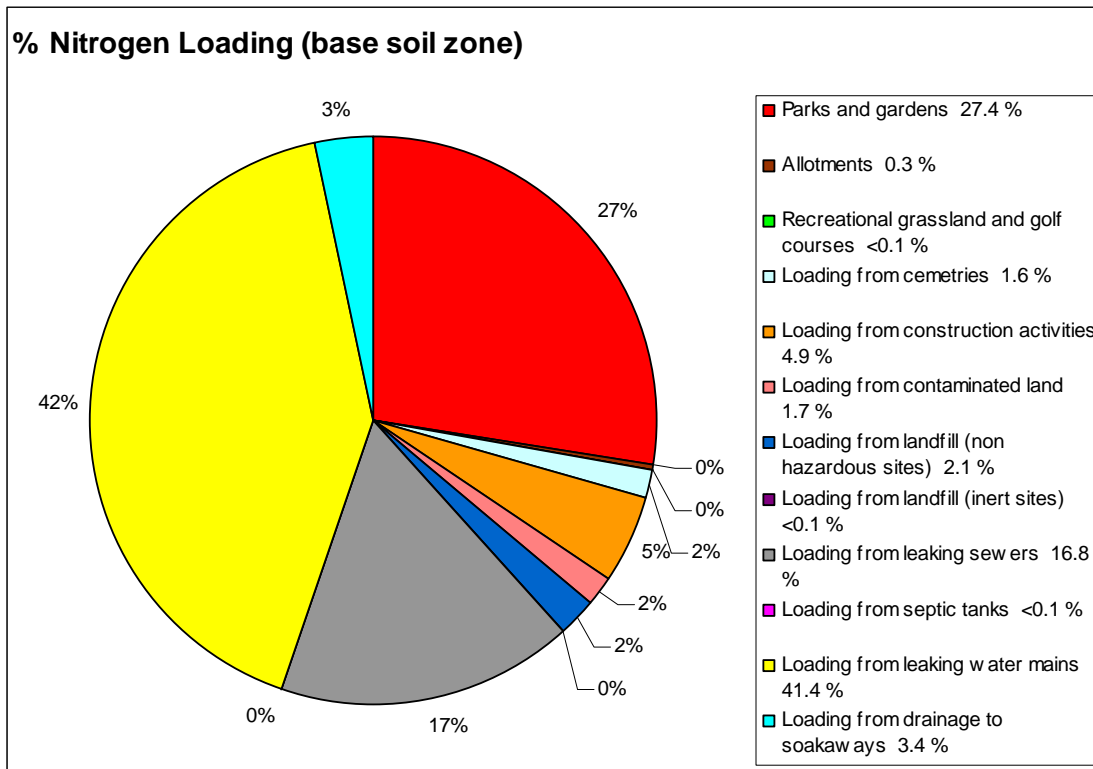
Results and Outputs

An example of the output from a worksheet is given below:

Nitrogen Loading	Loading (Base Soil Zone) %	Average loading over Urban Area (Base Soil Zone) Kg N/ha	Concentration at Water Table mg N/l
Loading from application of fertilisers			
Parks and gardens	26.22	3.97	2.86
Allotments	0.37	0.06	13.10
Recreational grassland and golf courses	0.00	0.00	0.00
Loading from cemeteries	1.97	0.30	19.08
Loading from construction activities	4.72	0.72	28.57
Loading from land affected by contamination	1.65	0.25	80.00
Loading from landfill (non hazardous sites)	2.07	0.31	100.00
Loading from landfill (inert sites)	0.00	0.00	0.00
Loading from leaking sewers	18.40	2.79	30.00
Loading from septic tanks	0.00	0.00	not calc
Loading from leaking water mains	41.34	6.27	7.50

Nitrogen Loading	Loading (Base Soil Zone) %	Average loading over Urban Area (Base Soil Zone) Kg N/ha	Concentration at Water Table mg N/l
Total	100.00		
Total loading (base soil zone)	101666	Kg N/yr	
Total loading (to groundwater)	99986	Kg N/yr	
Catchment area	67.1	ha	
Total average recharge	251	mm/year	
Average loading (base soil zone)	15.2	Kg N/ha/year	
Average concentration (drainage)	6.0	Kg N/ha/year	
Average concentration (at water table)	5.9	mg N/l	

This is summarised in a pie chart as illustrated by the following plate.



The output from the phosphorus calculation is similar.

Table B1 Summary of Worksheet Calculations (Urban)**Application of Fertilisers (parkland, gardens, allotments) (Nitrogen)**

$$\text{Loading (L}_p) = A_p \times (0.01 \times (\text{PF} \times (\text{F} + \text{N}_A) \times \text{L}_N) + 0.01 \times (100 - \text{PF}) \times \text{N}_A \times 0.01 \times (100 - \text{L}_N))$$

A_p Area of parkland, gardens or allotments (ha)

PF Percentage area receiving fertiliser (%)

F Fertiliser application (Kg N/ha/yr)

L_N % Nitrogen lost due to attenuation (%)

N_A Atmospheric N deposition (Kg N/ha/yr)

Loss of Phosphorus from Parkland, Gardens, Allotments

$$\text{Loading} = A_p \times I \times (\text{SO}/70)^{0.31} \times 0.01 \times (100 - \text{L}_p)$$

A_p Area of parkland, gardens or allotments (ha)

I Infiltration (mm/year)

SO Soil Olsen Index (mg/kg)

L_p % Phosphorus lost due to attenuation (%)

Construction Activities

$$\text{Loading} = A_c \times \text{CA} \times 0.01 \times (100 - \text{L}_c)$$

A_c Area of construction (ha)

CA N or P lost due to construction activity (Kg N or P/ha/yr)

L_c % N or P lost due to attenuation (%)

Cemeteries

$$\text{Loading} = (\text{B} \times \text{BL} + A_g \times \text{N}_{gr}) \times 0.01 \times (100 - \text{L}_g)$$

A_g Area of cemetery (ha) (used to calculate average loading per hectare)

N_{gr} N loss from grassed areas (assume parkland)

B Number of burials (person/yr) (conventional and green burials calculated separately)

BL N or P loss per person (kg N/person)

L_g % N or P lost due to attenuation (%)

Land affected by contamination

$$\text{Loading} = A_{cl} \times I_{cl} \times \text{CL} \times 0.01 \times (100 - \text{L}_{cl})$$

A_{cl} Area of land affected by contamination (ha)

I_{cl} Infiltration (m/yr)

CL N or P concentration in drainage (mg/l)

L_{cl} % N or P lost due to attenuation (%)

Table B1 (continued) Summary of Worksheet Calculations (Urban)**Landfill**

$$\text{Loading} = A_L \times I_L \times LF \times 0.01 \times (100 - L_L)$$

A_L Area of landfill (ha)

I_L Leakage through base of landfill (m/yr)

LF N or P concentration in leachate (mg/l)

L_L % N or P lost due to attenuation (%)

Calculation undertaken for both hazardous and inert sites

Leaking Sewers

$$\text{Loading} = A_u \times I_s \times SE \times 0.01 \times (100 - L_s) \text{ (Option 1)}$$

Or

$$\text{Loading} = 0.01 P \times W \times LR \times (100 - L_s) \text{ (Option 2)}$$

A_u Urban area (ha)

I_s Average infiltration from sewers over urban area (m/yr)

SE N or P concentration in sewage effluent (mg/l)

L_s % N or P lost due to attenuation (%)

P Population served by sewers

W Water use per person (m³/year)

LR Leakage rate from sewer (%)

Septic Tanks

$$\text{Loading} = P_{st} \times W \times SE \times 0.01 \times (100 - L_{st}) \text{ (Option 1)}$$

Or

$$\text{Loading} = P_{st} \times SEL \times 0.01 \times (100 - L_{st}) \text{ (Option 2)}$$

P_{st} Population served by septic tanks

W Water use per person (m³/year)

SE N or P concentration in sewage effluent (mg/l)

L_{st} % N or P lost due to attenuation (%)

SEL N or P loading from sewage effluent (Kg/person/year)

Table B1 (continued) Summary of Worksheet Calculations (Urban)

Water Mains

Loading = $A_u \times I_m \times MW \times 0.01 \times (100 - L_m)$ (Option 1)

Or

Loading = $0.01 P \times W \times LMW \times MW \times 0.01 \times (100 - L_m)$ (Option 2)

A_u	Urban area (ha)
I_m	Average infiltration from mains water over urban area (m/yr)
MW	N or P concentration in mains water (mg/l)
L_m	% N or P lost due to attenuation (%)
P	Population served by sewers
W	Water use per person (m ³ /year)
LMW	Leakage rate from mains water (%)

Surface Water Drainage

Loading = $0.01 \times A_s \times R \times PI \times C_r \times 0.01 \times (100 - L_{sw})$

A_s	Area of draining to drainage areas (ha)
R	Rainfall (m/yr)
PI	Percentage of rainfall infiltrating to ground (%)
C_r	N or P concentration in runoff (mg/l)
L_{sw}	% N or P lost due to attenuation (%)

Table B2 Summary of Data Input (Urban)

Data Input	Units	Data Input Required or Default Parameter	Comment
Total urban area	ha	Yes	
Area residential (houses, gardens)	ha	Yes	Not used in calculation of loss as calculated elsewhere in worksheet
Area commercial/	ha	Yes	
Area roads	ha	Yes	
Area parks	ha	Yes	
Area gardens	ha	Yes	
Area allotments	ha	Yes	
Area recreational grassland and golf courses	ha	Yes	
Area of land affected by contamination	ha	Yes	
Area landfill (non hazardous)	ha	Yes	
Area landfill (inert)	ha	Yes	
Area of construction activities	ha	Yes	
Area cemeteries	ha	Yes	
Area draining to SuDs and other drainage areas	ha	Yes	
Total population		Yes	
Number of burials per year		Yes	
Number of green burials per year		Yes	
Population served by septic tanks		Yes	
Water use (population served by septic tanks)	l/person/d	Default	
Average sewer leakage rate below urban area	mm/year/m ²	Default	Only used for option 1
Sewer flow	l/person/d	Default	Only used for option 2
Sewer leakage	%	Default	
Water use	l/person/d	Default	Only used for option 1
Leakage rate	%	Default	
Water mains leakage	MI/d	Yes	Only used for option 2

Table B2 (continued) Summary of Data Input (Urban)

Data Input	Units	Data Input Required or Default Parameter	Comment
Input for N and P loading calculation			
Nitrogen			
Parks, Gardens, Allotments, Recreational grassland and golf courses			
Percentage area fertilised	%	Default	
Fertiliser application	Kg N/ha	Default	
Atmospheric deposition	Kg N/ha	Default	
Percent nitrogen leached from soil	%	Default	
Percentage nitrogen lost due to attenuation	%	Default	
Construction activities			
N loss	Kg N/ha	Default	
Percentage nitrogen lost due to attenuation	%	Default	
Sewer Losses			
N concentration in sewage	mg/l	Default	
Percentage nitrogen lost due to attenuation	%	Default	
Mains Water			
N concentration in mains water	mg/l		
Percentage nitrogen lost due to attenuation	%	Default	
Leachate			
N concentration in leachate	mg/l	Default	Inert and non hazardous
Percentage nitrogen lost due to attenuation	%	Default	
Surface water run-off			
N concentration in surface water run-off	mg/l	Default	
Percentage nitrogen lost due to attenuation	%	Default	
Land affected by contamination			
N loss from land affected by contamination	mg/l	Default	
Percentage nitrogen lost due to attenuation	%	Default	
Cemeteries			
N loss	Kg N/ha/person	Default	
Percentage nitrogen lost due to attenuation	%	Default	
Septic tanks			
N loss	Kg N/ha/person	Default	
or N concentration in effluent	mg/l	Default	
Percentage nitrogen lost due to attenuation	%	Default	

Table B2 (continued) Summary of Data Input

Data Input	Units	Data Input Required or Default Parameter	Comment
Phosphorus (See main text for suggested default values)			
Parks, Gardens, Allotments, Recreational grassland and golf courses			
Soil Olsen P Index	mg/kg	Default	
Coefficient A		Default	
Coefficient B		Default	
Construction activities			
P loss	Kg P/ha	Default	No data
Percent reaching groundwater	%	Default	
Sewer Losses			
P concentration in sewage	mg/l	Default	
Percent reaching groundwater	%	Default	
Mains Water			
P concentration in mains water	mg/l	Default	
Percent reaching groundwater	%	Default	
Leachate			
P concentration in leachate	mg/l	Default	
Percent reaching groundwater	%	Default	
Surface water run-off			
P concentration in surface water run-off	mg/l	Default	
Percent reaching groundwater	%	Default	
Land affected by contamination			
P loss from land affected by contamination	mg/l	Default	
Percent reaching groundwater	%	Default	
Cemeteries			
P loss	Kg P/ha/person	Default	
Percent reaching groundwater	%	Default	
Septic tanks			
P loss	Kg P/ha/person	Default	
or P concentration in effluent	mg/l	Default	
Percent reaching groundwater	%	Default	

Appendix C

Rural Catchment Loading Excel Workbook

10 Pages

Introduction

These notes accompany the rural catchment spreadsheet model which carries out calculations of nitrogen (N) and phosphorus (P) loadings to groundwater. The spreadsheets require input data on catchment activities (e.g. the urban area, number of livestock in the catchment etc) and estimated N and P losses to groundwater from each source or sector. Calculations are carried out on an annual basis, and include the following sources (this list is not exhaustive):

- Diffuse losses from agricultural land;
- Diffuse losses from urban areas;
- Leakage from sewers and water mains;
- Agricultural point sources;
- Other point sources (sewage treatment works etc.);
- Landfill sites (inert and non hazardous);
- Graveyards;
- Animal burials;
- Urban areas;
- Surface water run-off to ground.

For each source, an equivalent leaching rate is calculated expressed in terms of kg N/ha/year or kg P/ha/yr. These calculations are carried out in “model calculation” worksheets, and the more advanced user may wish to access these calculations and change model parameters should new or improved data become available. The total loadings to groundwater in a catchment are estimated based on the calculated leaching rates and catchment land use and cover (i.e. the area of land under each of several uses) and other geographical data such as population, rainfall, numbers of landfill sites and so on. At a less advanced level, it is possible to create a model for a new catchment by entering these catchment data and accepting the default model calculations, with no further data entry required.

The remainder of this section describes the entry of catchment data required when setting up a new catchment spreadsheet, the model parameters accessible to the more advanced user, and the outputs of the calculations.

Worksheets

Each spreadsheet comprises the following worksheets:

Readme	Brief Description of the Worksheet
NCYCLE Zones	Image to inform selection of appropriate N-CYCLE model output
Catchment Data Entry	Main catchment data entry sheet
Catchment Hydrology	Estimation of HER and recharge and data entry
Non-ag N Calculations	Model calculations nitrate from non-agricultural sources
Non-ag P Calculations	Model calculations phosphorus from non-agricultural sources

Agric N Calculations	Model calculations nitrate from diffuse agricultural sources
Agric P Calculations	Model calculations phosphorus from diffuse agricultural sources
Catchment N Calculation	Model output - nitrate from all sources
Catchment P Calculation	Model output - phosphorus from all sources
Nsoil chart	Nitrogen loss from the soil zone
Psoil chart	Phosphorus loss from the soil zone
Agri-N Chart	Diffuse agricultural nitrate source apportionment chart
All N Chart	Nitrate source apportionment chart - all sources (input to groundwater)
Agri-P Chart	Diffuse agricultural phosphorus source apportionment chart
All P Chart	Phosphorus source apportionment chart - all sources (input to groundwater)
NCycle output	Summary of output from NCycle model

Within each sheet the following colouring coding is used to help the user.

Yellow	Data entry
Green	Data carried forward
Blue	Calculated
Orange	Suggested default values

Some cells are marked as notes and the user can add extra information on the source of the data. Many of the column headings in the worksheets have comments attached giving further information on the calculations, or data required.

As previously noted, when creating a spreadsheet for a new catchment it is not necessary to change the default model parameters and these values may be accepted “as is”. More advanced users may wish to change these model parameters. Input parameters (yellow cells) must be input by the user. Green cells contain formulae and should not be changed.

Further details on the worksheets are given below

Catchment Data Input

If the user is happy to accept default model parameters then the only action required in setting up a new catchment spreadsheet is the population of catchment data. These data are entered in the “Catchment Data Entry” and “Catchment Hydrology” sheets.

Catchment Data Entry

The majority of catchment-specific data are entered in the “Catchment Data Entry” worksheet. Table C1 shows the data required and brief descriptions and suggested sources of each parameter. Many of the data sources are listed in the “Reference” worksheet.

NB: In the Master spreadsheet, calculations of N and P inputs from sewage have been separated by discharge type (i.e. discharges from sewage treatment works, septic tanks and package treatment plants). These changes, denoted by adjacent purple shading in the various data entry

and calculation sheets, have not been copied through to the example rural spreadsheets accompanying this report.

Table C1 Summary of Catchment Data Requirements (Rural)

Data Item	Possible Source
Catchment Geography	
Catchment area (ha)	
Annual average rainfall (mm)	National meteorological services web sites.
Annual average PE (mm)	For UK, map in Reference worksheet.
Catchment Base Flow Index (BFI)	
Dominant soil texture	
Atmospheric deposition of N	Map in reference worksheet for England, Scotland and Wales.
Atmospheric deposition of P	Default is a literature value, suggest not changed.
Population	
Sewered population	National Environment Agency or Water Company data.
Unsewered population	Can be estimated as the difference between the sewered population and the total population.
Land Use/Cover	
<i>Urban land use</i>	
Area gardens	
Area allotments	
Area of paved surfaces draining to ground	
Area of buildings and paved surfaces (no drainage to ground)	
Area of sports grounds etc	
Area of roads and paved surfaces (extra urban)	
<i>Rural land use</i>	
Area of grassland (cut, grazed and temporary), cereal crops, other arable, fallow, rough grazing, orchards, woodland	Agricultural land use data are available via agricultural census records. Data sources are shown in the Reference worksheet.
The user can also add extra crop types i.e. oertype user defined crop	Areas of woodland may be obtained from national land use datasets, for example, LCM2000 or CORINE (for England, Scotland and Wales).
Ploughed out long term grass	The area of ploughed out grass will be a rough estimate, perhaps guided by historic land use maps such as those available at http://www.visionofbritain.org.uk/maps .
Livestock numbers: Cattle, sheep, pigs, poultry	Livestock numbers are available via agricultural census records. Data sources are shown in the Reference worksheet.

Table C1 (continued) Summary of Catchment Data Requirements (Rural)

Data Item	Possible Source
Landfills and Graveyards	
Area of graveyards	
Area of landfill (inert)	
Area of landfill (non hazardous)	
Agricultural Point Sources	
Area of engineered slurry stores	These areas will need to be estimated based on local knowledge.
Area of unlined slurry stores	
Area generating farm yard run-off	
Area of constructed wetlands	

Catchment Hydrology

This sheet allows the user to specify a catchment average Hydrologically Effective Rainfall (HER) and recharge to groundwater which will be carried through to a number of model calculations elsewhere in the workbook.

Default values are calculated based on the rainfall and potential evapotranspiration data entered in the Catchment Data Entry worksheet. The user should enter a value for the catchment HER in the yellow cell, which may simply repeat the default value or may differ if better data are available.

The worksheet also requires the user to provide estimated infiltration rates for:

- Infiltration from base of engineered stores;
- Infiltration from base of unlined stores;
- Infiltration over 'paved' areas;
- Infiltration from base of wetland;
- Infiltration to graves;
- Leakage from landfill (non hazardous site);
- Leakage from landfill (inert site);
- Average infiltration urban areas.

The rates may be based on the HER, although in the case of engineered landfill sites or slurry stores the infiltration from the base of the facility is likely to be significantly less than the HER.

Reference Worksheets

The “Reference” and “NCYCLE Zones” worksheets contain reference information and links to data sources designed to assist the user in estimating input data values. Additional data are also included in the supporting calculations in the Agric N and P Calculations worksheets, which are

also designed to assist the user in selecting appropriate input data values. Table C2 lists the various data and links in these sheets.

Table C2 Data in Reference Worksheets (Rural)

Worksheet	Information Provided
Reference	<p>Map of atmospheric deposition of nitrogen for England, Scotland, Wales and Northern Ireland.</p> <p>Map of long term average PE for England, Scotland and Wales.</p> <p>Links to data sources for:</p> <ul style="list-style-type: none"> • Fertiliser application rates to agricultural crops; • Crop yields; • Atmospheric N deposition rates; • Agricultural census data.
NCYCLE Zones	<p>Screenshot from the N-CYCLE model showing the model climate zones and assumed rates of atmospheric N deposition. Note that the values given here for atmospheric deposition differ from those shown in the reference sheet; the latter should be used in preference.</p> <p>These maps cover England, Scotland and Wales only.</p>
Agric N Calculations	<p>Supporting information is given below the main calculation tables. This includes:</p> <ul style="list-style-type: none"> • For estimating nitrate leaching from grassland, tables of output from the N-CYCLE model. Select appropriate values using the lookup in rows 20-23, or directly from the tables, based on fertiliser input, soil type and climate zone; • Estimates of catchment manure production based on the livestock numbers entered in the Catchment Data Entry sheet and standard figures for nitrate production per head of livestock; • Standard values for nitrate uptake by various crops; • Table of field capacity of standard soil types (for use in the leaching calculation).
Agric P Calculations	<p>Supporting information is given below the main calculation tables. This includes:</p> <ul style="list-style-type: none"> • Estimates of catchment manure production based on the livestock numbers entered in the Catchment Data Entry sheet and standard figures for phosphorus production per head of livestock; • Summary data from surveys of fertiliser practice for estimating inorganic fertiliser application rates; • Tables of soil Olsen-P as a function of Defra soil P index or Teagasc soil P index, or Morgan-P; • Reference PIT model coefficients, used to estimate P transfer rates.

Calculation Worksheets

Model calculations are carried out in four worksheets, for agricultural and non-agricultural sources and for nitrogen and phosphorus. As previously noted, when creating a spreadsheet for a new catchment it is not essential to change the model parameters in these worksheets and the default values may be accepted “as is”. More advanced users may wish to change some of the

model parameters in these sheets. Throughout the worksheets, values in yellow cells are model parameters which may be changed. Green and blue cells contain formulae and should not be changed. The format of the non-agricultural source worksheets for N and P is identical, the only differences being in the values of the model parameters.

The remainder of this section describes the “tunable” model parameters in each worksheet and their meanings.

Non-Ag N Calculations

The worksheet is arranged vertically, with parameter and output descriptions in column A, values in column B and units in column C. Suggested default values for model parameters are shown in column D; it is recommended that the values in column D are not changed, so that they provide a reference to the original parameter values in the event that the numbers in column B are changed. Further information on input parameters can be found in the main Entec report.

Values in yellow cells in column B are model parameters which may be changed by the user if required. The default values provided are Entec’s best estimates based on available data, but new data or local knowledge may suggest different values, which may be overtyped in the appropriate cells in this worksheet.

Non-Ag P Calculations

The layout of this worksheet is identical to the Non-Ag N worksheet, and the calculations it carries out correspond to those in that worksheet, but obviously using model parameters appropriate for phosphorus rather than nitrate.

Agric N Calculations

Needs some text summarising what this sheet does i.e. losses from grassland, arable + calculates organic fertiliser available from livestock.

Grassland Systems

Estimates of inputs to groundwater from grassland systems are based on estimates of nitrate in soil drainage from the N-CYCLE model, and the catchment BFI, which is used to estimate the fraction of soil drainage which reaches the water table.

Default values for nitrate in soil drainage are provided, based on N-CYCLE predictions for loam soil/moderate drainage, climate zone 2 and fertiliser inputs of 50 kg-N/ha (grazed grass) or 100 kg-N/ha (cut grass). The user may select appropriate values from the N-CYCLE tables in the worksheet, based on the catchment soil type and drainage status, the climate zone (see the map in worksheet “N-CYCLE Zones”) and fertiliser inputs. A lookup is provided in rows 20-23 to assist in the selection of appropriate N-CYCLE values: enter data values in the yellow cells in column C, rows 21-23, and the relevant modelled value is displayed in cell C24. The selected values should be entered in the yellow cells in column D.

In this context, fertiliser inputs should include both applications of inorganic fertiliser and managed manure. Cycling of dung and urine from grazing animals is included in the N-CYCLE model and does not need to be included in fertiliser inputs.

Default values for catchment HER are based on the values calculated in the Catchment Hydrology worksheet (described above); these may be over-written in the yellow cells in

column G, or if column G is left blank the default values will be used. Finally, the user should enter a factor for the attenuation of nitrate in the unsaturated zone in the yellow cells in column I. This represents the removal of nitrate during transit through the unsaturated zone, so a value of 0% indicates no attenuation, while a value of 100% indicates that no nitrate reaches the water table.

Further down in the worksheet, supporting calculations are included to assist in the estimation of rates of application of managed manure, based on catchment livestock numbers and N excretion and the area of receiving land.

The results of the leaching calculations are carried forward to the Catchment N Calculation sheet where they are used to estimate total N loadings to groundwater.

Arable Systems

Arable calculations are based on a soil-N balance approach. For each crop type the user should enter:

Application rates of inorganic fertiliser	Inorganic fertiliser applications may be estimated from fertiliser surveys or recommendations.
Organic fertiliser	Organic fertiliser rates are estimated through calculation of N production by livestock in the catchment and the area of tillage and grassland available to receive manure (see supporting calculation Managed Manure Production and Spreading). This provides the default rate which may be overwritten if required.
N through fixation	Legumes and clover (in grass swards) may fix nitrogen. Clover can fix between 180 and 250kg-N/ha per year. Fixation by other crops is likely to be negligible and a value of zero is appropriate.
Mineralization	Net mineralization in most crops is likely to be zero in the long term average. The exception is ploughed out long term grass; more details are given in the main report.
Losses from volatilisation	This represents the loss of nitrogen through volatilisation of ammonia from organic manures. See the main report for more details.
Crop offtake	Crop uptake figures are based on the NIRAMS model, and are shown in a table in the worksheet. Note that for orchards, bare fallow, soft fruit and vegetables, the NIRAMS model gives a residual N figure; this corresponds to the values calculated in column Q of the worksheet.
Denitrification	The loss of soil nitrate through denitrification. This is a function of soil type, with very low rates likely on free-draining soils, and up to 35% on clay soils.
HER	Reference catchment hydrology.
Attenuation factor for transit through the unsaturated zone	Expressed as % reduction in N loading.
Soil field capacity factor (cell D131).	A default value for field capacity is provided based on the soil texture entered in the catchment data entry sheet; this may be over-written if required with a figure from the table provided (scroll down in the worksheet).

For all of these factors, default values are provided and the worksheet will automatically use these data.

In using this worksheet the following points are noted:

1. The worksheet calculates an average organic fertiliser loading to arable crops and grassland based on the numbers of livestock and automatically populates column E of the sheet. However, the user can enter organic fertiliser rates in column F and the worksheet will automatically use these rates. The default rate assumes standard rates

of N production by various livestock types, taking into account typical lengths of housing period, and that all excretion by housed animals becomes managed manure which is spread at a uniform rate to arable and grassland. Hence no allowance is made for net import or export of manure to or from the catchment.

2. The leaching calculation is sensitive to the soil field capacity and HER. The spreadsheet calculates the fraction of residual nitrate which is leached using the methodology of the NEAP-N model (see section 14 of the main report), which requires values of HER (entered in the Catchment Data Entry sheet) and soil field capacity (FC). A default FC is estimated based on the soil texture entered in the Catchment Data Entry sheet, but may be overwritten if required. Guidance on suitable values is given in the table at the bottom of the worksheet. The fraction of soil drainage which is recharge to groundwater is based on the catchment BFI, entered in the Catchment Hydrology sheet and reproduced at the bottom of the Agric-N sheet.

As for grassland calculations, attenuation factors are required representing loss of nitrate in the unsaturated zone; these are entered in column Z and the default values may be overwritten if required.

Agric P Calculations

P losses from agricultural land are estimated using the “Source - Mobilisation - Delivery” framework (after Haygarth et al, 2005). In this context, “Source” equates to inputs of P from organic and inorganic fertilisers and the soil P content. The soil Olsen P content is used as a metric for this last. Inputs of inorganic fertiliser are based on fertiliser surveys, and several examples for different countries are provided in the worksheet. Values may be changed by overtyping in the yellow cells in column D. Inputs of organic manures are estimated in the same way as for N; the production of P in manures is estimated based on standard figures for P excretion by livestock (which may be changed if required) and livestock numbers provided in the catchment data entry sheet. This provides a default rate (shown in column E) which may be over-ridden if required by entering data in column F. Soil Olsen P data are entered in column G; guidance tables showing Olsen P values corresponding to Defra and Teagasc soil P indices are provided further down in the worksheet.

Mobilisation and delivery of these sources of P is assumed to occur at the rates estimated by the PIT (Phosphorus Indicators Tool) model (Heathwaite et al, 2003). The coefficients are shown in columns J, K, L and V, and could be overwritten if the user has improved local data. Finally, the user may overwrite the previously entered HER for the catchment in column S. This may be appropriate if crop-specific HER data are available.

In common with most models of diffuse phosphorus transfer from agricultural land, PIT is a surface water model. It does include, however, an estimate of the contribution to P in surface waters from baseflow, and this is used here as a proxy for the delivery of P to groundwater. The relevant model parameter reflects the proportion of mobilised P (from all sources) which reaches surface waters in baseflow, and is assigned a value of 0.05 (i.e. 5% of the phosphorus in infiltrating soil drainage is assumed to reach streams in baseflow).

For each crop type the user is required to enter the following data.

Inorganic fertiliser inputs	Inorganic fertiliser applications may be estimated from fertiliser surveys or recommendations. Example figures for several countries are given in tables below the main calculation. Note that all calculations (and hence input data) refer to elemental P, not P ₂ O ₅ .
Organic fertiliser inputs	Organic fertiliser rates are estimated through calculation of P production by livestock in the catchment and the area of tillage and grassland available to receive manure (see supporting calculation Organic P Production Calculation). This provides the default rate which may be overwritten if required. Note that, unlike the corresponding N calculation, production rates are calculated for the whole year, not just the housed period. This is because of the different modelling approach employed for P, which assumes that P in dung is at risk of transfer for a period after excretion, rather than the soil-balance approach used for N.
Soil Olsen-P (mg/kg)	Soil Olsen P may be estimated from national soil P indices. Guidance on suitable values is given in supporting tables lower in the worksheet (Soil P status).
Inorganic fertiliser mobilisation coefficient	This is a PIT model coefficient representing the fraction of P applied in inorganic fertiliser which is mobilised. While the default values may be changed if necessary, this is not recommended.
Organic fertiliser mobilisation coefficient	The PIT model coefficient representing the fraction of P applied in organic fertiliser which is mobilised. While the default values may be changed if necessary, this is not recommended.
Soil P mobilisation coefficient	The PIT model coefficient representing the fraction of soil P which is mobilised. While the default values may be changed if necessary, this is not recommended.
Crop-specific HER	The default catchment HER (as entered in the Catchment Hydrology worksheet) is shown in column R. If crop-specific values are available these may be entered in column S. If column S is left blank, the default values will be used.
Groundwater delivery coefficient	The PIT model coefficient representing the delivery of mobilised phosphorus to surface waters in baseflow. See the note above. While the default values may be changed if necessary, this is not recommended.

Default values are provided for all of these parameters and the spreadsheet will use these defaults unless the user over-rides them. As with the N calculations, the calculation of P in organic manures assumes no net import or export of manure to or from the catchment.

Results and Outputs

Catchment Calculation Worksheets

Two “catchment calculation” worksheets are included in the workbook; one for N and one for P. Broadly, these worksheets use the loss rates (in terms of kg-N/ha/yr or kg-P/ha/yr) from each source or sector calculated in the “Agric” and “Non-ag” worksheets, to estimate actual inputs to groundwater of N and P. The area-specific loss rates are combined with the areas of each land use to calculate loadings (in terms of kg-N/yr or kg-P/yr).

For some of the non agricultural sources (e.g. mains water leakage), the loading is averaged over the entire catchment area.

The calculated area-specific loss rates may be overwritten by the user in column G of each sheet if required. If column G is left blank then the rates calculated by the model are used. There is no other user-input to these sheets.

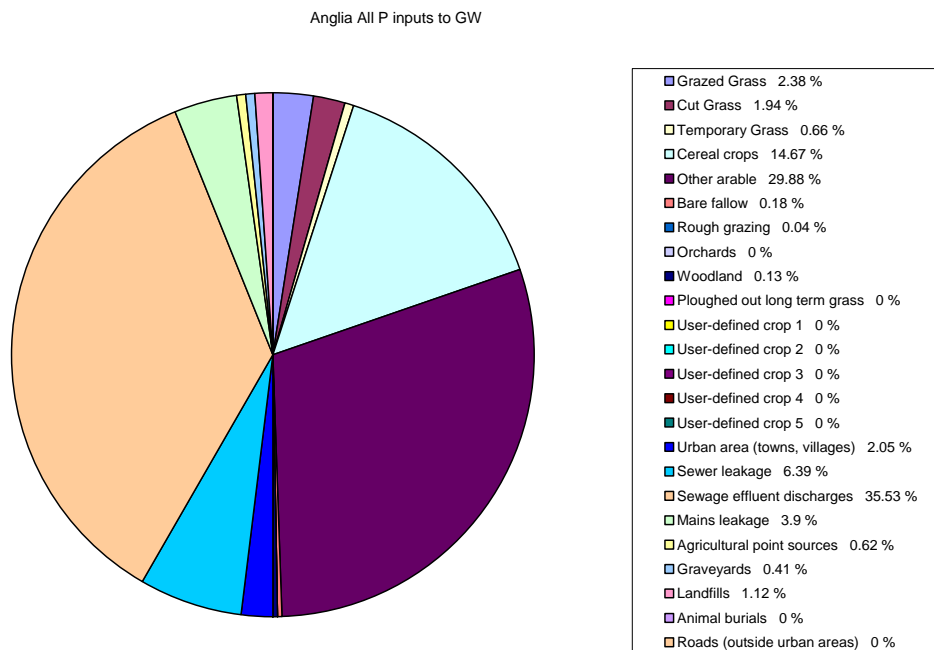
Each worksheet displays the following calculations:

1. The N or P loading leaving the soil zone (Kg/ha/year);
2. The concentration of N or P in soil drainage (mg/l);
3. The proportion of soil drainage which reaches the water table (i.e. recharge to groundwater);
4. Attenuation of N or P in the unsaturated zone;
5. The concentration of N or P in recharge to groundwater (mg/l);
6. The loading of N or P to groundwater (Kg/ha/year).

Charts

The workbook contains four pie charts which illustrate the relative contributions of N and P loadings to groundwater from (a) each activity within the agricultural sector, and (b) each sector (agriculture, mains leakage, sewage discharges etc.). Hover the mouse over the chart to see the estimated loading to groundwater from each sector, as kg of N or P and also as a percentage of the total. Plate C1 shows an example P source apportionment chart.

Plate C1 Example P Source Apportionment



Appendix D

Example Catchment Input Data

12 Pages

Example catchment workbooks are provided for two urban catchments and six rural catchments. As far as possible, these workbooks are populated with input data appropriate to the region being modelled, but there are some input parameters for which national datasets are not available. Table D1 shows a summary of the catchment input data for the six rural catchments. Table D2 shows default parameter values for the urban catchment calculations and Table D3 a summary of input data for the urban catchments. Parameters which contain significant uncertainty are commented as such, and these values should be checked and updated with local datasets, if possible.

Table D1 Summary Rural Catchment Input Data

		East Anglia Arable	South/ Central England Intensive Agriculture	Dumfries Livestock	Angus Arable	Tipperary Livestock	Louth Intensive Agriculture	Comments
Catchment Geography								
Catchment area	ha	2500	2500	2500	2500	2500	2500	All data are based on census data and other available sources, and pro-rated to a hypothetical total catchment area of 2500 ha.
Annual average rainfall	mm	600	700	1350	720	820	570	Rough estimate based on 1961-1990 LTA rainfall. Very rough estimate for Irish catchment.
Annual average PE	mm	400	500	400	500	600	500	Rough estimate based on 1961-1990 LTA PE. Very rough estimate for Irish catchment.
Catchment BFI		0.8	0.7	0.4	0.6	0.4	0.6	Guess - needs better local knowledge.
Dominant soil texture (pull down menu)		Sand	Loam	Clay	Loam	Clay	Sand	Guess - needs better local knowledge.
Atmospheric deposition of N	kg/ha/yr	20	20	20	20	20	20	
Atmospheric deposition of P	kg/ha/yr	0.2	0.2	0.2	0.2	0.2	0.2	SNIFFER 85.
Population								
Sewered population	hd	3133	7000	500	800	700	2333	Total population is based on published population density statistics pro-rated to 2500 ha.
Unsewered population	hd	783	1750	125	200	175	583	The split between sewered and unsewered population is a guess, based on an unsewered fraction of 20%.
Total population	hd	3917	8750	625	1000	875	2917	

Table D1 (continued) Summary Rural Catchment Input Data

		East Anglia Arable	South/ Central England Intensive Agriculture	Dumfries Livestock	Angus Arable	Tipperary Livestock	Louth Intensive Agriculture	Comments
Land Use/Cover								
Urban Land Use								
Area gardens	ha	200	200	200	200	200	200	These figures are guesses and should be checked or revised if possible.
Area allotments	ha	25	25	25	25	25	25	
Area of paved surfaces draining to ground	ha	100	100	100	100	100	100	
Area of buildings and paved surfaces (no drainage to ground)	ha	50	50	50	50	50	50	
Area of sports grounds etc	ha	25	25	25	25	25	25	
Total urban area	ha	400	400	400	400	400	400	
Area of roads and paved surfaces (outside urban)	ha	8	8	8	8	8	8	

Table D1 (continued) Summary Rural Catchment Input Data

		East Anglia Arable	South/ Central England Intensive Agriculture	Dumfries Livestock	Angus Arable	Tipperary Livestock	Louth Intensive Agriculture	Comments
Rural Land Use								
Grazed Grass	ha	181	233	421	200	684	142	All rural land use and livestock values are pro-rated to a total agricultural area of 2100 ha.
Cut Grass	ha	148	217	400	190	600	127	These should be revised if the total non-ag area is changed from the current value of 400 ha.
Temporary Grass	ha	47	167	241	317	600	61	
Cereal crops	ha	925	844	76	780	153	1034	Tipperary rural land use and livestock data are based on one reporting area (23089 Carrick on Suir Rural) pro-rated to 2100 ha.
Other arable	ha	628	330	37	384	44	626	For other catchments, data are pro-rated to 2100 ha based on county level census data.
Bare fallow	ha	37	78	21	25	0	61	
Rough grazing	ha	34	38	777	120	14	10	
Orchards	ha	1	4	0	0	0	1	
Woodland	ha	98	188	127	84	5	37	
Ploughed out long term grass	ha	0	0	0	0	0	0	
User-defined crop 1	ha	0	0	0	0	0	0	
User-defined crop 2	ha	0	0	0	0	0	0	
User-defined crop 3	ha	0	0	0	0	0	0	

Table D1 (continued) Summary Rural Catchment Input Data

		East Anglia Arable	South/ Central England Intensive Agriculture	Dumfries Livestock	Angus Arable	Tipperary Livestock	Louth Intensive Agriculture	Comments
Rural Land Use (continued)								
User-defined crop 4	ha	0	0	0	0	0	0	
User-defined crop 5	ha	0	0	0	0	0	0	
Total agricultural area	ha	2100	2100	2100	2100	2100	2100	
Total modelled area	ha	2500	2500	2500	2500	2500	2500	
Livestock Numbers								
Cattle	hd	312	458	1932	1224	2916	491	
Sheep	hd	519	1229	4781	2069	670	523	
Pigs	hd	1485	565	75	96	0	936	
Poultry	hd	57076	25506	3659	44655	0	57116	
Landfills and Graveyards								
Area of graveyards	ha	5	5	5	5	5	5	These figures are guesses and should be checked or revised if possible.
Area of landfill (inert)	ha	2	2	2	2	2	2	
Area of landfill (non hazardous)	ha	2	2	2	2	2	2	

Table D1 (continued) Summary Rural Catchment Input Data

		East Anglia Arable	South/ Central England Intensive Agriculture	Dumfries Livestock	Angus Arable	Tipperary Livestock	Louth Intensive Agriculture	Comments
Agricultural Point Sources								
Area of engineered slurry stores	ha	1	1	1	1	1	1	These figures are guesses and should be checked or revised if possible.
Area of unlined slurry stores	ha	0.5	0.5	0.5	0.5	0.5	0.5	
Area generating farmyard run-off	ha	1	1	1	1	1	1	
Area of constructed wetlands	ha	0.5	0.5	0.5	0.5	0.5	0.5	

Table D2 Default Parameter Values for Point Sources and Non-agricultural Loading

Water use	148	l/person/day	Section 6.2 report
	230	l/person/day	Section 6.2 (higher rate for calculation of mains water and sewer losses to reflect other water uses)
Sewer leakage rate	2	%	Section 7 Main report, Lerner 2000
Nitrogen concentration in effluent	45	mg N/l	Table 7.1, Bishop et al 1998
P concentration in effluent	9	mg P/l	Table 7.1, Main report
Nitrogen concentration in discharge to ground (Septic tank)	50	mg N/l	Table 6.7, Main report
P concentration in discharge to ground	15	mg P/l	Table 6.7, Main report
Mains water leakage rate	22	%	OFWAT 2007
Nitrogen concentration in mains water	7.5	mg N/l	Assumed to be 75% of DWS
P concentration in mains water	1	mg P/l	Assumes mains water dosed
N concentration in leachate from lined slurry stores	4000	mg N/l	Table 12.1, main report, and 10% volatilisation loss
P concentration in leachate from lined slurry stores	80	mg P/l	Table 12.1, main report and 90% attenuation at base of store
N concentration in leachate from unlined slurry stores	4000	mg N/l	Table 12.1, main report, and 10% volatilisation loss
P concentration in leachate from unlined slurry stores	80	mg P/l	Table 12.1, main report and 90% attenuation at base of store
N concentration in run-off from farm yards	17	mg N/l	Estimate based on Gouriveau 2007
P concentration in run-off from farm yards	0.6	mg P/l	Estimate based on Gouriveau 2007
N concentration in effluent from constructed wetlands	9	mg N/l	Assumes 50% removal of N in wetland
P concentration in effluent from constructed wetlands	0.3	mg P/l	Assumes 50% removal of P in wetland
Number of burials per year	-	burials per year	Use mortality rate of 9 per 1000
Release of N from corpse	1.35	kg N/person/year	Environment Agency 2004
Release of P from corpse	0.5	kg P/person/year	Environment Agency 2004
Grave density	1976	graves/ha	Environment Agency 2004a, b
N Leachate concentration - Non hazardous landfill	707	mg N/l	Table 4.7, Main report
P Leachate concentration - Non hazardous landfill	0.8	mg P/l	Table 4.7, Main report
N Leachate concentration - Inert landfill	27	mg N/l	Table 4.7, Main report (industrial commercial)
P Leachate concentration - Inert landfill	4		Table 4.7, Main report (industrial commercial)

Table D2 (continued) Default Parameter Values for Point Sources and Non-agricultural Loading

N Loading from gardens	5	kg N/ha/year	Table 10.2, Main report
N Loading from allotments	25	kg N/ha/year	Table 10.2, Main report
N Loading from paved surfaces	10	kg N/ha/year	Table 10.2, Main report
N Loading from sports fields	10	kg N/ha/year	No available data, estimated based on Soil P Index of 25 mg/kg
P Loading from gardens	0.1	Kg P/ha/year	No available data, estimated based on Soil P Index of 25 mg/kg
P Loading from allotments	0.1	Kg P/ha/year	No available data, estimated based on Soil P Index of 25 mg/kg
P Loading from paved surfaces	0.1	Kg P/ha/year	No available data, estimated based on Soil P Index of 25 mg/kg
P Loading from sports fields	0.1	Kg P/ha/year	Table 10.2, main report
N concentration in run-off	3.5	mg N/l	Table 10.2, main report
P concentration in run-off	0.34	mg P/l	Table 10.3, main report
Number of cattle	0	per year	
Number of sheep	0	per year	
Number of pigs	0	per year	
Number of poultry	0	per year	
Cattle weight	373	kg	From Table 5.4, main report
Sheep weight	31.8	kg	From Table 5.4, main report
Pig weight	27.6	kg	From Table 5.4, main report
Poultry weight	3	kg	From Table 5.4, main report
N released from slaughtered stock	4.5	Kg N/tonne	Table 5.3, Main report
N released from slaughtered stock	1.7	Kg P/tonne	Table 5.3, Main report

Table D3 Summary of Data Input for Urban Areas

	Unit	Exeter	Nottingham	Comment
Catchment Areas				
Total catchment area considered	ha	44.7	67.05	
Residential areas (houses gardens)	ha	2.66	6.39	Vision of Britain Website
Commercial/industrial areas	ha	1.83	4.51	Vision of Britain Website
Roads and other paved areas	ha	4.22	10.10	Greenspace
Area parks		25.30	25.85	Vision of Britain Website
Area gardens	ha	8.35	18.57	Average allotment size
Area allotments	ha	0.33	0.14	From OS map
Area recreational grassland and golf courses	ha	1.00	0.00	CORINE
Area of land affected by contamination		0.00	0.10	EAgency
Area landfill	ha	0.03	0.10	EAgency
Area of construction activities	ha	0.80	0.80	CORINE
Area cemeteries	ha	0.20	0.50	OS map
Area draining to SuDs and other drainage areas	ha	1.21	2.92	Estimate
Catchment Details				
Population	No	111076	266988	2001 census
Number of burials per year	No	350	900	Estimate
Population served by septic tanks	No	0	0	
Water use (population served by septic tanks)	l/s	150	150	

Table D3 (continued) Summary of Data Input for Urban Areas

	Unit	Exeter	Nottingham		
Catchment Details (continued)					
Sewer flow	l/s/person	230	330	National stats (water wise UK - average water use per person per day). Higher figure for Nottingham taken from Lerner 2000.	
Sewer leakage	%	2	2	Lerner 2000 estimates figure of 1.75%	
Water mains leakage (option 1)	ML/d	5.6		Based on 17% leakage rate	
Water mains leakage (option 2)	mm/year		28	Lerner 2000	
Rainfall	mm/year	500	500		
HER	mm/year	235	210		
Data for N and P Loading					
N concentration in mains water	mg/l	4	7.5	Concentration for Nottingham based on Lerner 2000	
P concentration in mains water	mg/l	1	1	Assumes dosing of mains water	
Default Values (see Tables 10.2 and 10.3 of Main report for details)					
Nitrogen					
Land Use or Activity	Percentage Area Fertilised	Fertiliser Application	% Nitrogen Leached	Nitrogen Loading Unfertilised Area	% Nitrogen lost due to attenuation
	%	Kg/N/ha/yr	%	Kg/N/ha/yr	%
Parks	25	200	10	10	0
Gardens	25	200	10	10	0
Allotments	50	200	25	10	0
Recreational grassland and golf courses	50	200	10	10	0

Table D3 (continued) Summary of Data Input for Urban Areas

Land Use or Activity	Exeter		Nottingham		% N lost due to attenuation
	N Concentration	Nitrogen Leached	Nitrogen Leached		
	mg N/l	Kg/N/ha/yr	Kg/N/ha/yr		
N loss construction activities		60	60	Wakida and Lerner 2002	0
Landfill leachate (non hazardous)		707	100	Robinson 1995, lower figure for Nottingham based on Lerner 2000 and assumes old waste	80
Landfill leachate (inert)	100	30	30	Westlake 1981	80
N concentration in sewage	30			Bishop, 1998	0
N concentration in surface water run-off	3.5			Assumes dosing of mains water	0
N loss from land affected by contamination	80			Table 10.3, main report	0
		Kg/N/person/year		Assumed	
N loss from cemeteries		1.35			0
N loss from septic tanks	37	3.5		Table 3.5, main report	40
Phosphorus					
Land Use or Activity	Olsen P Index	Coefficient a	Coefficient b		% P lost due to attenuation
	mg/Kg				%
Parks	25	70	0.31	Based on SNIFFER 2006	0
Gardens	25	70	0.31	Based on SNIFFER 2006	0
Allotments	25	70	0.31	Based on SNIFFER 2006	0
Recreational grassland and golf courses	25	70	0.31	Based on SNIFFER 2006	100

Table D3 (continued) Summary of Data Input for Urban Areas

Land Use or Activity	Nottingham		Exeter		% P lost due to attenuation
	P Concentration	Phosphorus Leached	Phosphorus Leached		
	mg P/l	Kg P/ha/yr	%	%	
P loss construction activities		0	0	No data	0
Landfill leachate (non hazardous)	0.8			Robinson 1995	80
Landfill leachate (inert)	4			Westlake 1981	80
P concentration in sewage	9			Bishop, 1998	0
P concentration in surface water run-off	0.34			Assumes dosing of mains water	0
P loss from land affected by contamination	0.5			Table 10.3, main report	0
		Kg P/person/year		Assumed	
P loss from cemeteries		0.5	0.5		0
P loss from septic tanks	15	0.8	0.8	Table 3.5, main report	90

Appendix E

Example Catchment Model Output

8 Pages

Tables E1 and E2 show a summary of output from six rural catchment workbooks.

Table E1 Predicted N Loadings to Groundwater for Six Rural Catchments

N Loading to GW (kg-N/yr)	East Anglia Arable	South/Central England Intensive Agriculture	Dumfries Livestock	Angus Arable	Tipperary Livestock	Louth Intensive Agriculture
Grazed Grass	4471.4	3523.0	579.3	1536.0	941.2	2085.7
Cut Grass	2064.9	1774.2	396.8	948.5	595.2	1146.0
Temporary Grass	1243.7	2661.9	1761.0	4331.0	4384.1	1210.7
Cereal crops	21696.3	11924.4	492.2	9445.8	990.9	18189.7
Other arable	18507.0	5857.8	301.1	5842.6	358.0	13836.0
Bare fallow	445.1	565.1	69.7	155.3	0.0	550.3
Rough grazing	204.5	137.7	1290.3	372.6	23.2	45.1
Orchards	31.6	54.5	0.0	0.0	0.0	20.5
Woodland	1178.8	1362.1	421.8	521.7	16.6	333.8
Ploughed out long term grass	0.0	0.0	0.0	0.0	0.0	0.0
User-defined crop 1	0.0	0.0	0.0	0.0	0.0	0.0
User-defined crop 2	0.0	0.0	0.0	0.0	0.0	0.0
User-defined crop 3	0.0	0.0	0.0	0.0	0.0	0.0
User-defined crop 4	0.0	0.0	0.0	0.0	0.0	0.0
User-defined crop 5	0.0	0.0	0.0	0.0	0.0	0.0
Urban area (towns, villages)	1610.0	1610.0	1150.0	1610.0	1463.6	2300.0

Table E1 (continued) Predicted N Loadings to Groundwater for Six Rural Catchments

N Loading to GW (kg-N/yr)	East Anglia Arable	South/Central England Intensive Agriculture	Dumfries Livestock	Angus Arable	Tipperary Livestock	Louth Intensive Agriculture
Rural (non-agricultural and point agricultural sources):						
Sewer leakage	121.9	272.3	19.4	31.1	27.2	90.7
Sewage effluent discharges	1353.5	3025.1	216.1	345.7	302.5	1007.8
Mains leakage	279.2	623.9	44.6	71.3	62.4	207.9
Agricultural point sources	1464.1	1464.1	2363.0	1464.1	1464.1	1464.1
Graveyards	133.6	133.6	133.6	133.6	133.6	133.6
Landfills	1075.2	1075.2	1920.0	1075.2	1075.2	1075.2
Animal burials	0.0	0.0	0.0	0.0	0.0	0.0
Roads (outside urban areas)	0.2	0.3	0.5	0.3	0.3	0.2

Table E2 Predicted P Loadings to Groundwater for Six Rural Catchments

P Loading to GW (kg-P/yr)	East Anglia Arable	South/Central England Intensive Agriculture	Dumfries Livestock	Angus Arable	Tipperary Livestock	Louth Intensive Agriculture
Grazed Grass	14.19	15.98	16.50	11.76	26.81	8.35
Cut Grass	11.60	14.89	15.68	11.17	23.52	7.47
Temporary Grass	3.99	12.39	10.22	20.16	25.44	3.88
Cereal crops	87.32	69.71	3.59	55.22	7.22	73.21
Other arable	177.85	81.77	5.24	81.56	6.23	132.96
Bare fallow	1.12	2.07	0.32	0.57	0.00	1.39
Rough grazing	0.27	0.27	3.11	0.72	0.06	0.06
Orchards	0.01	0.03	0.00	0.00	0.00	0.01
Woodland	0.78	1.32	0.51	0.50	0.02	0.22
Ploughed out long term grass	0.00	0.00	0.00	0.00	0.00	0.00
User-defined crop 1	0.00	0.00	0.00	0.00	0.00	0.00
User-defined crop 2	0.00	0.00	0.00	0.00	0.00	0.00
User-defined crop 3	0.00	0.00	0.00	0.00	0.00	0.00
User-defined crop 4	0.00	0.00	0.00	0.00	0.00	0.00
User-defined crop 5	0.00	0.00	0.00	0.00	0.00	0.00
Urban area (towns, villages)	12.25	12.25	8.75	12.25	11.14	17.50

Table E2 (continued) Predicted P Loadings to Groundwater for Six Rural Catchments

P Loading to GW (kg-P/yr)	East Anglia Arable	South/Central England Intensive Agriculture	Dumfries Livestock	Angus Arable	Tipperary Livestock	Louth Intensive Agriculture
Rural (non-agricultural and point agricultural sources):						
Sewer leakage	38.08	85.08	6.08	9.72	8.51	28.36
Sewage effluent discharges	211.49	472.68	33.76	54.02	47.27	157.47
Mains leakage	23.27	51.99	3.71	5.94	5.20	17.33
Agricultural point sources	3.71	3.71	5.99	3.71	3.71	3.71
Graveyards	13.00	13.00	13.00	13.00	13.00	13.00
Landfills	6.72	6.72	12.00	6.72	6.72	6.72
Animal burials	0.00	0.00	0.00	0.00	0.00	0.00
Roads (outside urban areas)	0.01	0.02	0.03	0.02	0.02	0.01

Table E3 Predicted Nitrate Loading to Groundwater, Nottingham Urban Catchment

Nitrogen Loading	Loading %	Average Loading over Urban Area (Base Soil Zone) Kg N/ha	Concentration mg N/l
Loading from Application of Fertilisers			
Parks and gardens	26.22	3.97	2.86
Allotments	0.37	0.06	13.10
Recreational grassland and golf courses	0.00	0.00	0.00
Loading from cemeteries	1.97	0.30	19.08
Loading from construction activities	4.72	0.72	28.57
Loading from land affected by contamination	1.65	0.25	80.00
Loading from landfill (non hazardous sites)	2.07	0.31	100.00
Loading from landfill (inert sites)	0.00	0.00	0.00
Loading from leaking sewers	18.40	2.79	30.00
Loading from septic tanks	0.00	0.00	not calc
Loading from leaking water mains	41.34	6.27	7.50
Loading from drainage to soakaways	3.27	0.50	3.50
Total			
Total loading (base soil zone)	101666	Kg N/yr	
Total loading (to groundwater)	99986	Kg N/yr	
Catchment area	67.1	ha	
Total average recharge	251	mm/year	
Average loading (base soil zone)	15.2	Kg N/ha/year	
Average concentration (drainage)	6.0	mg N/l	
Average concentration (at water table)	5.9	mg N/l	

Table E4 Predicted Nitrate Loading to Groundwater, Exeter Urban Catchment

Nitrogen Loading	Loading %	Average Loading over Urban Area (Base Soil Zone) Kg N/ha	Concentration mg N/l
Loading from Application of Fertilisers			
Parks and gardens	32.58	4.51	2.55
Allotments	1.44	0.20	11.70
Recreational grassland and golf courses	1.77	0.25	4.68
Loading from cemeteries	1.05	0.14	13.80
Loading from construction activities	7.75	1.07	25.53
Loading from land affected by contamination	0.00	0.00	80.00
Loading from landfill (non hazardous sites)	8.04	1.11	707.00
Loading from landfill (inert sites)	0.00	0.00	0.00
Loading from leaking sewers	32.47	4.50	45.00
Loading from septic tanks	0.00	0.00	50.00
Loading from leaking water mains	13.19	1.83	4.00
Loading from drainage to soakaways	1.71	0.24	3.50
Total			
Total loading (base soil zone)	61975	Kg N/yr	
Total loading (to groundwater)	46256	Kg N/yr	
Catchment area	44.7	ha	
Total average recharge	252	mm/year	
Average loading (base soil zone)	13.9	Kg N/ha/year	
Average concentration (drainage)	5.5	mg N/l	
Average concentration (at water table)	4.1	mg N/l	

Table E5 Predicted Phosphorus Loading to Groundwater, Nottingham Urban Catchment

Phosphorus Loading	Loading %	Average Loading over Urban Area (Base Soil Zone) Kg P/ha	Concentration mg P/l
Loading from Application of Fertilisers			
Parks and gardens	2.72	0.05	0.04
Allotments	0.01	0.00	0.04
Recreational grassland and golf courses	0.00	0.00	0.04
Loading from cemeteries	3.63	0.07	4.29
Loading from construction activities	0.00	0.00	0.00
Loading from land affected by contamination	0.08	0.00	80.00
Loading from landfill (non hazardous sites)	0.42	0.01	2.50
Loading from landfill (inert sites)	0.00	0.00	0.00
Loading from leaking sewers	45.30	0.84	9.00
Loading from septic tanks	0.00	0.00	not calc
Loading from leaking water mains	45.22	0.84	1.00
Loading from drainage to soakaways	2.61	0.05	0.34
Total	100.00		
Total loading (base soil zone)	12390.26	Kg P/yr	
Total loading (to groundwater)	12348.26	Kg P/yr	
Catchment area	67.05	ha	
Total average recharge	251.28	mm/year	
Average loading (base soil zone)	1.85	Kg P/ha/year	
Average concentration (drainage)	0.74	mg P/l	
Average concentration (at water table)	0.73	mg P/l	

Table E6 Predicted Phosphorus Loading to Groundwater, Exeter Urban Catchment

Phosphorus Loading	Loading %	Average Loading over Urban Area (Base Soil Zone) Kg P/ha	Concentration mg P/l
Loading from Application of Fertilisers			
Parks and gardens	4.36	0.06	0.04
Allotments	0.04	0.00	0.04
Recreational grassland and golf courses	0.13	0.00	0.04
Loading from cemeteries	2.67	0.04	3.72
Loading from construction activities	0.00	0.00	0.00
Loading from land affected by contamination	0.00	0.00	80.00
Loading from landfill (non hazardous sites)	0.09	0.00	0.80
Loading from landfill (inert sites)	0.00	0.00	0.00
Loading from leaking sewers	61.45	0.90	9.00
Loading from septic tanks	0.00	0.00	50.00
Loading from leaking water mains	31.21	0.46	1.00
Loading from drainage to soakaways	0.05	0.00	0.01
Total	100.00		
Total loading (base soil zone)	6549.21	Kg P/yr	
Total loading (to groundwater)	4198.37	Kg P/yr	
Catchment area	44.72	ha	
Total average recharge	251.67	mm/year	
Average loading (base soil zone)	1.46	Kg P/ha/year	
Average concentration (drainage)	0.58	mg P/l	
Average concentration (at water table)	0.37	mg P/l	